Vulnerability of Pacific Island agriculture and forestry to climate change

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In memory of Aleki Sisifa (1948–2014)

"Small is the voice of the chief, for gentleness and courtesy should walk hand in hand with power"

Aleki Sisifa devoted his working life to strengthening food security in the Pacific region and to improving the lot of the smallholder farmers who underpin it. He was a natural leader, with an uncanny ability to unite disparate team members from all disciplines and walks of life, finding consensus and delivering optimum development outcomes for the region. A true Pacific Chief and mentor to so many, he will not be forgotten.

Vulnerability of Pacific Island agriculture and forestry to climate change

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Foreword

Pacific Island countries and territories already face a range of development challenges due to their specific geographic and socio-economic characteristics, and their generally high exposure to natural hazards. The projected changes to the climate of the Pacific Island region over the coming decades present another challenging dimension that the region will need to grapple with. These changes could compromise the very ability of Pacific communities to meet their economic development needs.

Agriculture and forestry underpin the livelihoods of a large number of people across the region and also account for a significant share of export income for most countries. It is vital that we understand how climate change will affect these sectors and what we can do to manage these emerging impacts. The devastation to Vanuatu's crops and economic infrastructure caused by tropical cyclone Pam in March 2015 clearly demonstrates the potential consequences of the increased intensity of extreme weather events that will accompany climate change. It is essential that we identify measures to limit the impact of such events and ensure that food security and livelihoods are maintained.

It gives me pleasure to introduce this book, which provides the most comprehensive and up-to-date assessment of the potential impact of climate change on Pacific agriculture and forestry yet produced. To date, our understanding of the likely impacts of climate change on Pacific agriculture and forests has been somewhat limited and piecemeal, and projected impacts have often been based on extrapolations from research undertaken elsewhere by the international scientific community. It is therefore important that we shed more light on specific issues for the Pacific and better understand the implications for food security and island economies.

This publication, which is the second in a series of climate impact assessments for specific sectors completed by the Pacific Community, follows the 2011 publication, *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*. Similar to the findings of the 2011 fisheries vulnerability assessment, it is evident that climate change will, overall, have a negative impact on the productivity of the agriculture and forestry sectors across the Pacific over the coming decades. However, this research also highlights the underlying resilience of Pacific agriculture to climate change, particularly for many of the region's staple food crops, and the fact that we have some breathing space to enable us to put in place appropriate response measures to accommodate the expected changes and capitalise on any positive opportunities that may emerge. There are both potential winners and losers across the sectors.

This book identifies a range of potential response measures that could be implemented to significantly reduce exposure to climate related risks and enable the Pacific Community to better cope with emerging impacts. Many of these measures would contribute to improving agricultural productivity and livelihood resilience with or without climate change, but others would entail additional investment and changes to production systems.

This work represents a major step forward in progressing our understanding of climate change impacts on Pacific agriculture and forestry. However, in producing this publication it became evident that significant knowledge gaps still remain, especially in regard to Pacific staple and cash crops. It is important that we put in place suitable research strategies to address these gaps over the coming years, particularly through applied research and assessments at the country level, where decisions about appropriate adaptation investments are being made.

I extend my thanks to the many authors and experts who contributed to this publication, above all the principal editors, Mary Taylor, Andrew McGregor and Brian Dawson.

In particular, I acknowledge the Australian Government, which provided the funding support that made this book possible.

I trust this work will provide a valuable resource for decision-makers who can help guide and prioritise potential response options, especially in terms of the importance and timing of investment for adaptation measures.

Dr Colin Tukuitonga
Director-General
Pacific Community (SPC)

Acknowledgements

This book is the product of the partnership between Australia and the Pacific Community. It follows the publication in 2011 of *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*, which was also supported by Australia, and recognises the need for a similar assessment of climate challenges for Pacific Island agriculture and forestry.

In particular, the Australian Government's International Climate Change Adaptation Initiative provided funding support while SPC's climate change team and Land Resources Division provided the opportunity to bring the vision to fruition.

SPC and the editors are grateful to the authors who accepted the invitation to contribute their expertise to this assessment. We also appreciate the valuable contribution made by the internationally recognised scientists, economists and managers who provided peer reviews of each chapter as follows. Chapter 1: Steve Rogers, Patrick Nunn, Tim Martyn and Danny Hunter. Chapter 2: Gillian Cambers, Alistair Hobday and Jim Salinger. Chapter 3: Philip Thornton, Ehsan Dulloo and Morgan Wairiu. Chapter 4: Heiko Bammann and Tolo Iosefa. Chapter 5: Richard Markham and Padma Lal. Chapter 6: Yan Diezbalis, Richard Markham and William Wigmore. Chapter 8: Sairusi Bulai. Chapter 9: Aaron Buncle and Marita Manley. Chapter 10: Gillian Cambers, Marita Manley and Dean Solofa.

Many people were instrumental in the production of the book. Carla Appel undertook the task of design and layout of the large volume of technical information. Jipé LeBars provided original illustrations. Angela Templeton provided publishing and editorial advice throughout the development of the book. Penny Cook was responsible for copy editing, assisted by Julian Heinz. Emil Adams and Simione Tukidia were helpful in sourcing images for some of the chapters. Sherrey Quinn compiled the index, and Judy McDonald proofread the final text.

Finally, this book would not have been possible without the commitment and dedication of the farmers, researchers and extension agents throughout the Pacific who spend their lives engaged in agriculture and forestry, despite many challenges, and in generating the information and ideas on which this book is based.

Contents

Introduction

The agriculture and forestry sectors are of vital socio-economic importance to Pacific Island countries and territories (PICTs). These sectors underpin the livelihoods of a significant proportion of the region's population and also account for an important share of export earnings for many countries. It is essential therefore to assess the potential impacts of climate change on the agriculture and forestry sectors, what this may mean for livelihoods across the region, and what can be done to minimise emerging adverse impacts.

PICTs already face a range of challenges in terms of maintaining adequate food security and sustaining commodity export income. Continued population growth, urbanisation, low or stagnant agricultural production and yields, environmental degradation and price competition from imported food products are all risks to food security. The region also faces intense competition in international markets for the exports it produces, and income from most of these products has been relatively flat or falling for some time. Increasing the productivity, competitiveness and sustainability of agricultural production, and ensuring ongoing food and livelihood security in the coming decades, remains an important challenge for the region irrespective of climate change, and this must be kept in mind when assessing future impacts and response capabilities. Chapter 1 sets the scene for this book by providing an overall assessment of the importance of agriculture across the different PICTs and discusses some of the key challenges currently faced by the sector.

Climate change is likely to present an additional set of challenges for the agriculture and forestry sectors, particularly in terms of managing the projected increase in the frequency and intensity of extreme weather events. The region has always been highly vulnerable to the impacts of climate variability and extreme weather, such as floods, intense rain, droughts and cyclones and these have been the cause of significant production losses to the agriculture and forestry sectors in the past. While farmers, foresters and tree growers have developed agricultural and forestry systems that help minimise climate related risks, the magnitude of potential changes to key climatic variables projected for this century is likely to present a more formidable adaptation challenge.

Recent international research on the potential impacts of climate change on agricultural production suggests that warming of even 1.5–2C^{0} will adversely impact on global food production, especially for the world's major staple food crops such as wheat, maize and rice. It is a widely held view that agricultural commodity and food production in the Pacific will face similar impacts. However, in producing this publication it was evident that the body of research that specifically targets the impacts of climate change on Pacific agriculture is generally sparse and piecemeal. Only limited applied climate change impact research on agriculture has been undertaken in the region and, as a result, many gaps in the knowledge base relevant to the food production systems across the Pacific remain. Of those assessments that do exist, many have often been based on extrapolations from international research undertaken elsewhere. If farmers, scientists and policy makers are to make informed decisions on whether or not response options are needed, and when they may be needed, it is essential that our understanding of the Pacific context be improved.

This book aims to improve our understanding of climate change impacts on Pacific crops, livestock and forest production systems. Where information gaps exist the authors have drawn on expert opinion across the region and international research institutions. This has provided valuable insights into the vulnerability of particular agriculture and forestry production systems under projected changes to the region's climate. This book identifies and highlights these gaps and may guide the type of future research and assessment that needs to be undertaken in the coming years.

Identifying the likely changes to key climatic variables is crucial to the impact assessment process. Chapter 2 provides an overview of our current understanding about how the region's climate could change over time. It uses the most up-to-date climate change information available for the region, drawing heavily on the significant research work undertaken in recent years through the Pacific Climate Change Science Program, IPCC and other research efforts. Chapter 3 provides a summary overview of the broader implications of climate change across the agriculture sector and what are likely to be the key drivers for change, and where impacts can be expected to occur.

Each of the following five chapters discusses the optimum bioclimatic conditions for growth and productivity for specific crops and forest types, assesses the observed climate impacts over the past 30 years, then considers vulnerability to projected climate conditions under different emission scenarios and timelines. Chapter 4 discusses the potential implications for Pacific staple crops that are important for food security and underpin the livelihoods of a large number of people across the region. Chapter 5 specifically addresses the potential impacts on the region's major export commodities such as coffee, sugar, copra, palm oil and cocoa and identifies potential risks and opportunities. In particular, it highlights the high level of vulnerability of coffee production to even small changes in climate and the potentially significant impacts the projected changes may have on PNG, a major coffee producing country. Chapter 6 reviews the potential impacts on the horticultural industry, an important commercial activity in a number of countries, while Chapter 7 addresses potential climate change related impacts on the region's livestock production systems. Chapter 8 is devoted to the forestry sector and assesses what climate change could mean for the productivity of Pacific forestry, agroforestry and the vulnerability of specific forest ecosystems.

Finally, Chapter 9 draws on the results and conclusions of Chapters 3 to 8 and assesses the overall implications of climate change on the contribution of agriculture and forestry to Pacific Island economies and communities.

As this publication clearly demonstrates, the Pacific agriculture and forestry sectors are vulnerable to changes in the region's climate. Although the magnitude and extent of these changes will be influenced by the success of efforts to limit future greenhouse gas emissions it is evident that the climate will continue to change for many decades to come even if substantial reductions in emissions can be achieved in the near future. The region will need to respond to these changes and put in place measures to limit climate risk and maximise opportunities. The important question is what should be done and when.

The traditional crops and production systems are, in general, relatively resilient to variations in climatic conditions. However, many traditional farming practices have declined in recent years, often in response to commercial production needs. As a result it is likely that the vulnerability of Pacific food and commodity production systems to climate variability has increased in the past two decades. Irrespective of what climate change eventuates there is a clear need to address this increased level of vulnerability and put in place measures that improve the resilience of production systems and management regimes. Measures that address existing vulnerability, while also building resilience to future climate change, are generally referred to as 'no regret' measures; in other words actions that make sense even in the absence of climate change. Throughout this book the authors have identified a range of measures that could be viewed as 'no regret' actions and these should be the primary focus of climate change adaptation in the short to medium term (up to 2030).

As with agriculture, considerable uncertainty exists with respect to future impacts of climate change on Pacific Island forests and trees. Therefore, implementation of 'no regret' actions has to be the way forward, with the emphasis on the roles of good forestry management and agroforestry practices as a way of building resilience to all forms of environmental change, economic change, invasive species and human-induced climate change.

The full impacts of climate change are relatively slow to emerge but it is likely that more substantive adjustments and adaptation investments may be needed over time. For decision-makers to make informed judgements about what adaptation response measures should be implemented they need appropriate information on what is likely to occur and when. They also need reliable information on the outcomes of existing adaptation response measures, what potential measures exist and what such measures would cost. It is important that we have good understanding of the social and economic trade-offs associated with implementing different response measures. Given the limited resources available to farmers and other actors in the agricultural and forestry sectors it is essential that investment decisions be based on actual identified needs and informed cost–benefit analysis.

The time dimension is also critical to the decision-making process as some changes will occur in the short to medium term while others are much longer term in nature. Throughout the various chapters the authors have aimed to provide insights to the timing of potential impacts and, when appropriate, potential response measures that could be implemented. While it is important to understand what impacts may emerge over the longer term it makes no sense, either economically or socially, to devote substantial resources to adaptation investments to respond to climate change impacts that may occur 30–50 years from now.

Chapter 10, the final chapter in this book, addresses many of these issues and discusses adaptive capacity, the timing and importance of potential adaptation response measures and a range of other important issues that policy makers and providers of development assistance need to be aware of. The chapter identifies a wide range of potentially viable adaptation measures that exist and the relative importance of the different adaptation response measures. It uses the findings of the preceding chapters to draw a range of conclusions and recommendations relating to the projected impact of climate change on Pacific agriculture and forestry, and what can be done to reduce the risks posed by these projected changes. It also highlights areas where more applied research and assessment are required to improve the quantity and reliability of information flows to policy and investment decision-makers.

Although uncertainty and knowledge gaps around specific climate change impacts on Pacific agriculture and forestry remain, this book is an important step towards building a better understanding of potential impacts and their timing. As a result it is a useful resource for policy decision-makers, the donor community and the general public.

Photo: RM Bourke

Chapter 1

Pacific Communities, Agriculture and Climate Change

Aleki Sisifa, Mary Taylor, Andrew McGregor, Anna Fink and Brian Dawson

Contents

1.1 Introduction

As discussed in the introduction, the agriculture sector is of vital importance to the Pacific region. Agricultural products are a significant component of exports for many countries in the region and food production activities (agriculture and fishing) continue to employ the greatest percentage of the labour force, either in commercial enterprises, or more commonly, in self-sufficiency endeavours. This is despite the Pacific region comprising the most environmentally vulnerable nations in the world. Natural disasters, such as cyclones, floods and droughts are not new to the region. However, the climate projections for the 21st century and beyond, (discussed in Chapter 2), suggest that extreme events such as heatwaves, droughts and floods are likely to increase in frequency and intensity, projected rainfall and rainfall patterns are likely to create problems for a region already affected by droughts and floods, and cyclones are most likely to increase in intensity. Extreme high tides and storm surges will probably continue to threaten low-lying islands, as will the ongoing sea level rise, which will cause contamination of groundwater.

Jon Barnett (2011) summed up the potential impact of climate change in the region:

'Climate change will adversely affect food systems in the region, including the supply of food from agriculture and fisheries, the ability of countries to import food, systems for the distribution of food, and the ability of households to purchase and utilize food. In these ways, climate change puts at risk the very basic and universal need for people in the islands to have access to sufficient, safe and nutritious food at all times' (p.1)

It is vital therefore that the Pacific region assesses the vulnerability of its agriculture sector, so that strategies can be developed both to cope with extreme climate events and improve the resilience of production systems to the changing climate.

This chapter sets the scene for this publication. It outlines the approach used for assessing the vulnerability of the agriculture and forestry[1] sectors and considers the assets[2] available within the region that can influence the adaptive capacity of communities (Adger et al. 2004). The chapter also discusses the importance of agriculture, and existing constraints to agricultural productivity, such as declining soil fertility and future challenges with regards to food supply and food security, such as increasing population and urbanisation, all of which need to be taken into account in any analysis of the sector.

1 Forestry is discussed in full in Chapter 8.
2 Natural, human, social, physical and financial capital.

1.2 Assessing the vulnerability of the agriculture and forestry sectors to climate change

1.2.1 Defining vulnerability

Agriculture and forestry systems are vulnerable to climate variability, whether it is part of a natural pattern or caused by human activities. The Intergovernmental Panel on Climate Change (IPCC) definition for vulnerability (V) is 'vulnerability is a function of character, magnitude, rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity' (IPCC, 2001). V = E x S/A is generally accepted as an interpretation of the definition. Assessing the vulnerability of a system requires analysis of the exposure and sensitivity to climate variation and change, and the adaptive capacity of the system to cope with the variation. The term 'system' includes species, ecosystem and society (Figure 1.1).

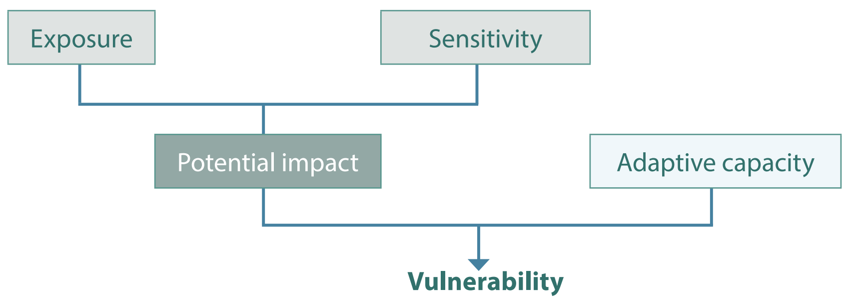

Figure 1.1 Framework used for assessing vulnerability (source: Bell et al. 2011).

Exposure (E) is considered as the nature and degree to which a system is subjected to significant climate variations (IPCC, 2001). These variations, which can be direct or indirect, include long-term, slow onset changes such as increases in mean annual temperature and also variations to natural extremes that exceed known stress thresholds, that is, extreme events. An example of a direct effect of climate change on livestock would be productivity losses resulting from physiological stress caused by temperature increases; an indirect effect would be a change in the availability and/or quality of the fodder affecting the productivity of the livestock.

Sensitivity (S) is the degree to which a system is affected, either adversely or beneficially, by exposure to the direct and indirect effects of climate change (Bell et al. 2011). Direct effects on crop productivity would include a response to changing temperature whereas an indirect effect could be crop damage caused by floods, landslides, etc. Assessing sensitivity requires an understanding of threshold limits. Very sensitive species or systems will have low threshold limits and therefore even relatively small changes in the climate will elicit a response; the timing and duration of the exposure can have a significant influence on sensitivity. The combination of exposure and sensitivity results in a potential impact; however, the response to this impact will depend on the sensitivity and adaptive capacity of the system.

Adaptive capacity (A) is described as 'the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities or to cope with consequences' (IPCC 2001). The IPCC distinguishes between autonomous adaptation, where existing knowledge and technology is utilised in response to the changes in climate experienced, and planned adaptation, where adaptive capacity is strengthened by implementing policies to bring about effective adaptation as well as investment in new technologies and infrastructure (Parry et al. 2007).

The resilience of a system is based on its ability to absorb shocks and to bounce back, for which certain conditions are necessary, namely the abilities to self-organise, to buffer disturbance and have the capacity for learning and adapting (Tompkins et al. 2005). Increasing resilience can be achieved by reducing exposure to risk, reducing sensitivity and strengthening adaptive capacity. For example, an ongoing pest or disease problem could be exacerbated by a changing climate. Addressing this problem now will reduce risk in the future and increase the resilience of the system. General resilience, being 'about coping with uncertainty in all ways' (Folke et al. 2010) avoids the risk that too much focus on a specified resilience can result in a loss of resilience in other ways (Cifdaloz et al. 2010).

1.2.2 Reducing vulnerability

Reducing sensitivity will decrease vulnerability. For example, projected climate change is likely to increase the possibility of taro leaf blight (TLB) in certain countries currently free of the disease. Therefore the cultivation of TLB-resistant varieties now would help to reduce sensitivity and, to some extent, exposure to the disease in that the presence of resistant varieties will reduce the level of disease inoculum available for infection. Similarly, reducing sensitivity to drought could be achieved by cultivating drought resistant varieties within an agroforestry system. Cultivating varieties with specific climate tolerant traits is not the only way to reduce vulnerability, as described in Chapter 4. Enhancing the genetic diversity within a crop gene pool by increasing the inter- and intra-specific diversity being cultivated, also improves the resilience of the system.

Vulnerability to climate change has different dimensions as the focus turns from plants, trees and animals through agricultural systems and landscapes, to individuals, households, communities and countries. Individual plants, trees and animals have vulnerabilities to changes in climate, which can be assessed by considering their physiological thresholds or limits within different emission scenarios. The vulnerability of agricultural systems can be modified by changing practices, such as altering planting dates and changing the mix of varieties or species.

1.3 Adaptive capacity

Adaptive capacity considers the farmers and communities involved in agriculture and forestry. It is a product of natural, human, physical, social and financial capital, and is the means by which we can understand whether environmental change will impact communities. Moser et al. (2010) consider that the amount and diversity of assets held by a community determine the level of vulnerability to climate change. An asset is defined as a 'stock of financial, human, natural or social resources that can be acquired, developed, improved and transferred across generations. It generates flows or consumption, as well as additional stock'. Larger amounts and diversity of assets increase the resilience of communities to climate change. Adaptive capacity can explain why some communities may be less at risk than modelling studies portray. For example, Adger et al. (2004) report that previous research in coastal environments has shown that social capital, which comprises networks and relationships between individuals and social groups that facilitate economic well-being and security, is an important element for coping with climate variability and hazard in the present day. Adaptive capacity will be further discussed in Chapter 10.

1.3.1 Natural capital

The Pacific Islands comprise more than 20,000 islands and atolls in 28 countries and territories often referred to as Oceania. The region covers a third of the earth's surface and is home to an estimated 10 million people on islands with a land area of 550,000 km^2 surrounded by the largest ocean in the world.

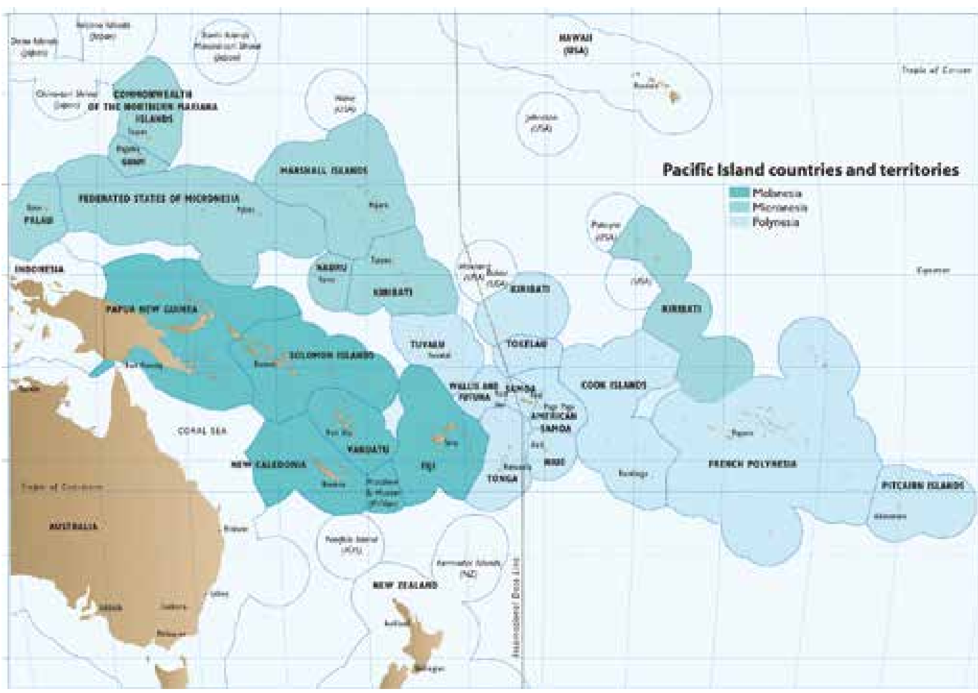

Figure 1.2 The three subregions of Melanesia, Micronesia and Polynesia. (source: Bell et al. 2011).

Twenty-two of these countries and territories are members of the Pacific Community (SPC),[3] and are referred to in this book as Pacific Island countries and territories (PICTs). Five island members of SPC (Fiji, New Caledonia, Papua New Guinea (PNG), Solomon Islands and Vanuatu) account for 90% of this total land area and more than 85% of the population. The region is also home to some of the world's smallest island countries and territories, such as Nauru, Tuvalu and Tokelau.

The Pacific region is generally referred to as three sub-regions: Melanesia, Polynesia and Micronesia. The large size of the high islands in Melanesia and prevailing weather conditions have provided good opportunities for agriculture, fisheries, and forestry, thus supporting the expansion of human settlements. Rainfall is higher than in the low-lying islands further east, but there are strong spatial variations in rainfall with windward (usually eastern) slopes typically receiving more rain than the leeward (usually western) slopes.

Differences in cloud cover accentuate the differences between the windward and leeward sides of the island Photo: Richard Markham

The islands within Polynesia and Micronesia vary greatly in size, and are smaller in land area than Melanesia. Atolls (ring reefs formed around a completely submerged peak) are found in all three sub-regions. In atoll nations such as Tuvalu and Kiribati reef islands provide the only habitable areas.

3 The 22 Pacific Island countries and territories are American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Republic of the Marshall Islands, Nauru, New Caledonia, Niue, Commonwealth of the Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn Islands, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu and Wallis and Futuna.

Atolls are found in all three sub-regions Photo: Richard Markham

Land mass accounts for only 2% of the entire Pacific region of 30,000,000 km^2. It is unevenly distributed throughout the region which, together with the largely traditional land tenure system, places intense pressure on the available arable land to provide for housing, food, waste disposal, fresh water and other resources. On small atoll islands, land availability is an overwhelming constraint. Systems of ownership, inheritance and use are complex and vary greatly across the region, but generally land is mostly vested in groups based on common descent, place of residence, and participation in social and economic activities. Land means identifying with a family, a clan, a lineage, and is therefore valued for its symbolic value, not just because it meets most subsistence requirements.

Agriculture has supported Pacific communities for thousands of years, but in recent years, population growth, deforestation and the intensification of crop production for commercial purposes has threatened the very foundation of agriculture: the soil. Soil condition and fertility vary considerably across the Pacific, with more fertile and productive soils found in volcanic islands. The loss of soil fertility threatens the productivity of crops, and soil erosion through run-off into the sea is damaging the coral reefs on which island communities largely depend for their protein.

The survival of many communities is fundamentally linked to the state of their freshwater resources, whether these occur as rivers and streams, underground aquifers, or rainwater collected from roofs. These resources are essential for basic human needs such as drinking, washing and cooking, and are also vital for agriculture in all its forms. Across the region, agriculture has been developed alongside and reliant upon these freshwater resources. Both commercial and self-sufficiency agriculture has progressed on the basis of fresh water availability.

On atolls, surface water resources are usually non-existent and fresh groundwater resources, which exist as thin freshwater lenses floating over seawater, can be very limited. Storage and availability of fresh water is also constrained by very small land areas, aquifer geology, demand from both human settlements and agricultural activities, and waste disposal issues.

Forests have always been an integral part of the lives of communities, particularly on high islands. In fragile island ecosystems, forests, agroforests and trees, and their associated biodiversity, are vital for economic prosperity and building resilience to all forms of change. Forests, and trees outside forests, provide food and fodder, traditional medicines, wood for building materials, implements and fuel, and products for local sale and export. Forests also provide vital ecological services, such as coastal and watershed protection, soil replenishment, water purification and conservation, and also act as reservoirs of biodiversity (habitat for pollinators and countless other important plants and animals) and carbon (both as a carbon stock and sink). The loss of forest areas through agriculture conversion, forest degradation arising from unsustainable harvesting, forest clearance for development and plantation establishment, is likely to enhance sensitivities associated with the effects of climate change.

Yela Ka (*Terminalia carolinensis*) forest, Kosrae, FSM Photo: Cenon Padolina


Native forest near Monosavu dam, Naitasiri, Fiji Photo: Lex Thomson

1.3.2 Human capital

The population of the region, estimated at 10.5 million in mid-2013, is growing at about 2% per annum[4]. The high growth rates are predominately driven by Melanesia, especially PNG. The populations of PNG, Solomon Islands and Vanuatu are all projected to double by 2050 (Table 1.1), at a time when climate change impacts are expected to be more pronounced. Of the Melanesian countries, Fiji, due to outmigration, has a low overall population growth, with the majority of the population now living in urban and peri-urban areas. In 2007, the urban population was 51% and at the current rate of growth is projected to reach 61% by 2030[5]. The western Melanesian countries (PNG, Solomon Islands and Vanuatu) all have overwhelmingly rural populations, but urban population growth exceeds rural population growth in all Melanesian countries except PNG. Food production in some locations is becoming increasingly difficult because of population pressure, as can be seen in parts of the PNG Highlands and north Malaita in Solomon Islands (Rogers and Martyn 2009). Increasing population, especially in urban areas, increases the demand for imported food.

Population growth in Cook Islands, Samoa and Tonga has been moderated by outward migration to neighbouring New Zealand, Australia and the United States. A similar process also exists in the Federated States of Micronesia (FSM), Palau and the Republic of the Marshall Islands (RMI), with movement to urban Guam, Honolulu and the west coast of the United States.

4 http://www.spc.int/sdd/
5 http://www.spc.int/prism/fjtest/cens&surveys/cens&surveystats_index.htm

Some of the smaller PICTs (Guam and Nauru) are experiencing high rates of population growth, whereas others, such as Niue and Tokelau are seeing their populations decline. Some smaller PICTs have a high percentage of rural dwellers (FSM, Kiribati, Niue, Tokelau, Tuvalu, Wallis and Futuna), while others have largely urban societies (Guam, RMI, Nauru, the Commonwealth of the Northern Mariana Islands (CNMI), Palau, Cook Islands)

The aggregate age profile across the region is: 0–14 (37.3%), 15–24 (19.5%) 25–59 (38%), and 60+ (5.2%)[6].

Table 1.1 Population estimates for the 22 PICTs for 2013 with projections to 2030 and 2050 (source: http://www.spc.int/sdd/).

PICT	Last population census	Population count at last census	2013		2030 mid-year estimate	2050 mid-year estimate
			Mid-year estimate	Annual growth rate		
Melanesia			9,392,000	2.1	13,021,800	17,418,800
Fiji	2007	837,271	859,200	0.5	936,200	1,026,700
New Caledonia	2009	245,580	259,000	1.3	310,900	343,200
PNG	2011	7,059,653	7,398,000	2.3	10,491,900	14,212,300
Solomon Islands	2009	515,870	610,000	2.5	912,400	1,353,700
Vanuatu	2009	234,023	264,700	2.5	370,400	483,000
Micronesia			524,900	1.6	618,000	711,500
FSM	2010	102,843	103,000	0.0	97,900	97,300
Guam	2010	159,358	174,900	2.6	214,800	233,500
Kiribati	2010	103,058	108,800	2.1	149,800	208,000
Marshall Islands	2011	53,158	54,200	0.8	58,700	70,700
Nauru	2011	10,084	10,500	1.7	13,700	17,100
CNMI	2010	53,883	55,700	1.3	64,400	66,800
Palau	2012	17,445	17,800	0.5	18,600	18,000
Polynesia			649,600	0.2	696,700	814,800
American Samoa	2010	55,519	56,500	0.6	62,800	82,200
Cook Islands	2011	14,974	15,200	0.5	16,000	16,000
French Polynesia	2012	268,270	261,400	0.2	292,800	316,900
Niue	2011	1,611	1,500	-2.4	1,300	1,300
Pitcairn Island	2012	57			*	*
Samoa	2011	187,820	187,400	0.0	191,000	238,200
Tokelau	2011	1,205	1,200	-0.9	1,000	900
Tonga	2011	103,252	103,300	0.1	105,900	127,200
Tuvalu	2011	10,564	10,900	1.6	14,400	19,600
Wallis & Futuna	2008	13,445	12,200	-2.0	11,200	12,300
Total			**10,566,500**	**2.0**	**14,336,400**	**18,945,100**

Key: * Population for Pitcairn Islands not estimated (currently 57).

6 http://www.spc.int/sdd/

The Human Development Index (HDI) focuses on human elements of development, combining indicators of health and education with the more traditional economic indicators. The Index can help to identify key development needs and assist in determining cost-effective strategies for human development. Table 1.2 below shows the rankings of 10 Pacific Islands in the 2013 Human Development Report (UNDP 2013). Most countries ranked in the 'medium' human development category. When compared with other small developing island states in the report, Palau, Fiji, Tonga, and Samoa are all doing better in terms of human development[7]. PNG and Solomon Islands are notable, however, in having a low HDI and they rank 156 and 143 out of 187 in the world. Average life expectancy in PNG is 10 years less than in Tonga.

Table 1.2 Human Development Indicators for the Pacific 2012 (source: UNDP Human Development Report 2013).

Country	HDI Value (2012)	Life Expectancy	GNI per capita	Global ranking	HDI Group
Fiji	0.70	69	4,087	96	Medium
Kiribati	0.63	68	3,079	121	Medium
FSM	0.65	69	4,674	117	Medium
Papua New Guinea	0.47	63	2,386	156	Low
Palau	0.79	72	11,463	52	High
Samoa	0.70	73	3,928	96	Medium
Solomon Islands	0.53	68	2,172	143	Low
Timor-Leste	0.58	63	5,446	134	Medium
Tonga	0.71	73	4,153	95	Medium
Vanuatu	0.63	71	3,960	124	Medium

In September 2011, the Pacific Forum Leaders acknowledged that non-communicable diseases (NCDs) (diabetes, cancer, chronic respiratory diseases, heart disease including hypertension and stroke) have reached epidemic proportions in the region and are creating a 'human, social and economic crisis', requiring an urgent and comprehensive response[8]. Many studies have discussed how the change from a diet of predominantly root vegetables, coconuts and fresh fish to one consisting of bread, rice, tinned fish, and more processed foods high in sugar and salt have contributed to the escalation of NCDs (World Bank 2012). Improving access and availability of local, more nutritious foods would help to minimise the contribution of diet to NCDs (Snowdon et al. 2010).

7 This is based on the HDI value. The HDI value for small developing island states is 0.69.
8 http://countryoffice.unfpa.org/filemanager/files/pacific/TOR_NCDs.pdf

1.3.3 Social Capital

Social capital as it relates to climate change has been described as 'close bonds within communities, and networks of relations between communities and external organisations, that enable informed, collective, and coordinated responses to manage climate risks' (Commonwealth of Australia 2012). The socio-ecological systems of the Pacific region have historically adapted well to environmental change. Local knowledge sustained over generations, through a variety of traditional and cultural practices maintained via informal education and oral tradition, has been the basis of this ability to adapt, as well as the social safety net provided by community cooperation and collaboration. Although these systems are arguably not as strong as they once were, especially in the more urban and peri-urban areas, the level of community cooperation that exists in the PICTs, and which is maintained through ceremony, feasting and exchange of goods, can provide the social capital important for climate change adaptation. The local knowledge held by communities is also a crucial resource for any community-based adaptation strategy.

Understanding social and community structures and functions is important when implementing policies and activities in PICTs. Distinct differences in social organisation and cultural practices exist between the three sub-regions. For example, throughout Melanesia, social and political status and power are usually acquired on the basis of individual merit and effort, whereas in most of Polynesia patrilineal descent is the deciding factor. In Micronesia, the situation is more complex: on high islands and more fertile atolls, close similarities to the Polynesian system are found, whereas on the smaller atolls, age plays a more prominent role; political responsibility is traditionally exercised by a council of elders (Haberkorn and Jorari 2007).

In Polynesia and parts of Micronesia, sharing of information is generally broad-based and often systematic, with support from government, village and church committees. In Melanesia and parts of Micronesia, sharing of information has traditionally been constrained, firstly by the diversity of languages and cultures, and secondly by the fact that traditionally, women are not expected to contribute in meetings of mixed sexes, thus in many cases separate meetings for the sexes are called for.

Women from the village of Pessena, N Espiritu Santo, Vanuatu looking after their cocoyams Photo: Vincent Lebot

In Melanesia and most of Micronesia, the role of food production (crop, forestry and animal) and food preparation belongs to women, while commercial crops, forestry and animal production are the responsibility of men. Children and other household members help out with the labour as required in food production, and supplement labour requirements in commercial agriculture production. In Polynesia and in parts of Micronesia, women's role in agriculture and forestry is typically confined to preparation and storage of crops after harvesting in addition to food preparation or processing and selling of the produce.

Women tend not to have access to the key information and education critical for adapting to a rapidly changing climate (McOmber et al. 2013). This is due to many factors linked to tradition (as previously stated) and work burdens. At best, this reduces their potential to contribute to household, community and national responses and at worst their vulnerability to extreme weather events is increased. It is crucial that women are fully involved in the development of climate change adaptation strategies and in capacity-building related to climate change, as it is women who tend to remain behind to run farms and gardens when men move away to seek employment in urban areas.

Understanding the gendered division of labour within Pacific communities can assist in providing more in-depth understanding of community perspectives on changes to climate and the environment. It can also provide a useful entry point for harnessing specialised knowledge in developing strategies for adapting to climate change. Adaptation solutions must build on the diverse knowledge, priorities and capacities of both women and men. Further, promoting equitable access to adaptation knowledge for women and men is a key practical step for inclusive adaptation.

1.3.4 Physical capital

Poor infrastructure, including roads, ports, shipping, transport, communications and markets, contributes significant constraints to agricultural development (Rogers 2008). Physical capital can be very climate sensitive, with poor-quality infrastructure more easily and severely affected, especially by extreme weather events. A Community Based Vulnerability Assessment (CBVA) carried out by SPC in Samoa after Cyclone Evan reported major infrastructure damage (roads, bridges, water and electricity supply), and despite reasonably quick recovery, significant effort was needed to return to a pre-Evan state. As highlighted in several reports, investment in agriculture will only reap benefits if combined with improvements in infrastructure and market access (Abbot and Pollard 2004). The importance of marketing infrastructure is further highlighted in Section 1.5.6.

Infrastructure damage after Cyclone Evan, Samoa, 2012 Photo: Tolo Iosefa

1.3.5 Financial capital

CBVAs conducted by SPC Land Resources Division (LRD) in Fiji, Kiribati, Samoa, Solomon Islands, Tonga and Vanuatu showed that the most limiting capital was financial, in combination with other capitals including physical, human and natural (Halavatau pers. comm). Financial capital includes the level, variability and diversity of sources of income, and access to other financial resources, such as credit and savings, and is obviously important with regards to cushioning shocks from extreme weather events, diversifying options and taking on board new technologies. In Fiji, the Women's Social and Economic Development Programme (WOSED) is implementing the Grameen Banks model of microfinance, where social capital is used as collateral. They are targeting disadvantaged women and providing small loans, of which 70% are used for agricultural activities (Deacon 2012).

1.4 Importance of agriculture to Pacific economies and communities

Any assessment of the importance of the agricultural sector to Pacific economies and communities needs to take into account the great diversity that exists between the PICTs in the region. Countries such as Tuvalu (population less than 11,000) and PNG (population approaching 7.5 million) have little in common other than proximity. For those PICTs where agriculture is of fundamental importance for food security, livelihoods and economic development, climate change is likely to have a significant impact, especially in the longer term. In those PICTs where agriculture is of minor importance and food security is more dependent on imports, the direct impact of climate change on agriculture will be less, but it is highly likely that climate change will drive up the prices of imported foods, threatening food security and hindering any possible agricultural development.

To facilitate analysis of the agriculture sector for such a diverse range of PICTs the following groupings have been proposed based on resource endowments, size and the importance of their agriculture sector (McGregor et al. 2008).

- **Group 1:** relatively large PICTs of Melanesia (PNG, Fiji, Solomon Islands, New Caledonia and Vanuatu). Of these, PNG, Solomon Islands and Vanuatu (Western Melanesia) and Fiji have been selected for analysis.
- **Group 2:** middle-sized PICTs of Polynesia (Samoa, Tonga and French Polynesia). Of these, Samoa and Tonga have been selected for analysis.
- **Group 3:** land-poor micro-states that are predominantly atolls. (FSM, Kiribati, Niue, Tokelau, Tuvalu, Wallis and Futuna, Guam, RMI, Nauru, CNMI and Cook Islands). Of these, Kiribati and Tuvalu have been selected for analysis.

Traditional food production in the Pacific is based on agroforestry. The most common is shifting cultivation or slash and burn rain-fed gardens associated with arboriculture of local fruit and nut species. In a given area farmers will cultivate land for about three years before abandoning it for a much longer period. In the drier areas such gardens were often dominated by yams, and in the more humid areas, taro was found. But many other food crops were also cultivated, (including banana, sweet potato, sugar cane, kava, aibika,[9] leafy vegetables and other minor species; all crops of good nutritional value, and with little dependence on external inputs or extension services). These multi-crop garden systems, protected by trees within the garden and often by forest (primary or secondary) reduced risk from disasters. These systems were adjusted for resource endowments, the seasons, and occasional natural disasters.

Families often had several traditional food gardens, albeit relatively small, which used the best locations for particular crops, maintained the use of land, and importantly, reduced the risk of all crops being lost at one time. In Vanuatu, three food gardens were established for each year in a three-year period, but since the early eighties, the

9 *Abelmoschus manihot* – also known as pele, bele, and island cabbage.

number of food gardens has significantly decreased. At the present time only one garden is established for each of the years within the three-year period (Lebot pers. comm). This has greatly increased the food security vulnerability of households to cyclones. Vanuatu is highly vulnerable to natural disasters, being located in one of the most cyclone-prone parts of the south-west Pacific (McGregor and McGregor 1999).

Informal agroforestry in Samoa Photo: Richard Markham

Strategic planting timetables and sequential harvesting techniques also enhanced food security. SPC (2011) further notes that:

"These structurally complex agro-forestry systems buffer crops from large fluctuations in temperature, keeping crops closer-to-optimal growing conditions. Shade trees protect crops from lower precipitation and reduced soil water availability and improve soil water infiltration. Such agro-forestry systems also help protect crops from extreme storm events" (p 9).

As well as complex and shifting multi-crop gardens, intensive permanent cultivation also existed; for example, taro cultivation in irrigated terraces or permanent compost pits on atolls. Moreover, there was also an extensive use of wild plants, such as ferns and other greens (Thaman 1982).

Throughout the region free-range chickens and pigs are an integral part of self-sufficiency production, whereas larger commercial pig and chicken production systems are only found in Fiji and PNG. Vanuatu has a notable beef industry based on smallholder cattle farms and larger holdings. A significant beef cattle sector is present also in New Caledonia. Fiji has a significant dairy and goat industry and also a small sheep industry.

Keeping pigs in Kosrae, FSM Photo: Mary Taylor

The integration of agriculture to the global economy commenced with colonisation and the production of commodities such as copra, sugar, coffee and cocoa. This development of cash cropping has led to a more permanent occupation of land. The commercial production of taro in Fiji and Samoa, ginger in Fiji, kava on the sloping lands of Fiji and the FSM, and squash in Tonga, has generally resulted in increased soil erosion, reduced yields and decreased household food security (Buresova and McGregor 1990; SPC 2011).

Commercial ginger production Fiji Photo: SPC

FAO data suggest that since the 1960s agricultural production has been increasing steadily across the region. These production increases, however, are mainly attributable to increases in the area of land farmed rather than increases in productivity. FAO data indicate that productivity (measured by yield) has only improved marginally since the 1960s and has actually declined since the late 1990s (Figure 1.5).

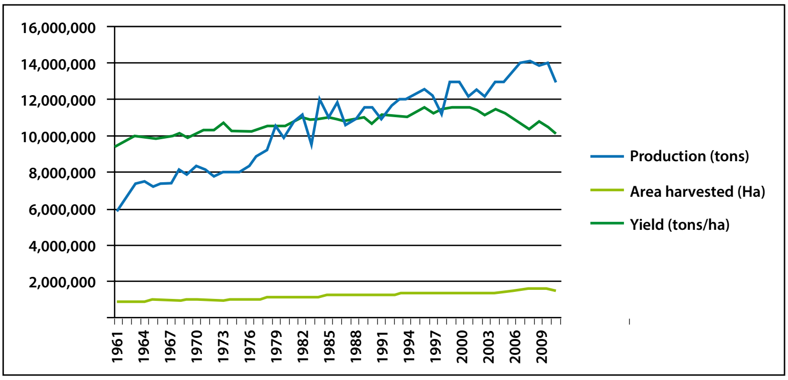

Figure 1.3 Production, area harvested and yield of food crops in the Pacific 1960-2012 (source: FAO Statistics database, October 2013[10]).

Data for livestock production is very difficult to compile because in most of the PICTs the majority of livestock production is not recorded in the absence of slaughterhouses and meat inspection services (Manueli pers.comm)

A more in-depth analysis of the importance of agriculture is discussed in the following sections using the areas listed below:

- Economic growth and trade
- Food security
- Livelihoods

1.4.1 Economic growth and trade

1.4.1.1 Group 1: Melanesia (Fiji, PNG, Solomon Islands and Vanuatu)

The economic growth performance of Melanesian countries over the last decade has been erratic and overall has barely kept up with the growth in population (Tables 1.1 and 1.3). PNG, after a negative and low growth experience at the beginning of the decade, has experienced exceptionally high real growth rates in recent years (11% in 2011), due to a surge in mineral and energy exports, particularly commodities such as oil, copper and gold.

10 Data for American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Nauru, New Caledonia, Nuie, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna.

In PNG the total value added created by agriculture makes up a high percentage (36%) of GDP (Table 1.4). PNG is also by far the region's largest agricultural exporter, with exports in 2011 equivalent to USD 1.28 billion; nearly six times that of Fiji, the region's next largest agricultural exporter, but less than 20% of the share of total exports. Minerals, petroleum and logs, outputs of the extractive industries, dominate PNG's export earnings, generating a large foreign exchange that has not, by and large, been converted into more sustainable long-term industries such as agriculture and agroforestry. In PNG significant disparities exist in the income earned by the largely urban and mining enclaves compared with rural, largely informal areas, which is where 94% of PNG's poor live (ADB 2012).

Solomon Islands experienced significant negative growth between 2000 and 2002 when commodity exports ceased due to social unrest and the resulting collapse of law and order. Since 2003 Solomon Islands has experienced a strong recovery driven by exports of logs and post-crisis aid inflows, together with agricultural commodities and tuna exports. However, 50% of the value of exports comes from the unsustainable exports of logs sourced from native forests. Agriculture accounts for around 20% of total exports with modest production growth achieved through cocoa and palm oil. Thus, Solomon Islands could face a major economic crisis with the imminent collapse of log exports during the course of the decade.

Vanuatu has displayed the most consistent positive growth performance over the last decade, principally driven by tourism and construction (Howes and Soni 2009). The contribution of Vanuatu's agriculture to GDP is relatively low at 23% compared with western Melanesian countries; however, this figure could be misleading due to the method used to calculate the contribution of subsistence agriculture to GDP, which may significantly underestimate its importance (Bain 1996). In recent years Vanuatu's agricultural products have made up around 80% of total export earnings; by far the highest of any Pacific Island country. Vanuatu has no mineral exports and very limited forestry exports.

Fiji has experienced the lowest average growth of the Melanesian countries over the last decade or so, and the lowest agricultural share of GDP at 13%. Overall slow growth can be attributed to disruptions caused by a number of coups and the steady decline in Fiji's sugar industry. Fiji's modest growth in fresh fruit and root crop exports has so far not been sufficient to offset this decline. That said, Fiji does have a diversified export trade portfolio and like Vanuatu has managed to offset some of its trade imbalance with tourism receipts as well as aid and remittances.

As discussed, agriculture plays a key role in the economies of Melanesia. Consequently the impact of climate change on agriculture in these countries will have major implications for economic growth and trade.

Table 1.3 Melanesian countries' real GDP growth rates, 1999–2011. (source: IMF Statistics).

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average over period
Fiji	9.9	-1.8	2.0	3.2	1.0	5.5	2.5	1.9	-0.9	1.0	-1.3	0.1	1.9	2.1
Papua New Guinea	1.9	-2.5	0.0	2.0	4.4	0.6	3.9	2.3	7.2	6.6	6.1	7.6	11.1	4.5
Solomon Islands	0.5	-14.3	-8.0	-2.8	6.5	8.1	12.9	4.0	6.4	7.1	-4.7	7.8	10.7	3.1
Vanuatu	0.3	5.9	-3.4	-5.2	4.3	4.0	5.3	8.5	5.2	6.5	3.3	1.6	1.4	3.4

Table 1.4 Total value added created by agriculture as a percentage of GDP for Melanesian countries (2008–2012) (source: World Bank Development Indicators 2013).

	2008	2009	2010	2011	2012
Fiji	14	13	12	13	
Papua New Guinea	34	36	36	36	36
Solomon Islands	41	39			
Vanuatu	20	20	21	23	23

1.4.1.2 Group 2: Polynesia (Samoa and Tonga)

For the first half of the decade Tonga and Samoa enjoyed strong economic growth (Table 1.5), and with a low population growth, per capita income increased significantly. However, in the second half of the decade the Tongan economy has experienced minimal growth and the Samoan economy has slowed considerably.

Agriculture's share of GDP for Tonga is about double that of Samoa, which is about the same as Fiji (Table 1.6). In both countries, agriculture's contribution to GDP is significantly less than it is for the countries of western Melanesia. In Samoa, for example, the service sector now comprises over 60% of GDP and employs some 30% of the labour force (AusAID 2012).

Both Tonga and Samoa have large trade imbalances. The value of exports averages less than 10% of the value of imports although agricultural products do make up a relatively high proportion of these limited exports. Trade imbalances have, to date, been offset by remittances sent by diaspora communities and aid inflows. Samoa's agricultural export sector has been in sharp decline since the early 1990s due to weather-related disasters. Cyclones Ofa (1990) and Val (1991) destroyed approximately 20% of the coconuts growing at the time and spelt the end of the once substantial cocoa export industry. Taro leaf blight (1993)[11] saw taro exports fall to virtually zero and exports are yet to recover to any significant extent.

11 See Chapter 4 for a discussion on the relationship between taro leaf blight and climate.

During the 1990s Tonga was unusual in that economic growth was led by export agriculture, principally squash exports to Japan and vanilla to the United States (Sturton 1992). The average annual value of squash exports to Japan from 1991 to 1994 was around USD 10 million. However, the industry has faced both marketing and sustainable production problems, particularly in terms of Tonga's fragile water resources, and value of squash exports is now only 10% of the level a decade ago, with no significant replacement agricultural export earner in place.

The importance of agriculture to the economies of Samoa and Tonga has declined substantially from what it was some two decades ago. The sector is less important to these economies than it is for the countries of Melanesia. Consequently the impact of climate change on agriculture in Polynesia can be expected to have fewer implications for economic growth and trade, compared with Melanesia.

Table 1.5 Samoa and Tonga real GDP growth rates, 1999–2011. (source: IMF Statistics).

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average over period
Samoa	-0.6	4.8	8.0	6.2	3.8	4.2	7.0	2.1	1.8	4.3	-5.1	0.4	2.0	3.6
Tonga	2.3	2.8	3.8	4.1	1.2	2.2	0.7	-4.5	-2.4	0.5	0.9	1.6	1.5	1.1

Table 1.6 Agricultural value added as a percentage of GDP for Samoa and Tonga (2008–2012) (source: World Bank Development Indicators 2013).

	2008	2009	2010	2011	2012
Samoa	12	12	10	10	10
Tonga	18	18	19	20	

1.4.1.3 Group 3: The Micro-states (Kiribati and Tuvalu)

The growth performance of the micro-states has been highly erratic and, on average, poor (Table 1.7) and below the growth in population for most of these countries (Table 1.1). The per capita income of Kiribati stands at around the equivalent of USD 1,600, approximately the same as Solomon Islands and slightly below that of PNG. Tuvalu, FSM and the RMI all have per capita incomes just above USD 3,000. Palau enjoys a much higher per capita income due to the contribution of tourism.

Agriculture's contribution to GDP is mainly through self-sufficiency activities. In Tuvalu, despite severe constraints faced by terrestrial food production, agriculture value added accounted for 23% of GDP in 2011; however, this figure is more a measure of material impoverishment than of the strength of the sector. The 2010 Household Income and Expenditure Survey (HIES) estimates that around 20% of household income comes from self-sufficiency activities, confirming the high percentage of GDP estimate for self-sufficiency. For the more affluent micro-states of the northern Pacific the contribution of agriculture to GDP is considerably less. For example, in Palau, agriculture and fisheries constituted 3.1% of GDP while services constituted 62% of the economy in 2005[12].

The micro-states have even more extreme trade imbalances than those faced by the mid-sized Polynesian countries. The trade merchandise of Kiribati is typical, where over the period 2003 to 2010 the value of exports averaged only 6% of the value of imports. To date these micro-states have largely been able to offset their large trade imbalance through a combination of foreign income remittances, aid inflows and in some cases, tourism and fishing licence receipts.

Agriculture is much less important to the economies of the micro-states than it is to Melanesian and Polynesian countries, and as such economic growth and trade in the micro-states will be less affected by the impact of climate change on agriculture.

Table 1.7 Real GDP growth rates for selected Pacific Island micro-states, 1999–2011. (source: IMF Statistics).

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average over period
Kiribati	1.4	4.9	-3.2	6.7	4.2	0.2	0.3	1.2	0.5	-2.4	-2.4	1.4	2.0	1.2
Marshall Is	-2.4	5.9	5.4	2.6	0.2	0.0	2.6	1.9	3.2	-1.9	-1.5	5.6	0.8	2.3
FSM	1.6	4.5	1.7	0.5	1.7	-3.2	2.2	-0.2	-2.1	-2.6	1.0	2.5	2.1	0.7
Tuvalu	n/a	n/a	1.6	7.9	-3.3	-1.4	-3.8	2,6	5.5	7.6	-1.7	-2.9	1.1	1.3

1.4.1.4. Summary

Agriculture's importance for economic growth and trade of the three groups of PICTs can be summarised as:

- Group 1 – major importance
- Group 2 – moderate importance
- Group 3 – minor importance

Accordingly, the impact of climate change on agriculture is expected to have major implications for Group 1 economies, moderate implications for Group 2 economies and minor implications for Group 3 economies. Chapters 4, 5 and 6 discuss these impacts in detail for specific crops, while Chapter 9 endeavours to translate these impacts into growth and foreign exchange consequences.

12 http://www.spc.int/prism/

1.4.2 Agriculture and food security

Agriculture and food security are closely linked and therefore the impact of climate change on agriculture will have significant consequences for food security. Chapter 9 analyses in some detail the expected impact of climate change on food security; the following discussion establishes the baseline for that analysis.

The World Food Summit, 1996, defined food security as 'when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life'.[13] This definition highlights the four key dimensions of food security: adequate food supply; available food supply; stability of food supply and access to food at the household level.

Traditional farming systems, as previously described, have provided resilience against external shocks and helped to maintain food security (McGregor et al. 2008). Today threats to food security have intensified with the move away from the more resilient agro-ecosystems of the past, and with increasing population and urbanisation. The projections for climate change add a further threat, by increasing the vulnerability of food production systems both within the region and beyond.

The Food Import Capability Index (FICI), developed by FAO, is the ratio of food imports to total mercantile exports and is used as the aggregate measure of a country's food security. The premise on which the FICI has been established is that a country's food security depends on its ability to both produce and buy food. A country with a FICI greater than 50% is considered vulnerable in terms of food security. However, with climate change an over-reliance on imported food the supply of which is externally determined, increases vulnerability. Further, any analysis of food security must also consider the reliability of income to purchase food and the access to that income at the local and household level.

1.4.2.1 Group 1: Melanesia (Fiji, PNG, Solomon Islands and Vanuatu)

Agriculture is the basis of food security where there is a solid foundation for food availability through self-sufficient production of staple and other food crops, and also through export earnings generated from agriculture products.

PNG has a FICI of less than 10%, indicating a high level of food security (Table 1.8). Yet an estimated 1.3 million people in PNG live in urban centres or non-village locations, with no opportunity to grow food, and an insufficient income with which to purchase adequate quantities of nutritious food (Bourke and Harwood 2009). Many households do not receive the flow-on income benefits from mineral exports, responsible for PNG's positive trade balance. Similarly, in Solomon Islands, with a low

13 ftp://ftp.fao.org/es/ESA/policybriefs/pb_02.pdf

food security vulnerability (FICI of 30%), the income generated by unsustainable log exports does not reach the population at large. According to the FICI, Fiji and Vanuatu have moderate and high food security vulnerability respectively; however, income from tourism in both countries helps to offset the substantial mercantile deficit (McGregor et al. 2009).

Table 1.8 Food security indicators for Fiji, PNG, Solomon Islands and Vanuatu (2007–2012) (source: Central and reserve banks for respective countries).

	2007	2008	2009	2010	2011	2012	Average for period
Fiji							
FICI (Food imports as a % of total exports)	48%	53%	58%	54%	72%	70%	59%
Food imports as a % of total imports	14%	14%	19%				
Food imports as a % agricultural exports	151%	156%	192%				
Papua New Guinea							
FICI (Food imports as a % of total exports)	7%	7%	8%	7%	7%	8%	7%
Food imports as a % of total imports	20%	17%	13%	12%	11%	10%	14%
Food imports as a % agricultural exports	61%	49%	60%	53%	37%	54%	52%
Solomon Islands							
FICI (Food imports as a % of total exports)	32%	32%	38%	35%	21%	20%	30%
Food imports as a % of total imports	17%	21%	21%	19%	18%	19%	18%
Food imports as a % agricultural exports	185%	121%	160%	134%	95%	145%	140%
Vanuatu							
FICI (Food imports as a % of total exports)	120%	133%	209%	171%	129%	140%	150%
Food imports as a % of total imports	17%	16%	18%	19%	20%	18%	18%
Food imports as a % agricultural exports	182%	174%	306%	214%	162%	175%	202%

All Group 1 countries have strong domestic staple food production (Bourke and Harwood 2009; McGregor et al. 2009). However, they all suffer from significant levels of malnutrition, as shown by the high levels of stunting in children under five; high levels of obesity and non-communicable diseases (mainly in urban areas), and micronutrient deficiencies such as iron, vitamin A and iodine (SPC 2011).

Group 1 countries, with their substantial land resources and strong agricultural base, have significant potential to enhance their food security through agriculture, both through self-sufficiency and export production. Fiji, however, with an over-reliance on imported foods, is more vulnerable to external shocks, such as the 2008 food crisis. As Chapter 4 discusses, climate change could result in such an external shock through a real increase in the price of imported grain. The rate of growth of urbanisation in all countries is also an increasing threat to food security.

1.4.2.2 Group 2: Polynesia (Samoa and Tonga)

The FICI of both Samoa and Tonga indicates extreme food security vulnerability (Table 1.9). These countries have been able to purchase sufficient imported food with foreign exchange provided by remittances and aid transfers. Increasing consumption of imported food with generally higher levels of sugar, salt and fats has been linked to the increased incidence of obesity and diabetes seen in both countries.[14]

Maintaining the current level of food imports is only possible if remittances remain at their current high value. However, both countries do have a strong traditional subsistence base as demonstrated by Samoa with its response to the loss of taro production from taro leaf blight (Chapter 4), indicating the food security buffer that agriculture can provide when needed.

Table 1.9 The Food Import Capability Index (food imports as a percentage of total exports) for Samoa and Tonga (2011–2012) (source: Central Bank of Samoa and Tonga Department of Statistics).

	2011	2012	Average
Samoa	313%	260%	287%
Tonga	212%	198%	205%

1.4.2.3 Group 3: The Micro-states

These countries have a low capacity to produce food domestically and to generate export earnings. Thus, almost all purchased food is imported. Consequently, the FICIs for the atoll countries are very high suggesting that these countries are amongst the most food-insecure countries in the world. For example, the average FICI for Kiribati in the period 2008–2010 was 750%. The outer island communities of these countries are more involved in self-sufficiency food production, with the marine sector being far more important than agriculture.[15] *Cyrtosperma merkusii*, (swamp taro) remains important in the outer islands of some atoll countries.[16]

1.4.2.4. Summary

All three PICTs' groupings rely on agriculture for food security, with Group 1 being more reliant than Group 2 or Group 3. Levels of food security vulnerability vary both between and within the three groupings. The larger Melanesian countries have good natural resources with which to strengthen agriculture's contribution to food security. Increasing urbanisation, especially in some of the small micro-states and Melanesia, and high population growth rates, especially in Melanesia, present a significant challenge both for food production and the generation of sufficient income to ensure future food security. However, all PICTs, even the smaller micro-states, could enhance food security and thus their resilience to climate change through strengthening production practices for traditional crops. Chapter 4 pays particular

14 http://www.worldbank.org/content/dam/Worldbank/document/the-economic-costs-of-noncommunicable-diseases-in-the-pacific-islands.pdf

15 According to FAO per capita fish consumption in the micro-states is twice as high as it is in Polynesia and three or four times higher than it is in Melanesia (FAO 2010).

16 The value of pulaka to subsistence in Tuvalu is second only to fish and marine products. The 2004 HIES estimated that the total value of pulaka consumed by households to be AUD 1.8 million, of which most came from the outer islands. The estimated value for pulaka per household in the outer islands is AUD 1700 but only AUD 61 for Funafuti (Rogers and Martyn 2009).

attention to strengthening traditional food production systems and discusses the opportunities that exist if this is achieved.

1.4.3 Agriculture and livelihoods

Livelihood has been defined as 'the activities, assets and access that jointly determine the living gained by an individual or household' (Ellis 2000). Agriculture is the main source of livelihoods in western Melanesia, and is also important in Fiji, Samoa, Tonga, Cook Islands, Kiribati, FSM and Tuvalu (SPC 2011). Thus future climate change impacts on agriculture in these countries will directly and significantly affect livelihoods. Chapters 4, 5 and 6 discuss these impacts for specific crops in detail, while Chapter 9 tries to translate these impacts into consequences for livelihoods. The discussion below briefly establishes the current baseline as it relates to agriculture and livelihoods.

1.4.3.1 Group 1: Melanesia (Fiji, PNG, Solomon Islands and Vanuatu)

Countries in this grouping rely heavily on agriculture for employment and livelihoods. In PNG more than 50% of rural households generate some income from Arabica coffee (Bourke and Harwood 2009). In lowland locations, a further million people derive their income from the sale of cocoa and/or copra. The vast majority of these people receive very little, if any, income from the mineral boom in PNG. According to Vanuatu's 2006 Agricultural Census, 71% of Vanuatu's rural households earned income from coconuts, and received little or no income from tourism. In Solomon Islands, according to the Agricultural Census (last conducted in 1999), 80% of rural households earned income from copra and around 20% sold cocoa. Very few of these households will have earned any income from log exports. The Fiji sugar industry still directly employs about 13% of the labour force and 17,000 people are directly or indirectly dependent on the export of taro for their livelihood (Koka Siga Pacific 2012). Income derived from agricultural products sold at domestic markets is also an important source of livelihoods. In PNG, 90% of the rural population live in areas where income is derived from the sale of fresh food, an income estimated to be second only to the income derived from the sale of coffee (Bourke and Harwood 2009).

Copra cutting in Pessena, Espiritu Santo, Vanuatu Photo: Vincent Lebot

1.4.3.2 Group 2: Polynesia (Samoa and Tonga)

Although Samoa's and Tonga's export agriculture has declined since the early 1990s domestic trade in locally grown goods has continued to thrive. In Samoa, following the TLB disaster significant substitution of other traditional staples for taro has taken place (Chapter 4). In Tonga, as with Samoa, large volumes of food are domestically traded. In Tonga, the 2011 HIES confirmed that on average, 14% of household income is obtained from the sale of produce[17].

1.4.3.3 Group 3: The Micro-states

Micro-states have very limited land resources but vast marine resources. A few micro-states earn meagre, but important, cash income from agriculture. Kiribati and the RMI intermittently continue to export small quantities of copra. A few other micro-states earn income from diversified agricultural exports, such as the Cook Islands (previously papaya, now noni juice and some floriculture products), Niue (taro) and FSM (kava and betel nut). Crop sales to domestic markets make a small contribution to household income. For example, according to Tuvalu's most recent HIES, sales from subsistence agriculture contributed 7% of household income[18]. In the case of Kiribati, sales of household-grown produce provided on average 11% of household income.[19] The Palau HIES shows a much lower contribution of household food production to household income with subsistence agriculture estimated to make up on average only 3% of household income and the sale of produce even less (Government of Palau 2006).

17 http://www.spc.int/prism/tonga/index.php?Itemid=23
18 http://www.spc.int/prism/tuvalu
19 http://www.spc.int/prism/country/ki/stats/

1.4.3.4 Summary

All three PICTs' groupings rely on agriculture for livelihoods, with Group 1 being more reliant than Group 2 or Group 3. Tree crop commodities are obviously very important in the Melanesian countries for livelihoods. Any change that affected coffee production, for example, would have a significant impact on rural livelihoods in PNG. The possible future impacts of climate change on the more important crops and forestry products that contribute to the livelihoods of Pacific Island people are analysed in later chapters.

1.4.4 A recap of the importance of agriculture to Pacific economies and communities

Agriculture has a varied importance for the socio-economic wellbeing of Pacific populations. Agriculture is extremely important for economic growth and exports of PICTs in Group 1 but less so in Group 2 and Group 3 countries. It is vital for supporting livelihoods in all PICTs, particularly in areas which rely on subsistence production; however, it is relatively more important in Group 1 due to its greater contribution to household income and employment. Relatively limited agricultural production in Group 2 and Group 3 PICTs increases their food import dependence, contributing to a higher level of food insecurity than Group 1 PICTs. This is particularly true of the PICTs in Group 3, which face greater environmental and natural resource challenges than those of Group 2 to increasing their domestic food production.

1.5 Main issues influencing agricultural productivity in the region

Climate change will, without doubt, have an impact on the agricultural sector in the Pacific; the possible impacts and how they might affect the different sub-sectors, and the timing of these impacts, is discussed in later chapters. Disaster risk reduction and climate adaptation strategies to manage both the more immediate and long-term risks from climate change are essential. However, despite the challenges from climate change, opportunities are also likely. In order to manage the risks and to take advantage of the opportunities it is vital that all challenges and constraints affecting agricultural development, both now and in the future, are acknowledged. Failure to take these into account is not only likely to exacerbate climate change impacts in the future, but will also affect the success of any climate change adaptation strategies.

1.5.1 Declining soil fertility

Shifting cultivation where land was allowed to revert to a period of bush-fallow ensured that the land was able to recover its fertility. The diversity of crops grown, with their differing nutrient requirements, also did not drain the fertility of the soil. Cash cropping, which tends to involve permanent cultivation, does not allow for this fertility recovery period and pushes traditional food production away from the villages where the people live. Evidence of declining yields of cash and staple food crops exists for many locations in western Melanesia and Fiji, with similar declines reported in Samoa and Tonga. An analysis of several commercial food production systems, such as taro and ginger exports from Fiji, highlights the pest and disease problems limiting the potential of these systems. An in-depth evaluation of these pest and disease problems points to declining soil health and fertility as the underlying cause (Markham 2013). This issue is further discussed in Chapter 4.

1.5.2 Inadequate investment in agriculture

Globally and in the Pacific, agricultural sectors have suffered from under-investment, with spending on agriculture by developing country governments either declining or remaining the same between 1980 and 2004 (Hoffmann 2011). It is only recently that national governments and international donors have begun to channel their efforts towards agriculture with, for example, the World Bank choosing 'Agriculture for Development' as the focus of its 2008 World Development Report, and increasing its loans and investments for agriculture by 50% to USD 6 billion in 2009 (Chambwera et al. 2011).

As discussed in Section 1.3.5. CBVAs recently carried out in several PICTs indicate that lack of financial capital is a major factor influencing vulnerability. The agricultural sectors throughout the PICTs face a financing and investment crisis—a result of the withdrawal of the commercial banks, and to a large extent the development banks, from providing financial services to rural areas (AusAID 2006). There has been virtually no mobilisation of rural deposits, denying the sector a major source for investment finance. The lack of formal finance means that growth in rural small and medium enterprises (including commercial farming) has been seriously constrained. A consequence has been the dearth of such enterprises involved in wholesaling produce in most countries, which is identified as a major marketing constraint.

In all PICTs, under-resourced extension and research services currently restrict farmers' access to the technical assistance required for improving productivity. Improved research services and technical assistance will become increasingly important as the challenges from climate change become more apparent. An over-reliance on centralised research models does not necessarily ensure that benefits reach farmers, especially in largely archipelago countries where climate and environmental conditions vary over relatively short distances. The benefits of establishing a more decentralized approach to research is discussed in more detail in Chapter 5.

Limited access to inputs such as improved planting material, home garden tools, improved livestock feed, suitable breeds, veterinary support, credit and land, along with the increasing costs of livestock feeds, fertilizer and fuel inputs, constrain the opportunities for increased agricultural production and productivity. Emerging farmer organisations are expected to play an increasingly important role in providing these and other services, including decentralised research. Availability and efficient use of water, often reflecting poor investment in associated infrastructure, is also becoming a critical factor, particularly for the small atoll islands.

1.5.3 Population growth, urbanisation and labour migration

As discussed in Section 1.3.2 most of the region is experiencing rapid population growth, especially in urban areas. Urbanisation and high population growth rates in Melanesian and Micronesian countries pose a serious challenge for farming systems to produce sufficient food and at the same time create market opportunities.

Pacific production remains labour intensive, and therefore lack of labour for agriculture undermines the sector across the region. The prevailing notion that employment and higher income opportunities are only available in urban areas and in the tourism sector removes labour, especially youth, and in particular young women, from rural areas. As a result, formal education and the aspirations of rural youth and their parents tend to focus on wage employment. Farming is often perceived as the option for 'drop outs'. Yet the experience in Fiji is that rural youth appropriately trained to use their own land can earn far more income than their urban counterparts (McGregor and Tora 2011).

Out-migration from some rural areas has created severe labour shortages that have adversely affected agricultural productivity in these locations (Fiji Ministry of Agriculture, Sugar and Land Resettlement/Asian Development Bank, 2005). The problem of rural labour shortages has been further accentuated in those countries participating in the Australian and New Zealand Pacific Seasonal Worker Scheme. These transient workers and those Pacific Islander migrants who venture overseas on a more permanent basis provide a source of financial support through remittances for the families they have left. However, remittances can encourage a dependency attitude, leading to neglect of other sources of livelihoods, as has been the case in Cook Islands, Samoa, Tokelau, Tonga and Niue (Rallu 2008). The experience in Vanuatu has been similar (Rogers pers. comm.)

1.5.4 Shortage of skills and education

The unwillingness of young people to be engaged in an agricultural enterprise is often attributed to the low prestige of the sector. Thaman (1982) discusses how changing aspirations and value systems have contributed to an under-valuing of traditional food systems and agriculture. A lack of understanding of the complexity of traditional food systems by many of the educated younger generation also contributes to the low status of agriculture, as does the perception that imported foods are 'superior' to traditional foods. Little has been done in the region to promote agriculture as a form of business with as much potential to enhance wealth and status as any other business.

Low et al. (1984) note:

Effective training in agriculture is perhaps the most difficult training task. It has been taught at schools and other institutions by churches and government, small-scale and large-scale throughout the Pacific this century. Success has been very limited and the reasons many. The most innovative and intelligent youth tend to leave rural areas, the prices for tropical produce have been low, isolation can be boring, land tenure and certain social practices greatly constrain action and innovation, and Pacific social systems were designed in such a way that the older generation effectively exploit the young, who have little alternative than to be submissive. Now they can escape and they do. Moreover, the western-derived education system instills in young people certain aspirations that can only be realized in town.

There is now a greater need than ever for rural youth to have the skills, motivation and access to their own resources to be able to generate worthwhile livelihoods in a sustainable way. These are the people who, in the future, must be able to meet the challenges of climate change. Working to improve the enabling environment is therefore a key part of any initiative to engage more young people in agricultural activities and enterprises (SPC 2010); their participation is essential if the agricultural sector is going to support Pacific communities, as it has in the past, in an era of climate change. Appropriate non-formal adult education has an increasingly important role to play in the area (McGregor and Tora 2011).

Photo: Andrew McGregor

Young farmers from Tutu Rural Training Centre, Taveuni, Fiji salvaging kava after Cyclone Tomas

1.5.5 Loss of biodiversity

Traditional self-sufficiency agriculture relied on the use of local landraces[20] which are now often discarded by producers due to market pressure to cultivate specific varieties. Reducing crop diversity increases vulnerability to disease outbreaks and other natural shocks, as demonstrated by the taro leaf blight (TLB) outbreak in Samoa in 1993. Food security and livelihoods were threatened and Samoa's main export industry came to a halt. Most of the aroids grown across the Pacific originated in Melanesia and as a result the genetic diversity of these crops declines from west to east. A narrow genetic base increases susceptibility to diseases that could become more widespread and vigorous with climate change. This issue is further discussed in Chapter 4.

Loss of biodiversity impacts on the ecosystem services essential for agricultural production, and reduces opportunities for systems to be self-buffering. The tropical Indo-Pacific area, with its centre in New Guinea, and stretching from Indonesia southward to Melanesia, eastward to Polynesia and northward to Micronesia, contains perhaps the biologically richest and most culturally diverse region on the planet. Some islands have over 80% endemic species, which occur nowhere else—yet up to 50% of the region's biodiversity is at risk. In fact, the Pacific has some of the highest extinction rates in the world.[21]

1.5.6 Marketing infrastructure and market access.

Adequate roads are a basic necessity for marketing. Through much of rural Melanesia this condition is not met. Unquestionably the economic returns from a strategically placed road are high. The establishment of the Highlands Highway in the mid-1960s led to the growth of coffee as the most important industry in PNG in terms of livelihoods. However, the budgetary demands of such infrastructure are also high and rarely met, even with considerable donor support. Comparable with the challenge of maintaining adequate roads is maintaining adequate inter-island shipping services. Overall there has been a marked decline in shipping services to the more remote areas. This can be linked to the demise of the copra industry and depopulation.

Satisfactory market houses and post-harvest storage facilities also help to encourage domestic trade in agricultural products. Some municipal marketplaces are impressive in terms of the diversity and quality of products on offer; where these exist they have helped in boosting small business development and enhancing food security.

20 A landrace is a variety of domesticated animal or agricultural plant species which has developed over a long period of time and as a result has adapted to the local natural environment in which it lives.

21 http://www.acpmeas.info/feature4.asp

Market House, Port Vila, Vanuatu Photo: SPC

Market access can present a major challenge and act as a deterrent for farmers and agro-processors. In the past, agricultural development has put too much focus on the supply side, without sufficient consideration being given to the sale of the produce. Gaining market access often requires much effort and patience. A study released by the European Union-funded Facilitating Agricultural Commodity Trade (FACT) project found that 'quarantine import protocols and their application are a major factor determining the ability of Pacific Island countries to maintain and expand taro exports' (McGregor et al. 2010). Westlake (2013) discusses the difficulties concerning taro exports to Australia and the exportation of papaya from Fiji to the United States. Improvement to marketing infrastructure and market access would be vital if any policy to increase local food production and improve agriculture's contribution to economic growth was to be successfully implemented. Improvements would have to take into account the likelihood of more frequent and more intense extreme climatic events in the future.

1.5.7 Globalisation and increasing dependency on imported food

The falling productivity of domestic food production and increasing availability of cheaper and often more convenient imported food has led to an increase in food import dependence and a dietary transition towards foods high in salt, sugar and fat.[22] The availability of low-cost food imports has probably been beneficial to the calorific intake of the poor, particularly in urban areas, but with serious health consequences for the community (Evans et al. 2001).

22 http://samples.jbpub.com/9780763775087/75087_ch02_Contento.pdf

The elimination of tariffs and non-tariff barriers to imports has compounded PICTs' food import dependence, and its impact upon the health of Pacific Islanders. A more nuanced approach to trade policy, globalisation and regional economic integration would see strategic use of policy and regulation (within the parameters of legal obligations at the WTO) to promote the competitiveness of domestic producers (McGregor 2006). Examples would include the use of WTO Special Products and Special Safeguard Mechanisms for developing countries, facilitating access to finance and removing domestic barriers such as price controls. International trade does provide a means by which the food requirements of a growing urban population can be met (Pinstrup-Andersen 2009), but trade must be combined with a sustainable increase in production in order to build resilience and reduce any over-reliance on imported foods (Nunn 2009). The risks of being too reliant on imported food in an era of climate change are further discussed in Chapters 4 and 9.

1.5.8 Land tenure and use

Security of ownership and tenure can unlock the economic development potential of land for food security, livelihoods and other commercial uses (SPC 2011). Secure tenure encourages farmers to maintain productivity of their land and enables them to be confident they will not waste resources and effort in land disputes. Maintenance of land productivity associated with secure tenure contributes to protecting the environment.

The system of land tenure varies between islands and cultures, but generally the cycle of cultivation and bush-fallow is typically managed by elders of the community. These elders are responsible for relatively large tracts of land, which are distributed to members of their community according to their need and status. Community members use this land to feed their own family and also to provide for community events. The safety net provided by these systems is to be admired; however, it could also act as a deterrent to producing a surplus. The system of re-allocation of land does not go hand in hand with long-term 'land care', (for example, practices to maintain soil organic matter) and investment in basic land improvement, (for example, fencing to keep out the feral pigs). Formal systems of commercial leases also tend to favour utilisation rather than conservation because they can be difficult and expensive to initiate and short in duration (Markham 2013).

The establishment of perennial plantations and permanent pastures represents the main cause of deforestation and contributes to increased pressure on land used for food production (Siméoni and Lebot 2012). Land degradation is one of the key environmental concerns in the Pacific (SPREP 2005). Some agricultural development has resulted in large-scale land clearance, intensification of land use and increased use of artificial fertilisers. In Fiji, for example, rapid expansion of sugar cane farms led to the cultivation of land with slopes greater than 8° (Lal 2008). This, together with poor agricultural practices including burning of fields after harvesting, has affected not only the productivity of the land itself but also resulted in land degradation and increased soil erosion. Degraded land and the resulting poor soil offer little resistance to extreme climate events such as drought or floods and fail to provide stressed crops or livestock with the buffer much needed for resilience.

Forest degradation in Upper Ba province, Fiji Photo: Sele Tagivuni

The complexity of issues and multiple objectives surrounding land use highlight the need for multi-level and multi-stakeholder involvement as recommended by Sustainable Land Management (SLM), and the landscape or ridge-to-reef approach. Agriculture is supported by multifunctional landscapes, which provide a wealth of ecological goods and services to the agricultural sector, of which land is one component. Ensuring the sustainable use of land and other goods and services goes beyond the agricultural sector.[23]

1.6 Conclusion

The importance of agriculture to food security and livelihoods throughout the region is clear. Further, the sector makes significant contributions to economic growth and foreign exchange in the larger countries. At the same time, some significant challenges are facing the region. In addition to climate change these include population growth, urbanisation, and an escalation in non-communicable diseases.

Food production systems based on multiple levels, multi-cropping and agroforestry with varying lengths of fallow periods have traditionally provided the resilience to withstand natural disasters and external economic shocks. These farming systems, where they still exist, have demonstrated sustainability in preventing loss of soil fertility, soil erosion and conserving available water, thus ensuring food and

23 For example, a pilot project in land use planning in Rarotonga, Cook Islands has begun with the development of draft land zoning maps, so it is clear which areas are suitable for agriculture, forestry, urban use, tourism and environmental protection.

livelihood security for communities. In the drive for greater productivity the attributes and benefits of traditional farming systems are often forgotten.

How climate change can impact on agriculture has been discussed in many papers and reports (Chapter 3). Much of the available information has focused on crops of global importance; however, it does serve to highlight the complexities resulting from the direct and indirect impacts of climate change as well as the uncertainties regarding climate projections and impacts. Chapters 4 to 7 provide some insights into the potential impacts of climate change on self-sufficiency crops, export commodities and livestock. They highlight where the risks and opportunities can be found, and identify the knowledge gaps that need attention in order to cope with the challenges of climate change.

What is clear throughout these chapters is the need to strengthen the resilience of food production systems, and not just resilience to short-term shocks but an enduring resilience that will be able to absorb the extremes of climate variability as well as the long-term changes, such as an increase in mean temperature. With limited access to additional agricultural land the increased food supply necessary to feed a growing population will only be achieved if the development of agro-ecologically efficient systems is considered a priority.

As Section 1.5 highlights, improving agricultural productivity and enhancing resilience to cope with climate change is not just the responsibility of the agricultural sector, but requires the efforts of other sectors such as transport, health, environment and education. Countries in the region are facing challenges with respect to youth unemployment. Increasing the participation of youth in agriculture, and in particular nurturing the development of young agricultural entrepreneurs, could improve food security and youth livelihoods and reduce migration to urban areas, all of which would greatly benefit communities and reduce vulnerability to challenges such as climate change.

Finally, reducing the vulnerability of the agriculture sector must also take into account the health of communities. Currently the NCDs epidemic in the region, if not resolved, will unfold in parallel with climate change, creating unprecedented challenges for governments to manage. Diet is without doubt one of the major factors contributing to this epidemic and therefore changes in the quality of food available to communities could help in alleviating this significant health crisis. Encouraging and investing in the sustainable production and processing of local, nutritious food would seem to be a step in the right direction for addressing the NCD challenge. As will be apparent from the discussions in later chapters, increased investment in local food production and processing will help communities and countries manage some of the climate change challenges faced by agriculture, and at the same time prepare communities for when the purchase of imported grains is likely to be a less attractive option than it is at the moment. The future grain market is likely to be vulnerable to climate change; therefore an increased effort now to expand sustainable local, diverse and more nutritious food production and utilisation would seem to be a healthy and sensible adaptation strategy. A healthy population is inherently more resilient than one that has to manage a whole range of debilitating diseases.

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Photo: John Elliott

Chapter 2

Observed and projected changes in surface climate of tropical Pacific Islands

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Contents

2.1 Introduction

Climate for a particular location and time of year is a description of the typical weather conditions experienced over a representative period of time (generally a few decades). Importantly, climate also describes the typical year-to-year variations and weather extremes of a region. The natural and managed biological systems on which we rely have become attuned to these local prevailing climate conditions.

Earth's climate varies naturally over a wide range of timescales. It varies from year to year and decade to decade due to a range of factors that can be either internal (such as the El Niño-Southern Oscillation and the Pacific Decadal Oscillation) or external (such as the amount of incoming solar radiation, or volcanic aerosols) to the climate system (Bindoff et al. 2013; Hartmann et al. 2013). Over much longer timescales, changes in the Earth's position relative to the Sun have produced swings between glacial and interglacial conditions (Masson-Delmotte et al. 2013). However, since the start of the Industrial Revolution in the late 18th century we have entered a new era of rapid global climate change that, while still influenced by natural cycles and forcings, is primarily driven by human actions. This is anthropogenic climate change (Stocker et al. 2013).

The observational record of global land and sea surface temperature clearly shows a general warming since the mid-19th century (Figure 2.1) with the first decade of the 21^{st} century being the warmest. Globally, average temperatures warmed ~0.89°C between 1901 and 2012 with most of this warming (~0.72°C) occurring since 1950 (Hartmann et al. 2013). This change is also reflected in the rate of warming, which has accelerated from 0.08°C/decade from 1900 to 0.11°C/decade since 1950. While the increase in global average temperature is still relatively small, the rate of human-induced warming is unprecedented. Warming of ~4-7°C at the end of the last glacial maximum 21,000 years ago, for example, is estimated to have occurred 10 times slower than the observed warming of the 20^{th} century (Jensen et al. 2007).

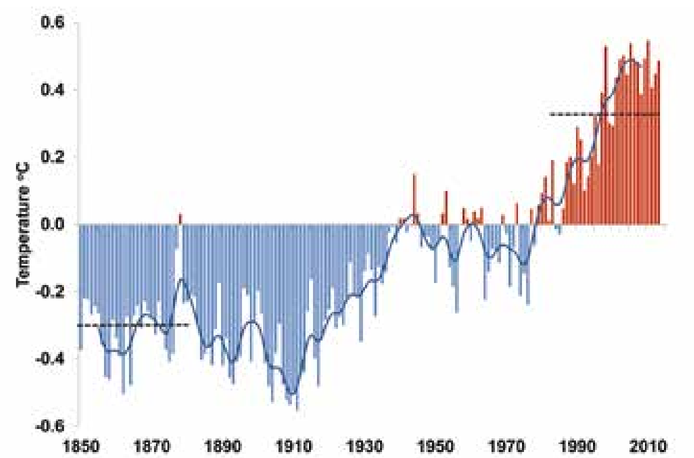


Figure 2.1 Annual global land and sea surface temperature anomalies (from 1961–1990 mean) for the period 1850–October 2013. Thick line is 10-year Gaussian filter emphasising decadal variability. Dashed lines show average for first 30 (1850–1879) and last 30 (1984–2013) years of record (source: HadCRUT4, Morice et al. 2012).

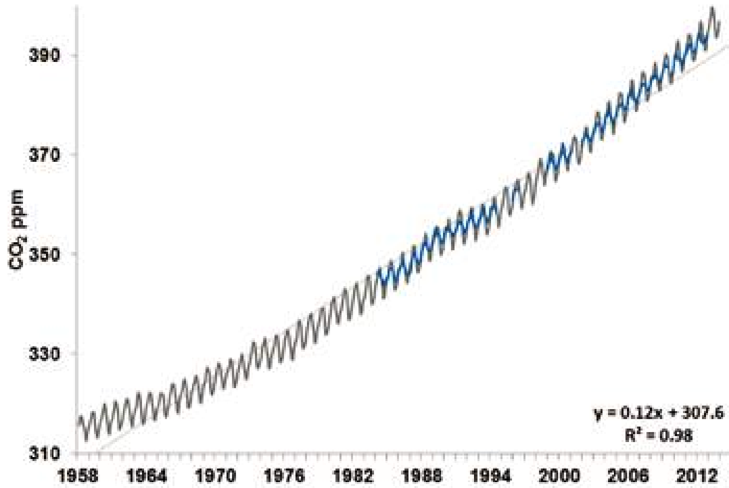


Figure 2.2 Monthly atmospheric carbon dioxide (CO2) concentration (ppm) for Mauna Loa, Hawaii, March 1958–December 2013, (grey) and Christmas Island, Kiribati, March 1984–December 2012, (blue). Dashed line is linear regression for Mauna Loa (source: World Data Centre for Greenhouse Gases, http://ds.data.jma.go.jp/gmd/wdcgg/introduction.html).

Recent global warming has been unequivocally linked to increasing atmospheric concentrations of greenhouse gases (Bindoff et al. 2013). Isotopic analysis of atmospheric carbon dioxide (CO_2), the main greenhouse gas, allows us to directly attribute this increase to the burning of fossil fuels and other human activities (Levin and Hessashimer 2000). The atmospheric concentration of CO_2 has increased by more than 40% from pre-industrial levels of ~278 ppm (Hartmann et al. 2013) to 396 ppm in 2013 (www.ersl.noaa.gov/gmd/ccgg/trends) with concentrations still rising rapidly (Figure 2.2).

Before projecting future climate conditions of significance to agriculture and forestry for the Pacific Island countries and territories (PICTs) it is necessary to understand past and current climates, and the major drivers of seasonal, interannual and longer-term climate variability. This understanding depends upon reliable long-term observations at as many locations as possible. Such observations include long-term weather station records and measurements of large-scale atmospheric and oceanic conditions and circulation patterns. The latter is especially important as the surface climate of the PICTs is dominated by the vast tropical Pacific Ocean (Lough et al. 2011; Ganachaud et al. 2011). The sheer size and inaccessibility of much of the Pacific region means that such observational records are of limited duration and quality, especially prior to the 1950s (L'Heureux et al. 2013). Tropical cyclones, which are major weather disturbances affecting many of the PICTs have, for example, only been well documented since the advent of satellite observing systems in the 1980s.

Projecting possible future climates relies on Global Climate Models (GCMs): numerical simulations of the global climate system incorporating complex physical, chemical and biological processes and their feedbacks. Many groups around the world have developed and routinely run climate models. None of these models is, however, perfect and hence we rely on combining projections from many models (multi-model ensembles) to obtain the most robust picture of possible future climates and to help quantify the uncertainties inherent in such projections. Climate models are continually refined and improved as our understanding of the global climate system grows and computational power increases. Earlier climate vulnerability studies for tropical Pacific nations (Bell et al. 2011; Australian Bureau of Meteorology and CSIRO 2011) relied on output from the Climate Model Intercomparison Project 3 (CMIP3; Meehl et al. 2007a). As part of the 5th Assessment Report of the Inter-Governmental Panel on Climate Change (IPCC-AR5), a new generation of model projections is now available (CMIP5) which we use here (Taylor et al. 2011; http://cmip-pcmdi-llnl.gov/). These models generally operate at higher spatial resolution and include a wider range of climate processes than CMIP3.

Despite these changes, climate projections from CMIP3 and CMIP5 are not radically different and the underlying conclusions from previous assessments remain largely valid (Knutti and Sedláĉek 2013). For agricultural impact research, local- to regional-scale projections (e.g. <100 km, ideally to a site scale) of key climate variables such as seasonal temperatures, rainfall, and frequency of temperature and rainfall extremes are required. Thus, the usefulness of GCMs, which are designed to provide information on large-scale changes, for informing management decisions is still limited. It may take many years before global climate models are able to make reliable local-scale projections of temperature and rainfall characteristics (Ramirez-Villegas et al. 2013). Given, however, current rates of global warming, we do not have the luxury of waiting that long to develop and implement appropriate adaptation strategies. We must, therefore, take a pragmatic approach and rely on information based on observed climate change, current assessments of agricultural/forestry sensitivity and the best available climate projections of the future.

To make climate projections, it is necessary to specify the future trajectory of atmospheric greenhouse gas concentrations. This depends on how society and governments respond to the challenge of rapid anthropogenic climate change; that is, the steps taken (or not) to significantly reduce (mitigate) the amount of greenhouse gases we are adding to the atmosphere. To account for these uncertainties, climate projections are based on a set of possible greenhouse trajectory scenarios. IPCC-AR3 and IPCC-AR4, as well as the earlier PICT-focused studies of Bell et al. (2011) and the Australian Bureau of Meteorology and CSIRO (2011), used projections based on the Special Report on Emissions Scenarios (SRES) (Nakicenovic et al. 2000). As part of the recent IPCC-AR5 process, these scenarios have been replaced with a new set: the Representative Concentration Pathways (RCPs) (Moss et al. 2010) which are named on the basis of their level of radiative forcing in 2100 (e.g. for RCP4.5, the change in the balance of incoming and outgoing radiation to the atmosphere due to changes in the atmospheric composition of greenhouse gases is 4.5 W.m2) (Table 2.1). Although not directly comparable, the SRES A2 high emissions scenario, with 2100 CO_2 concentrations of ~750-800 ppm, lies between the new RCP6.0 and RCP8.5 scenarios. Similarly, the SRES B1 low emissions scenario, with 2100 CO_2 concentrations of ~500-550 ppm, lies between the new RCP2.6 and RCP4.5 scenarios (Figure 2.3). RCP2.6, which has peak emissions before 2100 followed by a decline, and would constrain average global warming to ~+2°C by 2100, is now looking increasingly unachievable, especially as observed increases in atmospheric CO_2 are tracking at or above RCP8.5 (Peters et al. 2013).

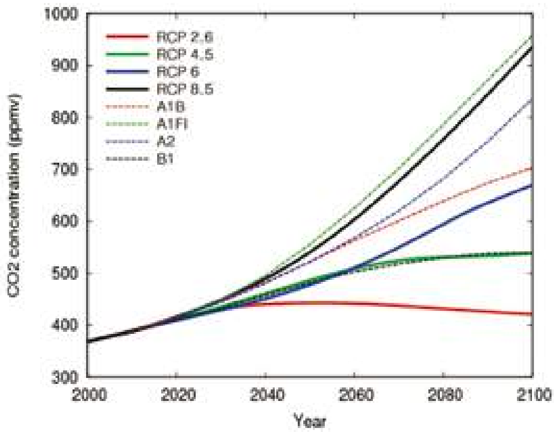


Figure 2.3 Comparison of carbon dioxide (CO_2) concentrations (ppm), 2000–2100, for the new Representative Concentration Pathways (RCPs), and the previous Special Report on Emissions Scenarios (SRES) scenarios (adapted from Collier et al. 2011).

Table 2.1 Characteristics of Representative Concentration Pathway (RCP) scenarios (adapted from Moss et al. 2010).

RCP	Radiative forcing	CO2 equivalent in 2100 (ppm)*	Description
RCP2.6	~3.0 $W.m^{-2}$ Peak before 2100 and then declines	Peak ~490 ppm before 2100 and then declines	very low emissions which plateau and declines
RCP4.5	~4.5 $W.m^{-2}$ at stabilization after 2100	~650 ppm at stabilization after 2100	low emissions which plateaus
RCP6.0	~ 6.0 $W.m^{-2}$ at stabilization after 2100	~850 ppm at stabilization after 2100	medium emissions
RCP8.5	>8.5 $W.m^{-2}$ at 2100	>1,370 ppm in 2100	very high emissions

* CO_2 equivalent is a measure of total amount of emissions from all the greenhouse gases (i.e. CO_2, methane, nitrous oxides and halocarbons).

Different PICTs are affected by different climatological features such as the South Pacific Convergence Zone (SPCZ) and the monsoon. As a result, individual PICTs will experience climate change in different ways with varying implications for agricultural and forestry productivity (Barnett 2011; Bell et al. 2011). Some changes will be relatively consistent across the region, including continued warming of air temperatures, continued increases in sea level increasing the risk of inundation, coastal erosion (Wetzel et al. 2013) and salt water intrusions (White and Falkland 2010) and, importantly, an increase in the frequency and intensity of extreme weather events and consequent reduction in the length of recovery periods between such events. Other projected changes are likely to be region- or location- specific. For example, projecting changes in rainfall patterns is more complex than for temperature and sea level. At a broad scale, theory and climate models suggest that large-scale warming will cause an intensification of the hydrological cycle with regions that are already wet becoming wetter and typically dry regions becoming even drier. However, this 'wet-gets-wetter' pattern of projected change is complicated by other factors such as spatial variations in the magnitude of surface warming, which causes changes in wind patterns and more complex rainfall changes (Huang et al. 2013). Small-scale changes are also strongly affected by local topographic features, such as high mountains, that are not properly resolved in current climate models.

Here, we provide a framework for subsequent chapters to assess the vulnerability of agriculture and forestry in the PICTs to a rapidly changing global climate. First, we describe current climate conditions in the tropical Pacific, the primary atmospheric circulation features and their seasonal variations. Second, we describe natural sources of interannual and decadal climate variability. Third, we analyse the observational records to determine what features of the current climate have already changed with the relatively modest amount of global warming observed to date. Fourth, we examine the latest CMIP5 climate models projections for different RCP scenarios over the 21st century. We conclude with some recommendations as to how the PICTs can continue to improve understanding of their current climate, and how it is already changing, and refine future climate projections.

2.2 Present-day surface climate of PICTs

2.2.1 Climatology of the tropical Pacific

The average seasonal climate of the tropical Pacific is affected by various large-scale atmospheric features. Flanking the equator are two regions of high rainfall: the Intertropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone (SPCZ) (Figure 2.4). Here surface winds converge over regions of warm sea surface temperatures (SST). This drives upward movement of moisture-filled air, resulting in thick clouds, deep convection and intense rainfall. This ascending air forms the upward branch of the east–west oriented Walker Circulation (Figure 2.5) which has compensating downward flow creating relatively dry conditions in the eastern tropical Pacific. Surface return flow from the eastern to the western Pacific occurs as the equatorial Trade Winds. Strong convection in the west and along the ITCZ also drives the north–south oriented Hadley Circulation with descending air and arid conditions in the subtropical high-pressure cells (Figure 2.5). Near-surface winds associated with anticylonic rotation produce the meridional (north–south) Trade Winds which are predominantly northeasterly in the north Pacific and southeasterly in the south Pacific.

The large-scale distribution of air temperature is closely coupled to the underlying SST. The equatorial Trade Winds push water, heated by the sun, to the west forming the Western Pacific Warm Pool (WPWP) made up of some of the world's warmest surface waters with SST exceeding 28–29°C (Figure 2.4c, d). In the central and eastern Pacific these same winds drive upwelling of cooler subsurface water that keeps air temperatures several degrees cooler than in the west. Year-to-year variations in the strength of the Walker Circulation and the equatorial Trade Winds, the eastward extent of the WPWP and the location of rainfall are primarily related to oscillations between El Niño and La Niña conditions (i.e. the El Niño Southern Oscillation—ENSO) (Section 2.3.1.1).

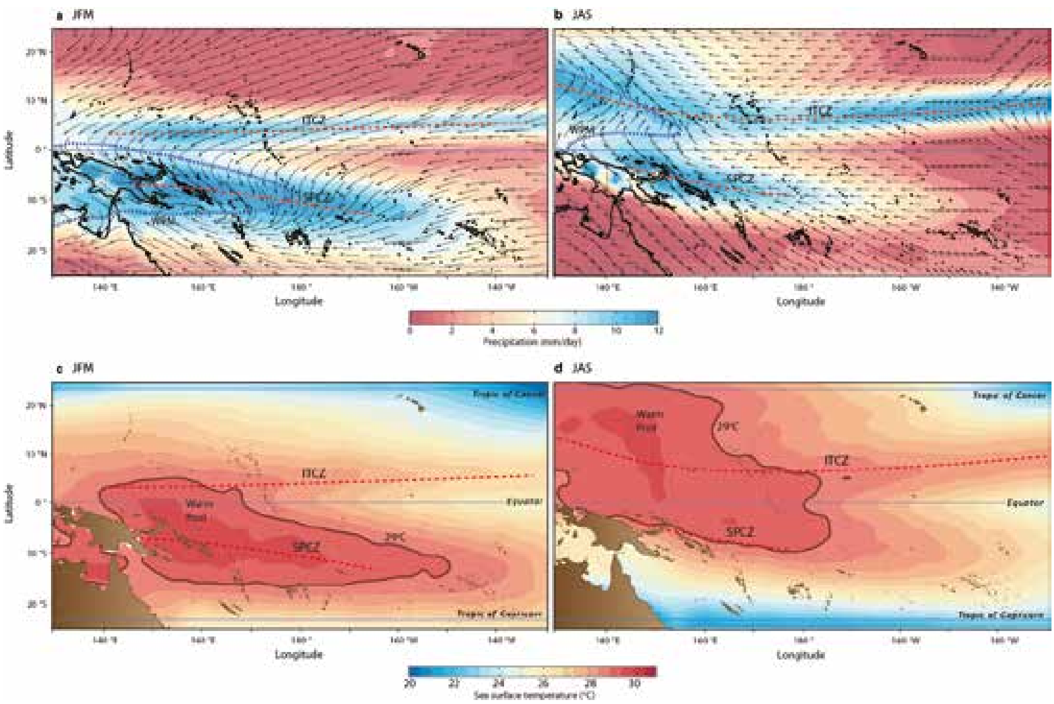


Figure 2.4 Average, 1979–2012, (a, b) rainfall and surface winds and c, d) SST for January to March (left) and June to September (right). Also shown are average locations of the ITCZ and SPCZ (red dashed line, a–d); the region affected by the WPM (defined as region of seasonal westerly winds, blue dashed line, a–b), and the edge of the WPWP (defined by 29°C isotherm, grey line, c–d) (source: surface winds and rainfall from ERA interim; HadISST, Rayner et al. 2003).

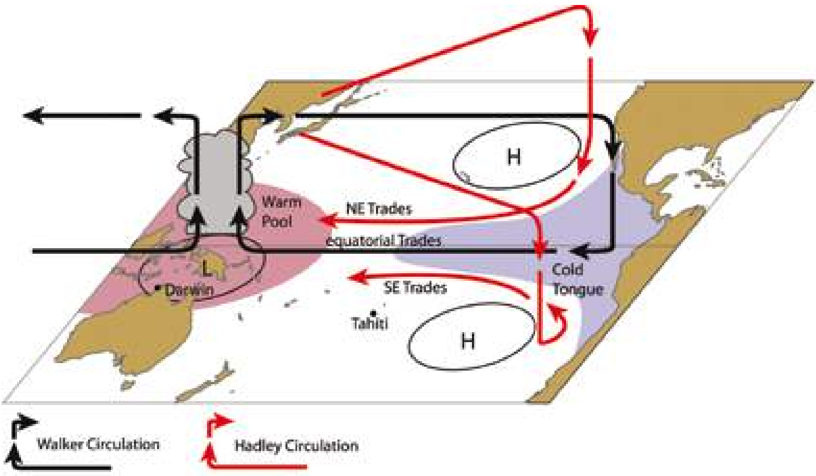


Figure 2.5 Schematic showing the Walker and Hadley Circulation Cells, the associated surface low (L) and high (H) pressure systems, the WPW and eastern Pacific cold tongue. The sea-level pressure difference between Tahiti and Darwin, the Southern Oscillation Index (SOI), is a measure of the strength of the Trade Winds and ENSO activity.

The strength of ENSO events are commonly measured using the sea-level pressure difference between Tahiti and Darwin—the Southern Oscillation Index (SOI) (Troup 1965) and the Niño 3.4 index of average SST anomalies between 5°N–5°S, 170°–120°W (Trenberth 1997).

Convection and heavy rainfall over the WPWP and along the ITCZ and SPCZ persist throughout the year. Typically rainfall over the WPWP averages about 2000–3000 mm per year (Delcroix et al. 1996; Table 2.2). However, the seasonal movement of the Sun causes important changes to the location of these features and associated rainfall. Differences in the rate of heating between the land and ocean during the summer season for each hemisphere drive a reversal of the prevailing easterly winds and heavy rainfall in the western Pacific associated with the Western Pacific Monsoon (WPM) (Wang 2006). In the Southern Hemisphere the WPM can extend from East Timor as far as Tuvalu and Vanuatu (Figure 2.4a), while in the Northern Hemisphere it can extend from Palau as far as the Marshall Islands (Figure 2.4b). The WPM is subject to large intra-seasonal and interannual variability, with timing of the onset and termination, and wet bursts and dry breaks affected by the Madden-Julian Oscillation (MJO) (Hendon and Liebmann 1990), mid-latitude troughs (Davidson et al. 1983) and ENSO events.

The SPCZ is strongest during Austral summer, when the Southern Hemisphere WPM peaks and regional SSTs are warmest (Figure 2.4a, c). The high rainfall rates of the SPCZ extend far into the central South Pacific. During Austral winter the SPCZ contracts towards the northwest (Vincent 1994; Figure 2.4b) and occasionally, between

June and August, is absent and a broad undisturbed east-to-southeast wind flow prevails over the island groups. SPCZ rainfall and cloudiness varies considerably on short timescales associated with synoptic events and intra-seasonal variability due to the MJO (Vincent 1994). It also undergoes substantial movement associated with ENSO events (Vincent et al. 2011; Section 2.3.1.1).

The ITCZ persists across the Pacific throughout the year but weakens considerably from January to March. It is closest to the equator between March and May and gradually moves equatorward during Boreal spring and summer, moving ~500 km further north and becoming broader in the central and eastern Pacific during August to October (Australian Bureau of Meteorology and CSIRO 2011). In the western Pacific the ITCZ extends northwards during Boreal summer when the WPM peaks (Figure 2.4b).

At higher subtropical latitudes, away from the equator, seasonal changes in the north-south temperature difference cause the high pressure systems (Figure 2.5) to migrate poleward during summer and equatorward during winter (Barry and Chorley 2003). These high pressure systems are generally accompanied by cooler, drier conditions.

On large islands, atmospheric circulation and rainfall are significantly modified by topography. Where the prevailing winds are obstructed by mountains, the moist surface air is forced upwards and can lead to very high local rainfall rates. For example, on Fiji's main island, Viti Levu, Suva on the southeast coast averages 3020 mm per year whereas Monasavu in the highlands averages 4970 mm. Conversely Nadi Airport on the leeward coast receives an average of 1880 mm. Heating of land and the convergence of sea breezes can also cause the development of convective cloud and rain over the larger islands in the late afternoon during the warmest months of the year.

The seasonal and spatial variations in solar energy and the resulting shifts in tropical Pacific atmospheric and oceanic circulations give rise to the seasonal changes in rainfall and temperature experienced on individual islands. Locations closer to the equator (e.g. Tarawa, Funafuti) have small seasonal ranges compared with higher latitude locations that exhibit larger seasonal variations (e.g. Nadi). Regional differences in the seasonal cycle of rainfall depend on the climatological features affecting particular islands. For example Fiji and the Marshall Islands are affected by the seasonal migration of the SPCZ and ITCZ, respectively, while Palau and Papua New Guinea are also affected by the WPM (Figure 2.6; Table 2.2).

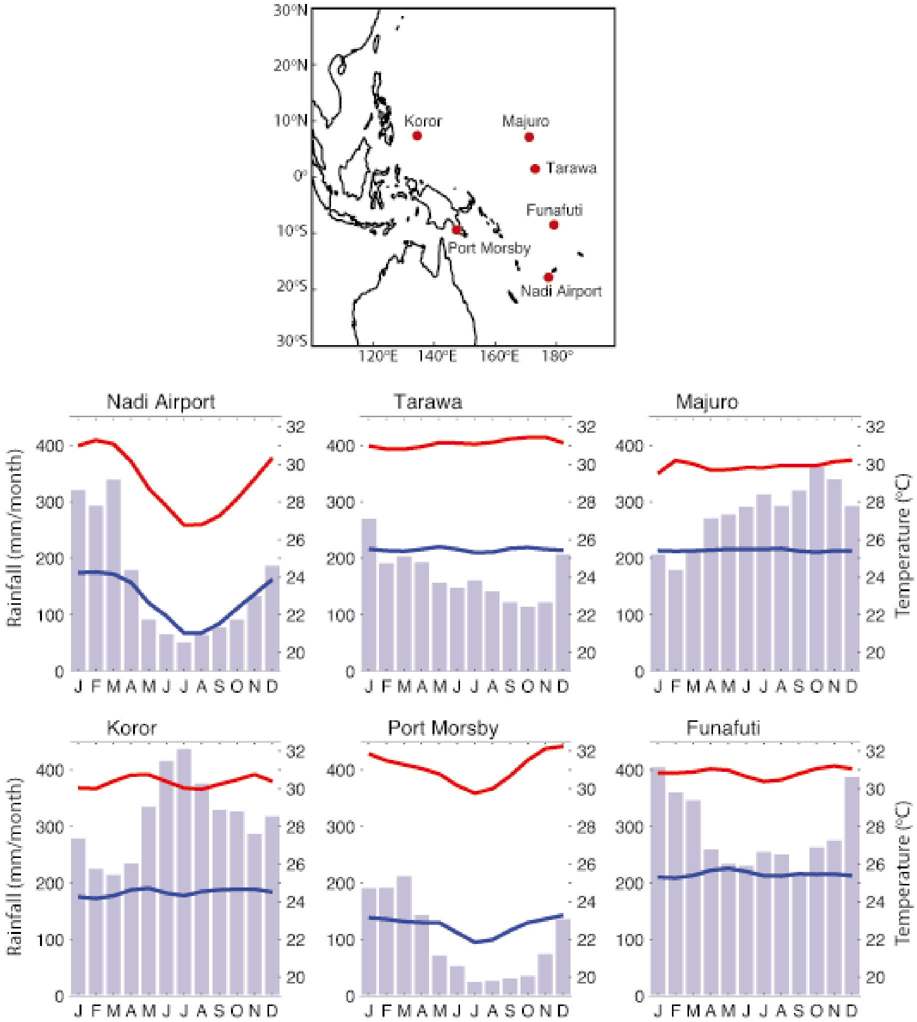


Figure 2.6 Monthly climatologies (based on ~50 years of data) for rainfall (purple bars; left hand scale), maximum (red lines) and minimum (blue lines) air temperature (right hand scale), for selected Pacific island meteorological stations (source: PCCSP).

2.2.2 Extreme events: tropical cyclones and sea level

Average climate conditions can be disrupted by extreme and destructive weather events. Of particular importance for many tropical Pacific Islands are tropical cyclones, which are associated with very high rainfall rates, destructive winds and extreme sea levels (storm surges). These can affect all countries except Kiribati, Nauru and the Pitcairn Islands (Table 2.2). In the most tropical cyclone-prone regions of the PICTs (southern Vanuatu and northern New Caledonia), a tropical cyclone will pass within a ~50 km radius on average every two years (i.e. frequency = 0.5). This is markedly lower than the Philippines in the Northern Hemisphere which averages up to 1.5 cyclones per year (Figure 2.7; see also Southern Hemisphere Tropical Cyclone Data Portal, www.bom.gov.au/cyclone/history/tracks).

Table 2.2 Average seasonal rainfall and maximum and minimum air temperatures (November–April and May–October) and most important climate influences for PICTs. Average statistics are for the 1986–2005 base period used in the climate projections. Also given is total annual rainfall. Main climate controls are: Intertropical Convergence Zone (ITCZ), South Pacific Convergence Zone (SPCZ), West Pacific Monsoon (WPM), El Niño-Southern Oscillation (ENSO) and Tropical Cyclones (TCs). '-' indicates insufficient data to produce meaningful climate statistics. * indicates partner countries with PCCSP and PACCSAP.

Country	Station	Main controls	Rainfall Nov–Apr mm	Rainfall May–Oct mm	Rainfall Annual total mm	Max T Nov–Apr °C	Max T May–Oct °C	Min T Nov-Apr °C	Min T May–Oct °C
American Samoa	Pago Pago 14.3S, 170.7W	SPCZ ENSO TCs	1847	1166	3013	30.8	29.4	25.5	25.1
Cook Islands*	North Penrhyn 9.0S, 158.1W	SPCZ ENSO TCs	1593	944	2537	-	-	-	-
	South Raratonga 21.2S, 160.0W	SPCZ ENSO TCs	1121	692	1813	28.7	25.9	23.2	20.3
Federated States of Micronesia*	West Yap 9.5N 138.1E	ITCZ WPM ENSO TCs	1078	2011	3089	31.1	31.3	25.7	25.7
	East Pohnpei 7.0N, 158.2E	ITCZ ENSO TCs	2236	2459	4695	30.8	31.5	23.3	22.8
Fiji*	Suva 18.1S, 178.4E	SPCZ ENSO TCs	1743	1060	2803	31.0	27.8	24.2	21.8
French Polynesia	Tahiti-Faa 17.6S, 149.6W	SPCZ ENSO TCs	1164	457	1621	31.0	29.6	24.1	22.2
Guam	Agana 13.5N, 144.8E	ITCZ ENSO TCs	868	1688	2556	-	-	-	-
Kiribati*	Gilbert Islands Tarawa 1.4N, 172.9E	ITCZ SPCZ ENSO	1329	988	2317	31.2	31.4	25.5	25.5
	Line Islands Kiritimati 2.0N, 157.5E	ITCZ ENSO	734	538	1272	-	-	-	-
Marshall Islands*	Central Kwajalein 8.7N, 167.7E	ITCZ ENSO TCs	959	1503	2462	29.8	30.2	25.8	25.8
	South Majuro 7.1N, 171.4E	ITCZ ENSO TCs	1479	1822	3301	30.0	30.3	25.6	25.6
Nauru*	Nauru Arc-2 0.5S, 166.9E	ITCZ SPCZ ENSO	1345	1001	2345	-	-	-	-

New Caledonia	Noumea 22.3S, 166.5E	SPCZ ENSO TCs	676	410	1086	28.6	24.6	22.5	18.6
Niue*	Hanan Airport 19.1S, 169.9W	SPCZ ENSO TCs	1331	746	2077	29.2	26.7	22.6	20.0
Northern Mariana Islands CNMI	Saipan Int Airport 15.1N, 145.7E	ITCZ ENSO TCs	544	1247	1791	-	-	-	-
Palau*	Koro 7.3N, 134.5E	ITCZ WPM ENSO TCs	1568	2201	3769	30.7	30.5	24.4	24.6
Papua New Guinea*	North Madang 5.2S, 145.8E	WPM ENSO	2092	1168	3260	31.0	30.7	23.9	23.8
	South Port Moresby 9.5S, 147.2E	WPM ENSO TCs	891	234	1125	32.0	30.8	23.7	23.0
Pitcairn Islands	Adamstown 25.1S, 130.1W	SPCZ	740	739	1479	24.9	21.5	-	-
Samoa*	Apia 13.8S, 171.8W	SPCZ ENSO TCs	2048	913	2961	30.5	29.8	23.2	22.7
Solomon Islands*	Central Honiara 9.4S, 160.0E	ITCZ SPCZ WPM ENSO TCs	1234	608	1842	31.3	31.1	23.9	23.2
	South Santa Cruz 10.7S, 165.8E	SPCZ WPM ENSO TCs	2280	1953	4233	30.6	29.6	24.2	24.0
Tokelau	Nokunono 9.2S, 171.9W	SPCZ ENSO TCs	-	-	-	-	-	-	-
Tonga*	Nuku'alofa 21.1S, 175.2W	SPCZ ENSO TCs	1029	633	1662	29.5	26.0	23.5	19.6
Tuvalu*	Funafuti 8.5S, 179.2E	SPCZ WPM ENSO TCs	2000	1446	3446	31.1	30.9	25.6	25.8
Vanuatu*	North Sola (Vanna Lava) 13.9S, 168.0E	SPCZ ENSO TCs	2297	1631	3928	31.3	29.9	24.1	23.6
	Central Port Vila 17.7S, 168.3E	SPCZ ENSO TCs	1534	711	2245	30.1	27.1	21.7	18.5
Wallis & Futuna	Hihifo 13.3S, 176.2W	SPCZ ENSO TCs	1925	1214	3139	30.6	29.6	24.9	24.6

Tropical cyclones derive their energy from warm surface waters and, therefore, tend to form over seasonally warm SST, such as found in the WPWP (Figure 2.4c, d). In the southwestern Pacific the highest frequency of tropical cyclones occurs between January and March (Australian Bureau of Meteorology and CSIRO 2011; Diamond et al. 2012, 2013) when the WPWP shifts into the Southern Hemisphere and the SPCZ is strong (which also favours tropical cyclone formation). In the northwestern Pacific conditions are highly favourable for tropical cyclone development (Gray 1979) and they may occur throughout the year, although numbers tend to peak in August and be lowest between January and March (Chan 2005). Tropical cyclones do not form within ~5° of the equator as the Coriolis Force, generated by the Earth's rotation, is not strong enough here to give the system the necessary rapidly rotating wind field. Because of this, equatorial PICTs are not affected by tropical cyclones and this is unlikely to change in the future (Table 2.2).

Coastal inundation from high sea-level events can cause crop and infrastructure damage and contamination of freshwater supplies. Unusually high sea levels are influenced by a number of factors:

- Tides are the twice daily rise and fall of mean sea level driven by the gravitational interaction between the Earth, Sun and Moon and are highly predictable. The strength of the tides (i.e. tidal range and tidal currents) can vary over time; for example, variations are associated with the 28-day spring–neap cycle. The largest high and low tides (king tides) occur at times during the year when the Earth, Sun and Moon are aligned. The state of the tide can, therefore, affect the severity of impacts due to other factors that influence sea level.
- Sea level varies due to seasonal and longer-term variations in winds, ocean temperature and sea-level pressure. For example, sea level increases (decreases) by tens of centimetres in the western tropical Pacific due to intensified (weakened) Trade Winds during La Niña (El Niño) events (Table 2.3).
- Storms and tropical cyclones approaching an island can create storm surges. The drop in atmospheric pressure associated with these systems raises sea level by ~1 cm for each 1 hPa drop in air pressure. In addition, strong winds can force water onshore and generate large waves that push water higher onto land. While wind-generated currents tend to be localised to the regions of high winds, swell waves from storms and tropical cyclones can propagate over large distances affecting islands far afield (Hoeke et al. 2013).

These large-scale climate controls and their seasonal variations result in the average climate typical of individual islands, with 73% influenced by the SPCZ, 36% by the ITCZ, 18% by the WPM and 86% affected by tropical cyclones (Table 2.2).

2.3 Observed surface climate variability and change

Superimposed on the average seasonal cycles of surface climate are natural sources of variability that modulate surface climate on timescales from weeks to decades. Here we first discuss the role of interannual and decadal variability in modulating Pacific surface climate. We then examine the evidence from observational records for climate already changing across the Pacific Islands, (i.e. significant long-term changes that exceed those expected from natural climate variability).

Data sources and importance of long, homogeneous observations

'Meteorology Services live and die by data, but many donors don't want to take on the ongoing maintenance costs of funding data collection equipment.' Ofa Fa'anunu (2013) [1]

To understand and document current climate conditions and how they may already be changing requires reliable, long-term, continuous, homogeneous observations of important weather elements. The Pacific Ocean covers a huge area, but only a small portion of it is routinely monitored using surface observations. It is only with the satellite era (starting in the early 1980s) that we have been able to examine Pacific Ocean climate variability as a whole. This highlights the enormous value of surface meteorological observations taken by National Meteorological Services (NMSs) over many years.

The Pacific Climate Change Science Program (PCCSP) and the Pacific-Australia Climate Change Science and Adaptation Planning Program (PACCSAP) have developed a climate database management system, Climate Data for the Environment (CliDE), specifically for 15 partner countries, 14 of which are PICTs (Table 2.2). These countries now have a modern, robust, secure and structured climate database management system to help in the provision of climate services to government, the community and researchers. CliDE has been populated with Pacific Island station data collected from in-country databases, the Australian Bureau of Meteorology (BOM), New Zealand's National Institute of Water and Atmospheric Research (NIWA), and the US National Oceanographic and Atmospheric Agency (NOAA) archives. During PACCSAP, limited funding was also provided to help catalogue and digitise priority station data such as maximum and minimum air temperatures, rainfall, wind, air pressure and sunshine measurements into CliDE (www.bom.gov.au/climate/pacific/about-clide.shtml).

Quality checks were performed to produce high quality rainfall and temperature datasets and, in cases where unrealistic shifts occurred, data were homogenised using the method of the Australian Bureau of Meteorology (Jones et al. 2013). The Pacific Climate Change Data Portal (www.bom.gov.au/climate/pccsp) is the current archive for homogenised data and also provides historical daily and monthly data for rainfall, maximum and minimum air temperature and mean sea-level pressure.[2] *The data portal provides detailed coverage for the region, including all PICTs, and allows historical climate data to be displayed over any period of interest where*

1 Ofa Fa'anunu, Director of Tonga Meteorological Service, PACNEWS, July 2013.

2 The climate trends and climatologies of the Pacific Climate Change Data Portal (www.bom.gov.au/climate/pccsp) are publically accessible. Requests for the original data are directed to the respective National Meteorological Service.

data are available. The NMSs can also view long-term data averages and readily extract this information for reports to government, regional organisations and others. Recently the portal has been developed further to include extreme temperature and rainfall indices based on those defined by the World Meteorological Organization Expert Team on Climate Change Detection and Indices (Peterson and Manton 2008; www.bom.gov.au/climate/pccsp/about-pi-extreme-indices.shtml).

The value to Pacific Islands of robust and reliable long-term weather observations cannot be understated. Such data are necessary both to document local climate conditions and to determine how climate is changing. Recent international aid efforts have significantly enhanced the climate data available to PICTs. There are, however, still large volumes of paper records in former colonial and Pacific countries. An imaging and digitising program would preserve these records and thus improve the breadth of the information available for the NMSs.

Ongoing collection of climatological data and enhancement of the observational networks in the Pacific Islands is of importance for both local and global scientific and socio-economic applications. There has, however, been an increase in the number of missed observations in recent years and a decline in the number of reporting meteorological stations. Network decline is primarily due to limited NMS operational budgets and increased costs of instrumentation. This decline introduces discontinuities in rare and high-quality records resulting, for example, in less comprehensive ENSO impact and historical trends and extreme climate analyses. International assistance and additional support from national governments is required to maintain these vital observational networks.

Surface climate data are complemented by sea level, sea surface height and SST data. Data used in this chapter include monthly tide gauge records from the South Pacific Sea Level and Climate Monitoring Project (www.bom.gov.au/oceanography/projects/spslcmp/spslcmp.shtml), satellite altimeter data, and reconstructed sea levels based on the methods of Church et al. (2006). We also use the HadISST SST data described by Rayner et al. (2003).

2.3.1 Interannual and decadal variability

2.3.1.1 Interannual variability

The largest differences in climate from year to year in the tropical Pacific are due to ENSO events (McPhaden et al. 2006). ENSO affects the risk of extreme events such as droughts, floods, tropical cyclones, strong winds and extreme sea levels. Consequently, ENSO can have significant impacts on agriculture, marine and land-based ecosystems, fisheries, water resources, disaster management and human health. ENSO-neutral conditions prevail in about 50% of years with the other 50% roughly split between El Niño or La Niña events. These two extremes of ENSO bring distinct surface climate anomalies to many parts of the tropical Pacific, typically develop between May and June and evolve over the following 12–18 months (McPhaden et al. 2006). The magnitude, timing and impacts of ENSO events vary from country to country but affect all PICTs apart from the Pitcairn Islands (Table 2.2). ENSO events can generally be predicted with reasonable skill about six months prior to their peak (usually from June onwards) and conditions conducive to their development are continuously monitored by various international agencies (including BOM: www.bom.gov.au/climate/ahead/model-summary.shtml#tabs=Overview, NOAA: www.elnino.noaa.gov/forecast.html and NIWA: http://www.niwa.co.nz/climate/icu/island-climate-update-155-august-2013).

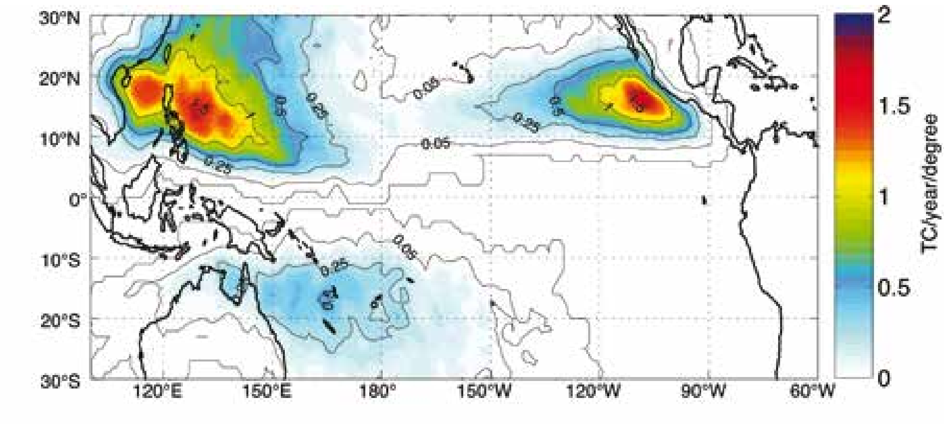


Figure 2.7 Average number of tropical cyclones per year per 1 degree boxes, 1969–2013 (source: IBtrACS, www.ncdc.noaa.gov/oa/ibtracs).

Typically, El Niños are associated with widespread warming of SST in the near-equatorial Pacific east of the dateline between November and April (Figure 2.8a), with greatest warming between December and March. Concurrently there is a weak cooling of SST in the far western Pacific and in a horseshoe pattern surrounding the regions of warming. The opposite pattern (with cooling in the eastern and central equatorial Pacific) occurs during La Niñas. While ENSO tends to peak in Austral summer, weaker effects often extend to other seasons (Figure 2.8b). Changes in SST and atmospheric circulation patterns associated with El Niño and La Niña cause large-scale shifts in rainfall patterns. In general during an El Niño event there is an increase in rainfall in the central and eastern tropical Pacific (overlying warmer SST) with smaller rainfall deceases in the far eastern Pacific and at higher latitudes (overlying cooler SST). The opposite response occurs during La Niña events. The strength of the rainfall response varies with the magnitude of the SST changes (Figure 2.8c, d). Winds also play an important role in ENSO. For example, El Niños are initiated by bursts of westerly winds in the far western Pacific that cause circulation changes in the ocean which in turn generate SST changes. During El Niños the Trade Winds weaken and may even change direction, while they strengthen during La Niñas (Figure 2.8c, d). Rainfall changes in the western Pacific are also linked with a more northeasterly location of the SPCZ and equatorward shift of the ITCZ during El Niños and more southwesterly location of the SPCZ and a shift of the ITCZ away from the equator during La Niñas (Salinger et al. 2014). The effect of ENSO extremes on island rainfall, therefore, varies with location. Fiji, for example, typically experiences wetter than normal conditions during La Niñas and drier than normal conditions during El Niños whereas northern Kiribati tends to be wetter during El Niños and drier during La Niñas (Table 2.3). The recent 2010–2011 and 2011–2012 La Niñas, for example, resulted in severe drought conditions in Tuvalu (http://www.ifrc.org/en/news-and-media/news-stories/asia-pacific/tuvalu/red-cross-responds-to-water-crisis-in-drought-stricken-tuvalu/) and floods in Fiji (www.redcross.org.au/fiji-floods-2012.aspx).

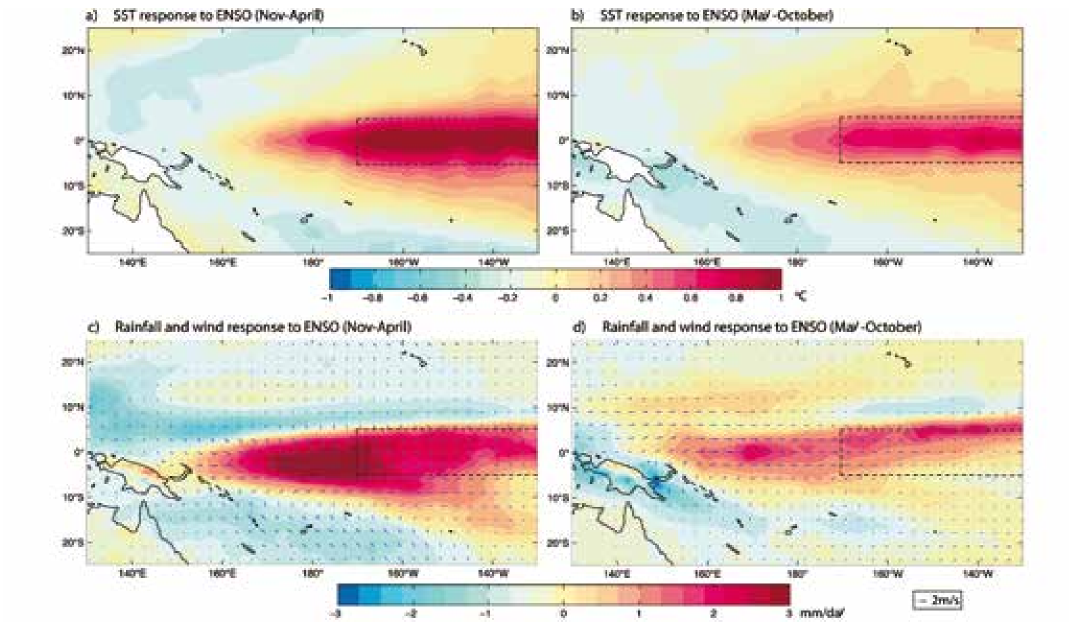


Figure 2.8 Typical ENSO-related changes to (a, b) SST, and (c, d) rainfall and surface winds for November–April (left) and May–October (right). Calculated as SST, rainfall or wind regressed against the NINO 3.4 index, 1979–2011. Box delineates the NINO 3.4 SST region which extends to 120°W (source: rainfall and winds from Dee et al. 2011; HadISST, (Rayner et al. 2003).

While ENSO events generally develop in a similar way, no two events are the same, with varying magnitude, timing and patterns of SST, wind and rainfall changes. ENSO events are commonly categorised into two types. Canonical (or 'eastern Pacific') El Niño and La Niña events are associated with greatest warming or cooling in the eastern equatorial Pacific (Figure 2.9a). In recent decades several El Niño events have, however, been associated with maximum warming in the central tropical Pacific, rather than in the east (Figure 2.9b; Ashok et al. 2007); called 'central Pacific', or 'Modoki' El Niño events.

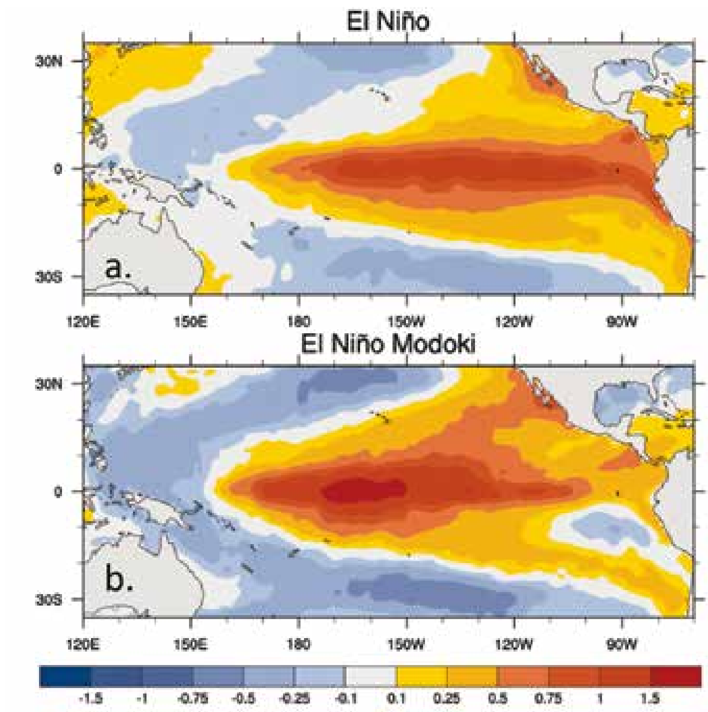


Figure 2.9 Average SST anomalies (°C) associated with a) eastern Pacific El Niño, and b) central Pacific/Modoki El Niño. Plots based on the regression of December–February SST against NINO 3 SST index (a) and Modoki SST index as defined by Ashok et al. (2007) (source: HadISST, Rayner et al. 2003).

Table 2.3 Summary of impacts of El Niño and La Niña on rainfall, sea level and tropical cyclone risk. Rainfall is for November–April in Southern Hemisphere countries and May–October for Northern Hemisphere countries. ⇳ indicates locations which can experience large opposite swings in sea level at the start of an El Niño event due to the passage of Rossby waves; ** indicates locations that may potentially show significant time lags in the sea level response to ENSO events; ‡ indicates northeast facing coastlines only (Rainfall data from Global Precipitation Climatology Project (GPCP), //precip.gsfc.nasa.gov/).

Country	Region	El Niño	Extreme El Niño	La Niña
American Samoa			Dry	
		↓ sea level**	↓ sea level**	↑ sea level**
Cook Islands	North	Wet	Very Wet	Very Dry
	South	↑ TC risk	Very dry	
Federated States of Micronesia	West	Wet	Dry	
		↓ sea level	↓ sea level	↑ sea level
	East	Wet	Wet	Dry
		↓sea level	↓ sea level	↑ sea level
Fiji		Dry	Very dry	Wet
			↓ sea level**	↑ sea level**
French Polynesia			Wet	Dry

Country	Region	El Niño	Extreme El Niño	La Niña
Guam		Wet ↓ sea level	Dry ↓ sea level	↑ sea level
Kiribati	Gilbert Islands	Very Wet ⇕ sea level*	Dry ⇕ sea level*	Very Dry
	Line Islands	Wet ↑ sea level	Very Wet ↑ sea level	Very Dry ↓ sea level
Marshall Islands	North	Wet ↓ sea level	Wet ↓ sea level	Dry ↑ sea level
	South	Wet ↓ sea level	Wet ↓ sea level	↑ sea level
Nauru		Very Wet ⇕ sea level	Dry ⇕ sea level	Very Dry
New Caledonia		Dry	Dry	Wet
Niue		Dry ↑ TC risk	Very dry ↓ sea level**	Wet ↑ sea level**
Northern Mariana Islands CNMI		↓ sea level	↓ sea level	↑ sea level
Palau		↓ sea level	Very Dry ↓ sea level	Wet ↑ sea level
Papua New Guinea		↓ sea level‡	Dry ↓ sea level‡	↑ sea level‡
Pitcairn Islands				Dry
Samoa		↓ sea level** ↑ TC risk	Very dry ↓ sea level**	↑ sea level**
Solomon Islands		Dry ↓ sea level	Dry ↓ sea level	Wet ↑ sea level
Tokelau		Wet	Very Wet ↓ sea level**	Very Dry ↑ sea level**
Tonga		Dry ↑ TC risk	Very dry	Very Wet
Tuvalu		Wet ↓ sea level	Wet ↓ sea level	Dry ↑ sea level
Vanuatu		Dry	Dry	Very Wet
Wallis & Futuna		↓ sea level**	Dry ↓ sea level	↑ sea level**

Notes:
November to April rainfall for all stations except those in the Northern Hemisphere (FSM, Marshall Islands, Palau and Guam), which are based on May to October rainfall.
El Niño years since 1979: 1986, 1987, 1991, 1994, 2002, 2004, 2006 and 2009.
Extreme El Niño years since 1979: 1982/83 and 1997/98.
La Niña years since 1979: 1988, 1998, 1999, 2007, 2010 and 2011.
Dry/Wet: greater than ± 0.5 standard deviations of mean seasonal rainfall.
Very Dry/Very Wet: greater than ± 2 standard deviations of mean seasonal rainfall.

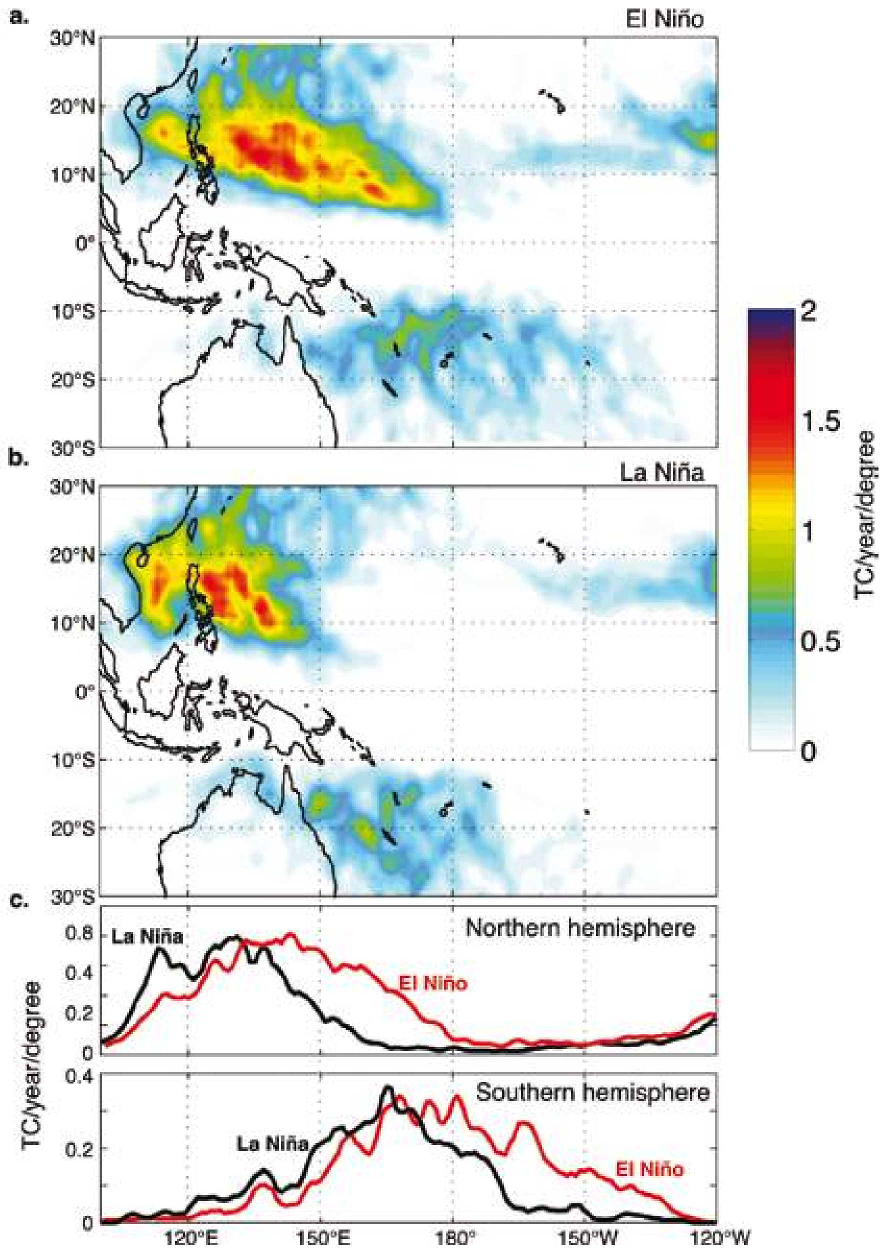


Figure 2.10 Average number of tropical cyclones per year and 1 degree boxes for a) El Niño, b) La Niña, and c) meridionally-averaged tropical cyclone numbers for the Northern (top; 0º–28ºN) and Southern (bottom; 0º–28ºS) Hemispheres during El Niño (red) and La Niña (black) (source: IBtrACS data, 1969–2013; years identified from NINO3.4 index > or < 1sd).

These different types of events can result in different impacts on countries of the Pacific. For example, central Pacific El Niños have a much larger impact on rainfall in Kiribati and Nauru than eastern Pacific events (Australian Bureau of Meteorology and CSIRO 2011). Similarly, differences in the intensity of ENSO events can result in modified climate impacts in some countries. Exceptionally strong El Niños occurred in 1982–1983 and 1997–1998 (McPhaden 1999) when both the SPCZ and ITCZ moved towards the equator and merged into one convergence zone. This caused lower than normal rainfall in Nauru and the western part of Kiribati (Gilbert Islands) rather than the above average rainfall that El Niño normally brings. In many countries (including FSM and the southern Marshall Islands in the northwest and Samoa, Niue and the southern Cook Islands in the southwest) the rainfall in these extreme El Niño years was much lower than normal and significantly drier than other El Niño years. (Table 2.3; Cai et al. 2012).

The location of tropical cyclone activity also shifts with ENSO extremes (Diamond et al. 2013). During El Niños, as the warmest SST extends eastward, so does tropical cyclone activity (Figure 2.10a). In contrast, during La Niñas the stronger Trade Winds confine the warmest waters further west and tropical cyclone activity is also confined towards the western Pacific (Figure 2.10b). Thus some countries (e.g. southern Cook Islands, Niue) experience a greater risk of tropical cyclones during El Niños and others (e.g. New Caledonia) during La Niñas (Table 2.3). The changes in atmospheric and oceanic conditions during ENSO phases also affects sea level which tends to be higher than normal in the west during La Niñas and lower in El Niños.

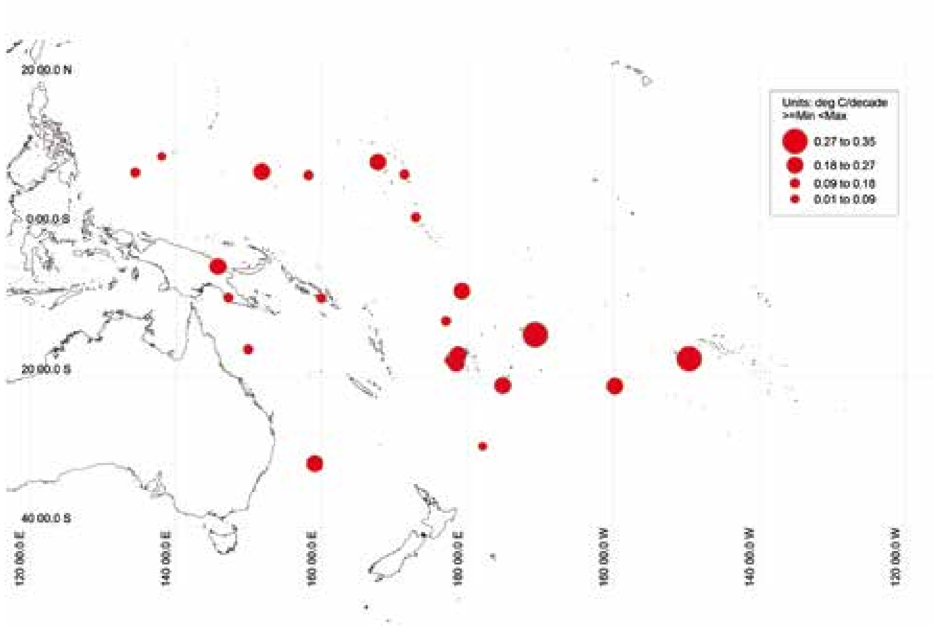


Figure 2.11 Sign and magnitude of trends (ºC/decade) in annual mean air temperature at Pacific island weather stations, 1961–2011 (source: PCCSP).

2.3.1.2 Decadal variability

Interannual variability of surface climate due to ENSO is modulated on decadal timescales by a pattern of Pacific climate variability known as the Inter-decadal Pacific Oscillation (IPO) or Pacific Decadal Oscillation (PDO) (Mantua et al. 1997; Power et al. 1999; Salinger et al. 2001; Folland et al. 2002; Deser et al. 2004). The PDO and IPO are both manifestations of the same Pacific decadal climate variability and their associated indices are highly correlated; they are just defined in different ways. The IPO is an 'ENSO-like' pattern of Pacific SST anomalies that persists in either a warm or cool phase for several decades and the PDO can be considered as the North Pacific component of this. Warm phases in the 1920s–1940s and 1970s–1990s were linked with a weakening of interannual climate variability due to ENSO events. Cold phases in the 1900s–1920s and 1940s–1970s were associated with ENSO events being a much stronger source of interannual climate variability in the tropical Pacific. There has been a change to another cold phase of IPO since the late 1990s (Burgman et al. 2008; http://www.jisao.washington.edu/pdo/) characterised by stronger La Niña-like conditions. Thus, patterns of surface climate anomalies, and their predictability associated with ENSO events, are modulated on decadal timescales.

2.3.2 Observed variability and trends in surface climate

As global temperatures warm (Figure 2.1) we are already observing large-scale changes in tropical ocean climate (Australian Bureau of Meteorology and CSIRO 2011; Bell et al. 2011; Sen Gupta and McNeil 2012). For example, SSTs across much of the tropical Pacific, significantly warmed by ~0.25–0.50^{o} C between 1950 and 1980 and 1981 to 2011 (Lough 2012). As well as warming, the WPWP is increasing in size and extending further eastwards (Cravatte et al. 2009). Sea surface salinity is decreasing (becoming fresher) in the western tropical Pacific and increasing in the southeastern tropical Pacific, consistent with an intensified hydrological cycle in the western Pacific (Durack et al. 2012; Biasutti 2013). While these salinity changes are important for understanding changes to the hydrological cycle, absolute changes are small and have no direct effect on saltwater intrusion on islands. Global average sea level is also rising (Rahmstorf et al. 2012; Church et al. 2013) but the rate of observed rise shows considerable spatial variability around the world. Here we use the available observational records from PICTs to examine changes in surface air temperatures, rainfall and sea level.

2.3.2.1 Temperature

Average surface air temperatures have warmed across the southern tropical Pacific since the late 19th century (Salinger 1995; Folland et al. 2003; Griffiths et al. 2005; Lough et al. 2011) and warming is also evident in the tropical north Pacific over the last half century (Jones et al. 2013; Figure 2.11). The rate of observed warming ranges from 0.05°C/decade to 0.34°C/decade with a mean warming of 0.18°C/decade averaged across all available stations for the period 1961–2011 (Whan et al. 2013). Not all the observed temperature changes will be due to anthropogenic climate change, and regional differences in warming rates may also be associated with natural interannual and decadal climate variability. Annual mean surface air temperatures at selected Pacific stations (Figure 2.12) show that on top of natural year-to-year variability there is, however, an underlying warming trend which is widespread, spatially homogeneous and statistically significant at most stations.

2.3.2.2 Rainfall

In contrast to temperature, total rainfall shows greater spatial variability in both the magnitude and sign of observed changes (Griffiths et al. 2003; Figure 2.13). Over the period 1961–2011, there are few clear trends in rainfall. Some stations have weak increasing trends (e.g. Hanan Airport, Niue), others have weak decreasing trends (e.g. Majuro, Marshall Islands) and some show no change. Statistically significant trends occur at only two of the 68 stations examined: Kiritimati, Kiribati (+110 mm/decade) and at Hihifo, Wallis and Futuna (–150 mm/decade). A notable change is, however, evident since 1981. Rainfall has increased across most of the WPM region, south and west of the SPCZ from Vanuatu to the southern Cook Islands and in the west ITCZ region from Koror to Pohnpei in the north Pacific. Rainfall has decreased north and east of the SPCZ at Nauru, Tarawa, Funafuti, French Polynesia and Pitcairn as well as north of the ITCZ at Guam and in the Marshall Islands eastern ITCZ region. Decreasing rainfall has also occurred at two sites in New Caledonia. Just over 10% of the trends from 1981 are statistically significant (McGree et al. 2013). Natural variability, linked to ENSO and the IPO, is the main influence on rainfall changes over the past 50 years (Folland et al. 2002; Griffiths et al. 2003) with the switch to a negative IPO phase and recent dominance of La Niñas the main reason for the trends observed since 1981 (McGree et al. 2013; Salinger et al. 2014). In contrast to air temperatures, interannual variability of total annual rainfall at selected Pacific stations (Figure 2.14) is much larger than any long-term trends observed to date.

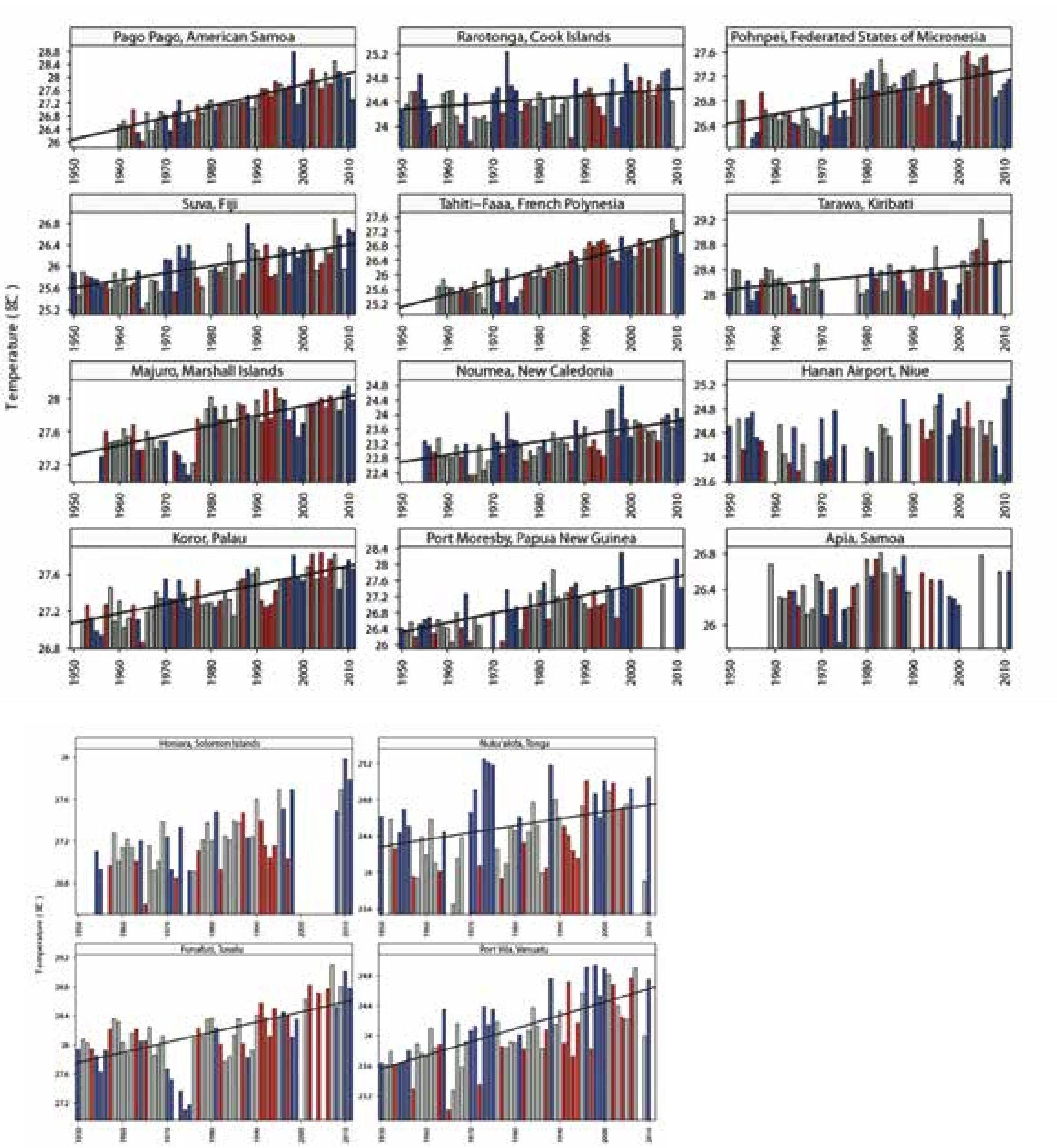


Figure 2.12 Annual mean surface air temperature (°C) at selected Pacific island weather stations. Black lines are linear trends for stations with less than 20% missing data. Red bars denote El Niño years and blue bars denote La Niña years (source: PCCSP).

2.3.2.3 Sea level

Global sea level is estimated to have already risen by 19 cm between 1901 and 2010 (Church et al. 2013). Estimates from reconstructed sea-level data (which include both satellite and tide gauge observations) indicate that global average sea level has been rising at about 1.7 ± 0.2 mm/year since 1900, and at about 1.9 ± 0.4 mm/year since 1960. From the satellite record, global average sea level has been rising at 3.2 ± 0.4 mm/year since 1993, indicating an acceleration in the rate of rise (Church et al. 2013). It is now possible to confidently apportion observed global sea-level rise to its various components. Since the 1970s most sea-level rise has been due to thermal expansion of the ocean (i.e. warming) and the melting of glaciers (excluding Antarctica), with greater contributions from melting of Greenland and Antarctic ice sheets in the last two decades (Church et al. 2013). In addition, since 1993, the rate of sea-level rise in the western Pacific and eastern Indian Oceans has been about three times faster than the global average (Church et al. 2006; Becker et al. 2012). This recent higher rate of regional sea-level rise is primarily a consequence of natural decadal variability (superimposed upon the global rise) associated with the IPO/PDO shifting from a positive to negative phase and an associated intensification of the Trade Winds across the tropical Pacific Ocean (Australian Bureau of Meteorology and CSIRO 2011; Merrifield et al. 2012; England et al. 2014). Time series of annual sea level at selected Pacific stations (Figure 2.15) all show high interannual variability superimposed on the general rising trend. Many of the extreme years also reflect modulation of sea level by ENSO events, for example, 1997/1998 (Table 2.3).

In summary, climate records from Pacific Islands show clear evidence of long-term regional warming of air temperatures consistent with anthropogenic climate change. Sea level also shows a general rising trend but also exhibits substantial interannual to decadal variability. In particular, western tropical Pacific sea level has risen much faster than the global average. This, however, is likely to be strongly influenced by natural decadal variability associated with the IPO/PDO. Rainfall trends are much less coherent and generally characterised by high interannual variability largely attributable to ENSO and IPO/PDO phase. These results illustrate the complexity of determining long-term climate trends (especially for rainfall) in the tropical Pacific where natural sources of interannual and decadal variability play a significant role in modulating surface climate and where long-term observational time series are limited.

2.3.4 Extreme temperatures and rainfall

While it is important to understand changes in the average climate of a region, it is often extreme events (e.g. droughts, floods, unusually hot conditions) that have the greatest impacts on societies and the natural and managed systems they rely on. As average temperatures have increased (Figures 2.11, 2.12), we have seen more warm days and nights (with temperatures exceeding the 90th percentile), and fewer cool days and nights (with temperatures below the 10th percentile) over the last 60 years (Manton et al. 2001; Griffiths et al. 2005; Figure 2.16). Averaged across the region, the frequency of warm days and warm nights has increased four-fold over the period 1951–2011. Once rare extremes, occurring ~20 days per year, are now happening much more frequently (up to 80 days per year). Changes in the number of cool nights and cool days are equally dramatic, becoming much rarer in the last decade (Whan et al. 2013).

In contrast to temperature extremes, there have been few spatially consistent trends in extreme rainfall since 1961. For most extreme indices, few of the station trends are statistically significant. As with total rainfall, extreme rainfall is strongly modulated by ENSO events (Table 2.3) and the IPO/PDO (Manton et al. 2001; Griffiths et al. 2003; McGree et al. 2013). Thus, any underlying trends resulting from anthropogenic warming are masked by this high natural variability, as are trends in drought or flood frequency or rainfall intensity.

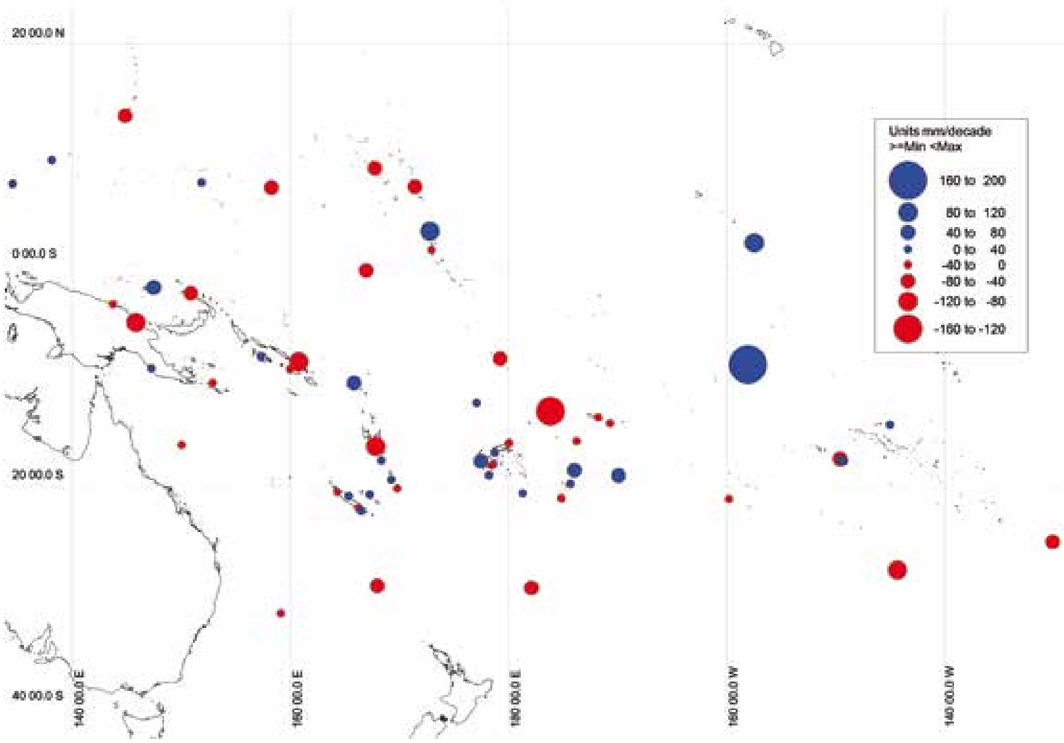


Figure 2.13 Sign and magnitude of trends (mm/decade) in annual total rainfall at Pacific island weather stations, 1961–2011 (source: PCCSP).

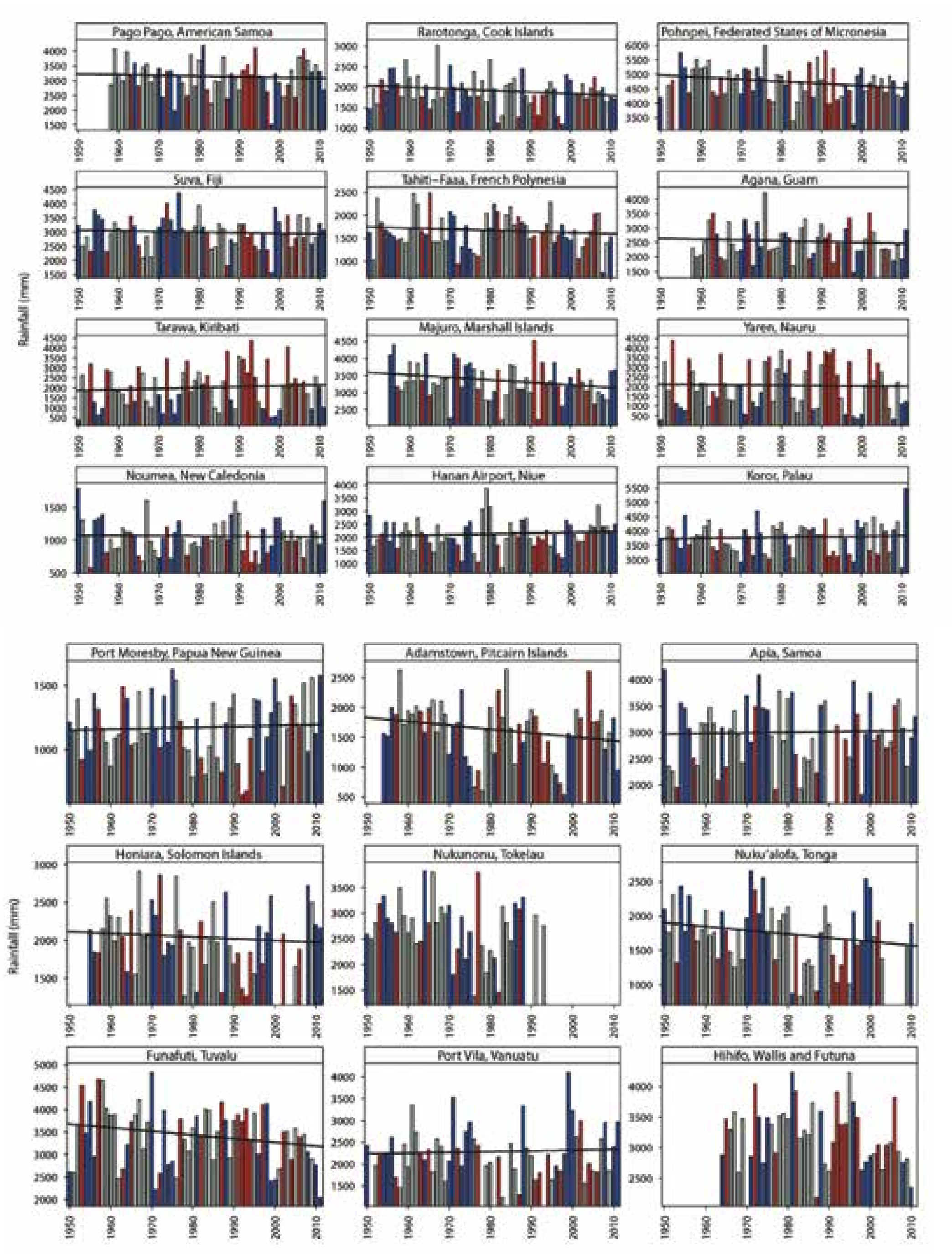


Figure 2.14 Annual total rainfall (mm) at selected Pacific island weather stations. Black lines are linear trends for stations with less than 20% missing data. Red bars denote El Niño years and blue bars denote La Niña years (source: PCCSP).

2.3.5 Tropical cyclones

Assessing changes in the frequency and intensity of tropical cyclones is difficult as they rarely approach observing stations and it is only since satellite observing systems became operational in the 1980s that all significant tropical cyclones can be identified (Kuleshov 2012). Thus, it is hard to draw any firm conclusions as to whether we have seen significant trends in recent decades in either tropical cyclone frequency or intensity (Knutson et al. 2010). Analysis of tropical cyclone best track data for the South Pacific from 1981–1982 through 2010–2011 (Kuleshov et al. 2010, 2013) shows a slight decrease in the total number of cyclones (minimum central pressure < 995 hPa) and severe cyclones (< 970 hPa), with little change in the numbers of the most intense cyclones (< 950 hPa) (Figure 2.17). The small downward trends are not, however, statistically significant.

2.4 Projected changes in surface climate: possible futures?

We now examine possible climate change under scenarios of future greenhouse gas emissions through the 21st century. We can make projections of how typical weather conditions (i.e. climate) are likely to respond to external factors, some of which can be plausibly estimated far into the future. External factors include changes to the output from the sun, atmospheric aerosols from volcanic eruptions and changes in the composition of the atmosphere due to human activities. The major driver of climate change in recent decades has been the increase in atmospheric concentrations of long-lived greenhouse gases and changes in anthropogenic aerosols. Human emissions of greenhouse gases are expected to continue to dominate and become stronger over the next century and beyond (Stocker et al. 2013).

As we cannot be certain what future greenhouse gases and anthropogenic aerosol emissions will be, projections of future climate use a scenario approach. This involves a set of hypothetical, but plausible, scenarios of human emissions (RCPs) and estimations of the response of the climate system for each. These scenarios are then fed into Global Climate Models (GCMs). There are many climate models developed by various modelling centres around the world, and no individual model is considered the single best as each has different strengths and weaknesses. The use of multiple models to form an 'ensemble' is an integral part of making climate projections. The spread in projections across different models provides us with a measure of certainty about different aspects of climate change. If different models agree on the sign and magnitude of a projected change, this gives us confidence in that projection, while if equally acceptable models show conflicting results we have lower confidence. Multiple models are also important for isolating the climate change signal from natural climate variability. Typically, current GCMs have a horizontal resolution of ~60–300 km, as higher resolution modelling over several decades is precluded by computational costs. Hence regional-scale features of island climates may be lost.

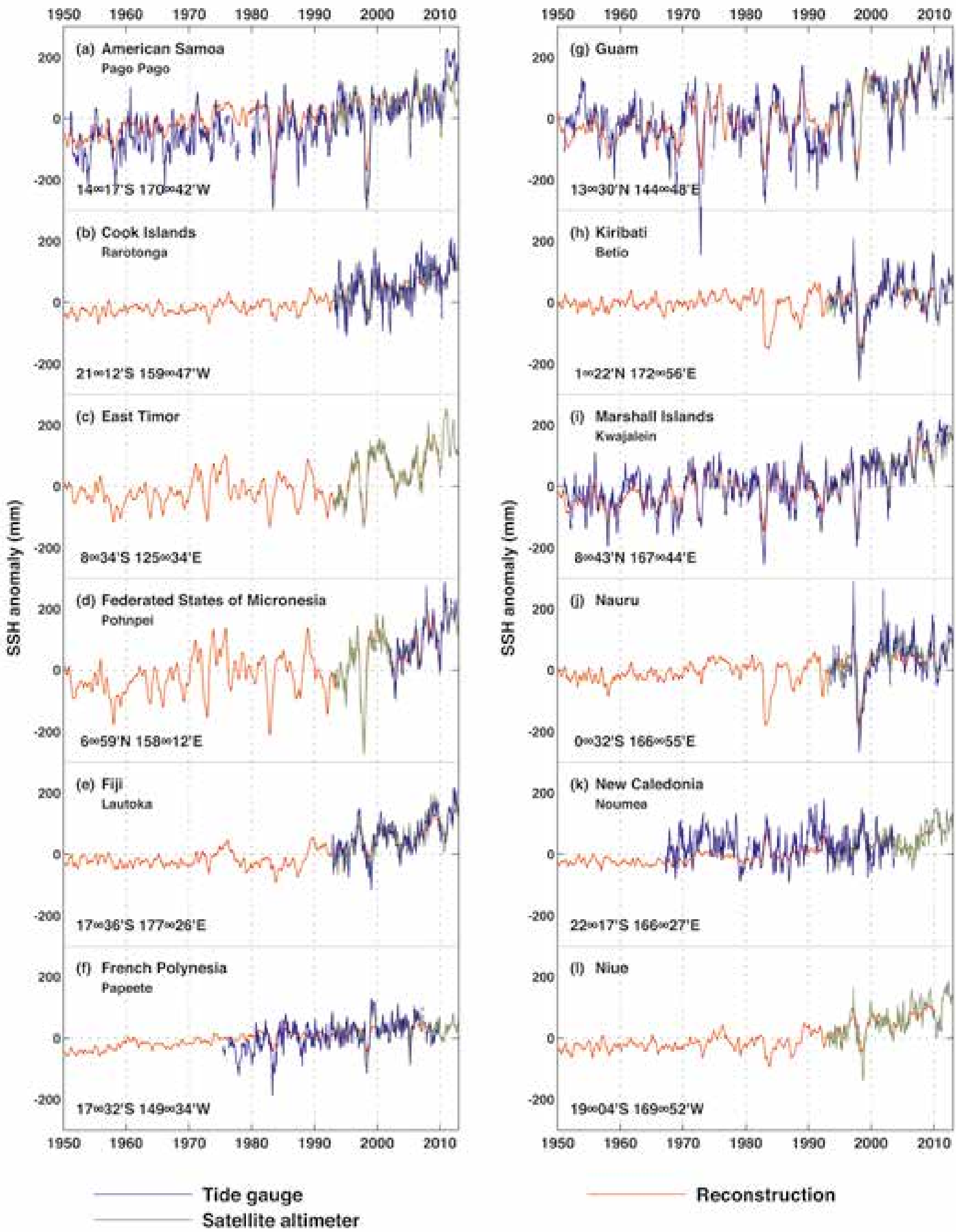
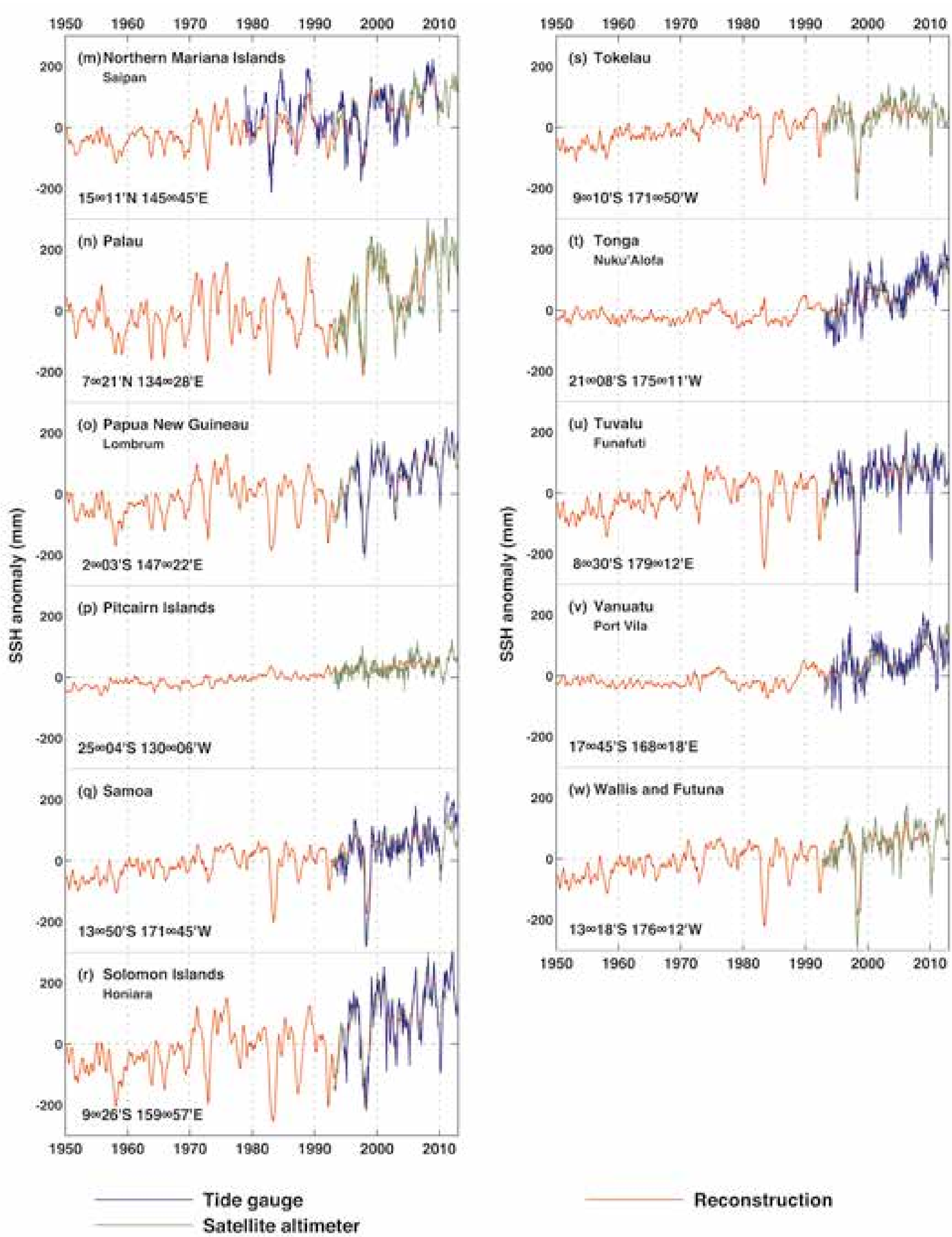


Figure 2.15 Monthly tide gauge data (blue) from the South Pacific Sea Level and Climate Monitoring Project (where available), satellite-altimeter data (green) and reconstructed (red) sea levels using both sources of data (see Church et al. 2006).



(m) Northern Mariana Islands
Saipan
15∞11'N 145∞45'E
(n) Palau
7∞21'N 134∞28'E
(o) Papua New Guineau
Lombrum
2∞03'S 147∞22'E
(p) Pitcairn Islands
25∞04'S 130∞06'W
(q) Samoa
13∞50'S 171∞45'W
(r) Solomon Islands
Honiara
9∞26'S 159∞57'E
(s) Tokelau
9∞10'S 171∞50'W
(t) Tonga
Nuku'Alofa
21∞08'S 175∞11'W
(u) Tuvalu
Funafuti
8∞30'S 179∞12'E
(v) Vanuatu
Port Vila
17∞45'S 168∞18'E
(w) Wallis and Futuna
13∞18'S 176∞12'W
SSH anomaly (mm)
Tide gauge
Satellite altimeter
Reconstruction

Models always contain some consistent differences to the observed climate, known as bias. Some bias is expected and does not invalidate the model projection, but large biases are a problem if they are likely to influence the projected change signal that the model produces. The Pacific Ocean is one of the most challenging regions for GCMs to realistically simulate and many models contain biases in this region. In general, the CMIP5 models show some incremental improvements in their simulation of Pacific climate over CMIP3. Despite these improvements, CMIP5 models retain many of the same systematic model biases present in CMIP3. These include a bias in the strength and position of the equatorial cold tongue, the WPWP, the position and orientation of the SPCZ and ITCZ, the WPM (Figure 2.5), and the simulation of ENSO events. Nevertheless, climate models are still the best tools we have to understand the processes and features involved in the climate system of the Pacific and their response to increased greenhouse gases (Irving et al. 2011; Perkins et al. 2012). Here we use a set of projections from up to 26 CMIP5 GCMs assessed for their ability to simulate tropical Pacific climate (Grose et al. 2014; Australian Bureau of Meteorology and CSIRO, 2014), in addition to some multi-model projections of IPCC-AR5 (Collins et al. 2013; Flato et al. 2013; Kirtman et al. 2013). Projections are for 20-year periods centred on 2030 (2020–2040), 2050 (2040–2060) and 2090 (2080–2100) relative to 1986–2005.

Confidence in model projections is higher where:

- models have low biases in the simulation of the present climate in the region of interest;
- models reproduce recent trends evident in observational data that are attributable to anthropogenic forcing;
- processes driving future change are understood and appear plausible; and
- models agree on the future change.

For many results we can assign a confidence rating following the IPCC guidelines on uncertainty (Mastrandrea et al. 2010). This involves examining the type, amount, quality and consistency of evidence and the agreement between those lines of evidence, and assigning a rating from *very low* to *very high* (noted in italics).

Table 2.4: Projected tropical Pacific air temperature change, from 1986–2005, for three time slices and four RCPs. The 5th-95th percentiles of the range of projections are rounded to nearest 0.5^{0}C.

RCP	2030	2050	2090
RCP2.6	0.5–1.0^{o}C	0.5–1.0^{o}C	0.5–1.0^{o}C
RCP4.5	0.5–1.0^{o}C	0.5–1.5^{o}C	1.0–2.0^{o}C
RCP6.0	0.5–1.0^{o}C	0.5–1.5^{o}C	1.5–3.0^{o}C
RCP8.5	0.5–1.0^{o}C	1.0–2.0^{o}C	2.0–4.0^{o}C

2.4.1 Climate features

The major climate features of the tropical Pacific (Figures 2.5 2.6) influence the regional pattern and seasonal cycle for rainfall, winds, tropical cyclones, ocean currents and many other aspects of the environment (Section 2.2). In addition, ENSO plays a central role in the year-to-year variability and the PDO introduces decadal variability in the climate of the tropical Pacific (Section 2.3.1.1).

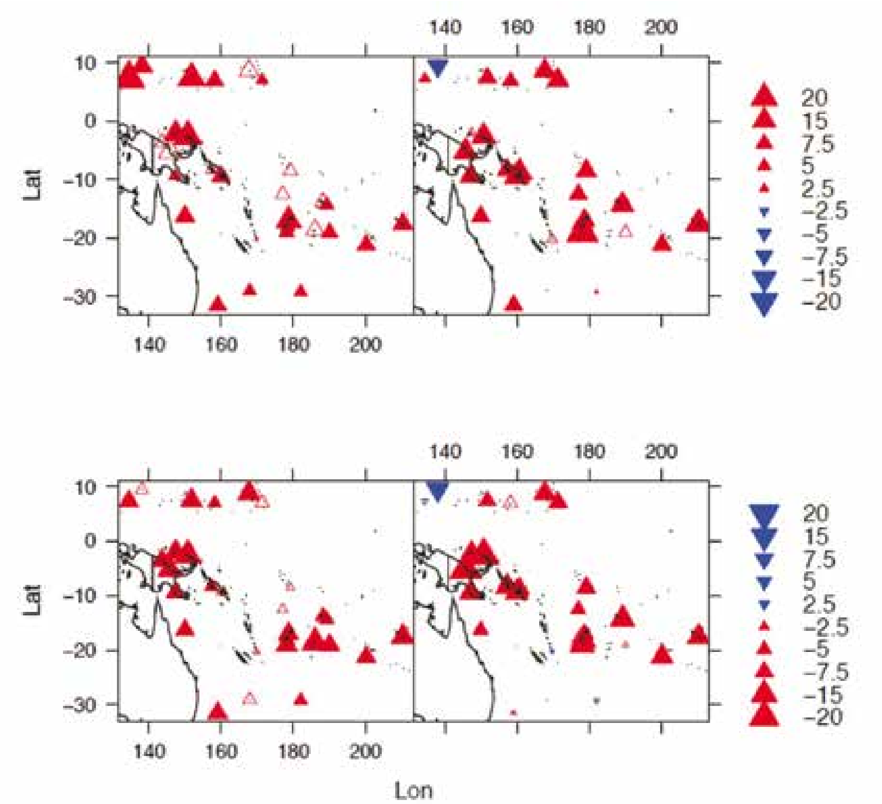


Figure 2.16 Trends in the number (events per decade) of warm days (top left), warm nights (top right), cool days (bottom left) and cool nights (bottom right), 1961–2011. Red indicates warming trends and blue indicates cooling trends. Red triangles depict positive trends in the upper panels (i.e. more warm days or more warm nights) and negative trends in the lower panels (i.e. fewer cool days or fewer cool nights). Filled triangles indicate trend is statistically significant at the 5% level. 'Warm' days and nights exceed the 90th percentile while 'cool' days and nights are below the 10th percentile (see www.bom.gov.au/climate/pccsp/about-pi-extreme-indices.shtml) (from Whan et al. 2013).

Virtually all climate models simulate a future increase in rainfall along the equator associated with regionally-enhanced warming of SST. Interpretation of this change in the western Pacific is complicated by the 'cold tongue bias' that exists in most models (where SST is too cool along the equator in the current climate). Most models project an increase in rainfall within the ITCZ, especially in the May–October season.

Although there is uncertainty in the projection of rainfall in the SPCZ region, many models project an increase in rainfall in the SPCZ and a reduction in rainfall to the east of the SPCZ under a strong warming scenario of >3°C (Widlansky et al. 2012). There is a lack of model agreement regarding the projected change in the orientation or mean latitude of the SPCZ, but most models show a contraction of the eastern edge of the SPCZ due to a strengthening of the southeast Pacific Trade Winds (Brown et al. 2012). Both CMIP3 and CMIP5 models indicate more extreme swings in the location of the SPCZ are likely in a warmer climate (Cai et al. 2012). There is also a general tendency for an enhancement of the seasonal cycle of rainfall in the WPM region.

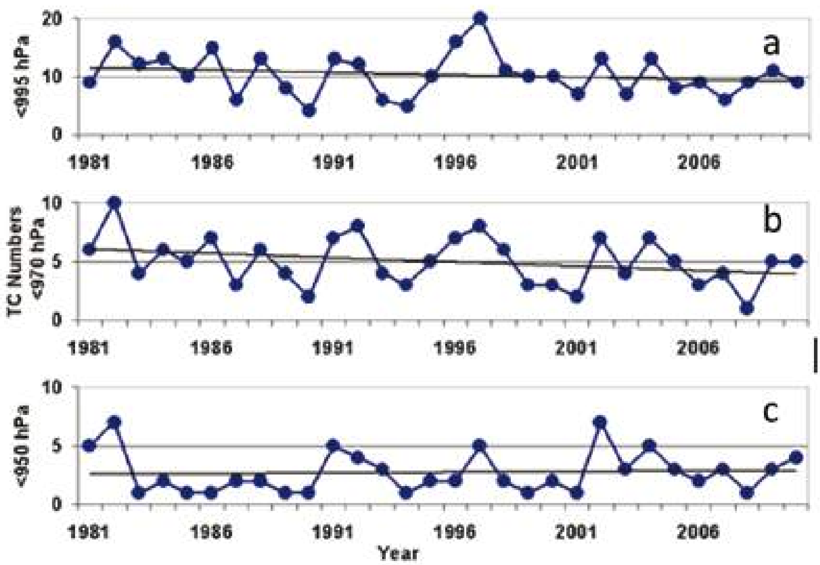


Figure 2.17 Annual number of tropical cyclones in the South Pacific Ocean, 1981–82 to 2010–11 for a) total number, b) severe tropical cyclones <970 hPa, and c) intense tropical cyclones <950 hPa. Linear trend lines also shown though none are statistically significant (adapted from Kuleshov et al. 2010).

A systematic change in the frequency, intensity or pattern of El Niño and La Niña events would have important impacts on average rainfall, rainfall variability, wet and dry extremes, tropical cyclones and sea levels (Tables 2.2, 2.3). Unfortunately, climate models do not yet provide consistent projections of the future of ENSO events (Vecchi and Wittenberg 2010; Guilyardi et al. 2012) but they are *very likely* to continue as the major source of interannual Pacific climate variability (Christensen et al. 2013). Future El Niño and La Niña events will, however, tend to be warmer than in the past and rainfall variability associated with ENSO events is likely to become amplified. This means that areas that are typically wetter (drier) during an ENSO event, will become even wetter (drier) for an ENSO of equivalent magnitude in the future (Christensen et al. 2013; Power et al. 2013). There is, however, *low* confidence as to how Pacific decadal climate variability may change in the future (Christensen et al. 2013).

2.4.2 Temperature

There is *very high* confidence that average temperatures will increase, bringing more hot days and warm nights and fewer cool days and nights. There is a slightly wider range across CMIP5 projections compared with CMIP3, mainly due to the larger range in the RCP emissions scenarios compared with previous SRES scenarios (Figure 2.3). Projected changes in island air temperatures in the tropical Pacific are lower than for large land masses, as air temperatures for PICTs are primarily controlled by SSTs, which warm more slowly than temperatures over land. There is little spatial variation in the pattern of warming across the Pacific so no map is shown. By 2030, projected warming in all Pacific countries is +0.5° to 1.0°C regardless of the emissions scenario (Table 2.4). This projected warming is in addition to the warming already observed to date (Section 2.3.2.1). Beyond 2030 there is a growing difference in the magnitude of temperature changes between different scenarios. These differences are most strongly evident by the end of the 21st century with maximum projected warming of 2.0° to 4.0°C with RCP8.5.

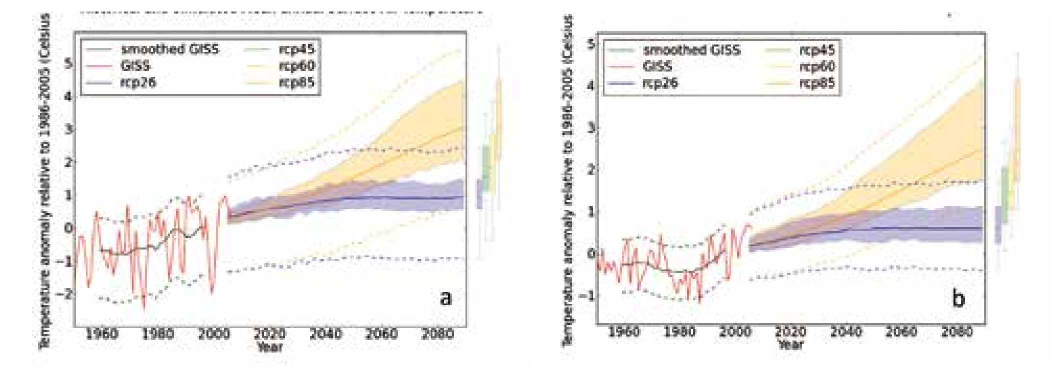


Figure 2.18 Historical and projected air temperatures for the region surrounding a) Gilbert Island group in western Kiribati, and b) southern Cook Islands. Observed temperature anomalies (Goddard Institute for Space Studies, GISS) from the base period 1986–2005 are shown in red with dashed black lines showing the 5–95th percentiles. The orange and blue lines show the 20-year running average multi-model mean anomaly for RCP8.5 and RCP2.6, respectively. Shading represents the 5–95th percentile spread of model values. Boxes to the right show the range of temperature changes for all four RCPs by 2090 (source: Australian Bureau of Meteorology and CSIRO, 2014; Hansen et al. 2010).

Example temperature time series for western Kiribati and southern Cook Islands (Figure 2.18) illustrate average temperature change under the RCP2.6 and RCP8.5 scenarios and the observed record. The series show the similarity of the scenarios until about 2030, then the growing difference between them towards the end of the century.

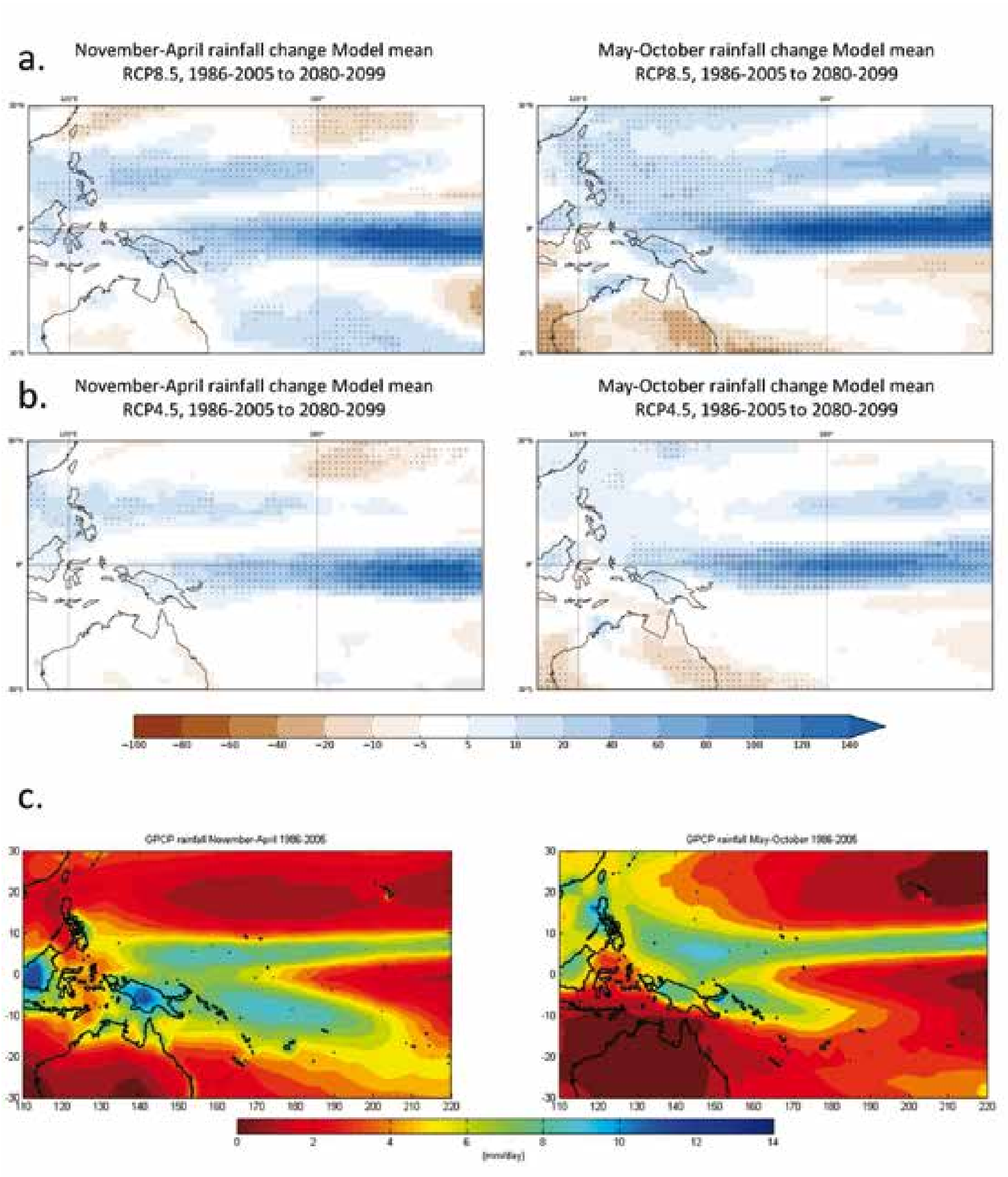


Figure 2.19 Percentage change in average November–April (left) and May–October (right) rainfall between 1986–2005 and 2080–2099 for a) RCP8.5, b) RCP4.5, and c) observed 1986–2005 average rainfall. Black crosses = 67% of models agree on a change >5%; black circles = 80% of models agree on a change >5%; no stippling = no model agreement (of 67% of models) on change (source: Australian Bureau of Meteorology and CSIRO, 2014).

2.4.3 Rainfall

There is a combination of thermodynamic influences (the 'wet get wetter' mechanism) whereby rainfall changes are driven by changes in atmospheric moisture content and dynamic influences (the 'warmer get wetter' mechanism), whereby rainfall changes are driven by changes in atmospheric circulation, that contribute to net rainfall change in the tropics (Xie et al. 2010; Chadwick et al. 2013; Widlansky et al. 2013). It has been suggested that a 'warmer get wetter' mechanism dominates the projection of mean annual rainfall along the equator, while the 'wet get wetter' mechanism is important for changes in seasonal rainfall and particularly an increase in rainfall in the high rainfall region in the wet season of each hemisphere (Huang et al. 2013). This is consistent with the general tendency in many tropical locations for the wet season to get wetter and the dry season to get drier (Biasutti 2013). While these general principles appear robust, there are many factors that affect rainfall projections for any location and model biases affect the precision of projections. As a result, confidence in regional rainfall projections is generally only *low* to *medium* and lower than for temperature. For example, model bias in the location of the SPCZ affects the interpretation of rainfall changes in those PICTs influenced by the SPCZ, particularly those situated at its edge. Also, topography can result in markedly different total rainfall across islands; for example, the west and east coasts of Vanuatu (Section 2.2.1). This is a problem when it comes to projecting rainfall changes, as the relatively low-resolution GCMs are unable to capture these important fine-scale details. As a result, these models cannot differentiate local changes in rainfall (e.g. from one side of an island to another); they only tell us about broad-scale changes.

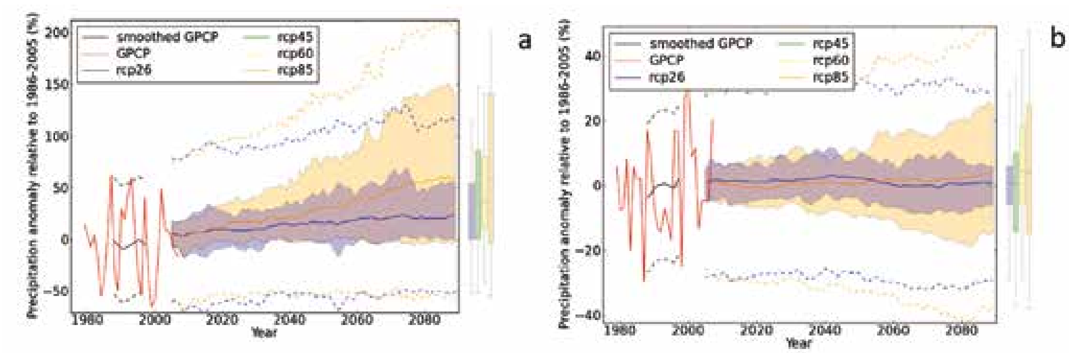


Figure 2.20 Historical and projected rainfall for the region surrounding a) the Phoenix Island group in eastern Kiribati, and b) Fiji. Observed rainfall anomalies (Global Precipitation Climatology Project, GPCP) from the base period 1986–2005 are shown in red with black lines showing the 5–95th percentiles. The orange and blue lines show the 20-year running average multi-model mean anomaly for RCP8.5 and RCP2.6, respectively. Shading represents the 5–95th percentile spread of model values. Boxes to the right show the range of rainfall changes for all four RCPs by 2090 (source: Australian Bureau of Meteorology and CSIRO, 2014; Adler et al. 2003).

Average annual rainfall is projected to increase over large parts of the tropical Pacific in a warmer climate. The effect of warming is likely to be small up to 2030 and mostly obscured by natural climate variability (Section 2.3.1). After 2030, distinctive patterns emerge that become progressively stronger for higher emissions scenarios (RCP6.0 and RCP8.5) and with time. To illustrate the pattern at its strongest, changes under RCP8.5 from 1986–2005 and 2080–2099 are shown in Figure 2.19a. The equivalent for RCP4.5 (Figure 2.19b), shows similar spatial patterns but smaller changes (Table 2.5).

Percentage change in rainfall should be interpreted in the context of the current baseline (Figure 2.19c). During November–April, large percentage increases in rainfall are projected along the equator, in the northeast near the Marshall Islands and in the middle of the SPCZ region, with decreases at the northeastern edge of the SPCZ near the Cook Islands and the southeastern Pacific subtropics (Figure 2.19a, b left side). During May–October, large percentage increases in rainfall are also projected along the equator and the northwest around Palau and the Federated States of Micronesia with small changes in the multi-model mean south of the equator (Figure 2.19a, b right side). Projected rainfall increases in the west around Papua New Guinea, parts of the Solomon Islands, Palau and the Federated States of Micronesia occur on top of high current rainfall and thus represent large absolute changes in rainfall.

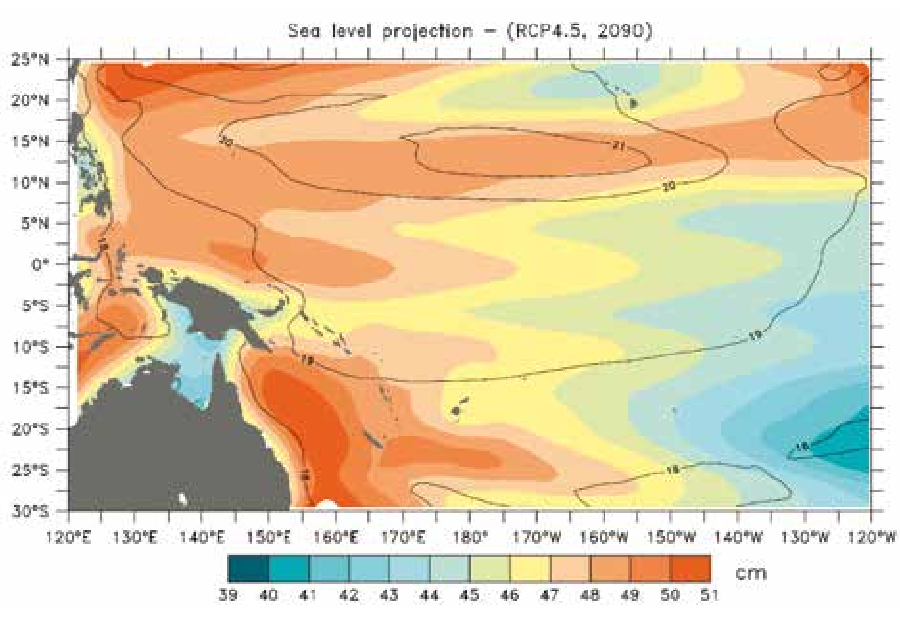


Figure 2.21 Projected sea-level change (cm), RCP4.5, for 2081–2100 relative to 1986–2005 indicated by shading, with the uncertainty indicated by contours. Sea-level changes are estimated by combining global average sea-level projections, the dynamic ocean departure from the global average and the regional changes associated with the changing mass distribution in the cryosphere (Australian Bureau of Meteorology and CSIRO, 2014).

Example rainfall time series for eastern Kiribati and Fiji (Figure 2.20) illustrate average rainfall changes under the RCP2.6 and RCP8.5 scenarios and the observed record. The Phoenix group in eastern Kiribati is within the region of projected rainfall increase along the equator (Figure 2.19), and this is reflected in the time series where multi-model mean rainfall steadily increases through the century. The increase is larger for the higher emissions scenarios and although there is a large spread in the magnitude of projected rainfall change between models, all indicate an increase in rainfall by the end of the 21st century. The spread is considerably larger for the highest emissions (RCP8.5) scenario. This suggests that while we can be confident of a projected increase in rainfall, the magnitude of change is still quite uncertain. In contrast, in Fiji the large model spread includes some models projecting a decrease and some an increase in rainfall. This is a reflection of the uncertainty in projections of the SPCZ and other processes in the region (Table 2.5) and as such we have *low* confidence in how rainfall will change in Fiji.

2.4.4 Sea level

There has been considerable progress in understanding past and possible future sea-level changes since the last IPCC assessment (Meehl et al. 2007b). As a result of improved modelling, there is also greater confidence in future sea-level projections due to improved constraints on thermal expansion and ice sheet changes (Church et al. 2013). As noted for temperature and rainfall projections, mid-century values for sea-level rise are similar across the different scenarios (Table 2.6) with median values 24–30 cm higher than 1986–2005. Differences amongst the scenarios are more marked by the end of the 21st century with the most extreme (RCP8.5) associated with sea levels 45–82 cm higher than the recent base period. This is in addition to the 19 cm rise observed over the 20th century (Church et al. 2013).

All PICTs can, therefore, anticipate sea levels at the end of the 21st century that are higher than present with a total projected range of 26 cm (lower bound of RCP2.6) up to 82 cm (upper bound for RCP8.5). For comparison, global sea-level rise for 2090–2099 relative to 1980–1999 reported in IPCC-AR4 (Meehl et al. 2007b), had a lower bound of 18 cm (SRES B1) and an upper bound of 59 cm (SRES A1F1). Thus, the most recent assessment of the magnitude of global sea-level rise is substantially higher than that of previous IPCC assessments.

Table 2.5 Summary of projected % rainfall change, from 1986-2005 average, for RCP4.5 and RCP8.5 for 2090 for PICTs. Change is ensemble model mean with 5th and 95th percentile range for up to 24 models, except for the following countries (where changes evaluated from tropical Pacific rainfall change maps (Figure 2.19)): American Samoa, French Polynesia, Guam, New Caledonia, Northern Mariana Islands, Pitcairn Islands, Tokelau and Wallis & Futuna. (from Australian Bureau of Meteorology and CSIRO, 2014). NMA – no model agreement.

Country	Station	Main controls	RCP4.5 November–April	RCP4.5 May–October	RCP8.5 November–April	RCP8.5 May–October
American Samoa		SPCZ ENSO TCs	NMA	NMA	NMA	–5 to 10%
Cook Islands	North	SPCZ ENSO TCs	2%(–5 to 9%)	–5% (–20 to 4%)	3% (–20 to 22%)	–11% (–35% to 13%)
	South	SPCZ ENSO TCs	1% (–15 to 18%)	0% (–8 to 12%)	3% (–18 to 26%)	3% (–15 to 26%)
Federated States of Micronesia	West	ITCZ WPM ENSO TCs	3% (–8 to 13%)	6% (–1 to 13%)	7% (–10 to 28%)	14% (–2 to 31%)
	East	ITCZ ENSO TCs	2% (–8 to 12%)	9% (2 to 17%)	7% (–10 to 21%)	18% (2 to 29%)
Fiji		SPCZ ENSO TCs	2% (–11 to 13%)	0% (–20 to 10%)	8% (–10 to 32%)	–1% (–21 to 18%)
French Polynesia		SPCZ ENSO TCs	NMA	–5 to 10%	–5 to 10%	NMA
Guam		ITCZ ENSO TCs	10 to 20%	5 to 10%	20 to 40%	10 to 20%
Kiribati	Gilbert Islands	ITCZ SPCZ ENSO	23% (–11 to 77%)	44% (11 to 110%)	42% (–8 to 128%)	78% (7 to 169%)
	Line Islands	ITCZ ENSO	12% (2 to 22%)	8% (–4 to 18%)	18% (5 to 35%)	14% (–3 to 29%)
Marshall Islands	Central	ITCZ ENSO TCs	8% (–5 to 26%)	4% (–6 to 21%)	18% (–4 to 52%)	13% (–6 to 44%)
	South	ITCZ ENSO TCs	2% (–11 to 14%)	5% (–5 to 16%)	5% (–11 to 31%)	11% (–6 to 26%)
Nauru		ITCZ SPCZ ENSO	27% (–7 to 90%)	48% (10 to 143%)	45% (–7 to 139%)	86% (3 to 202%)
New Caledonia		SPCZ ENSO TCs	NMA	NMA	10-20%	NMA

Country	Station	Main controls	RCP4.5 November–April	RCP4.5 May–October	RCP8.5 November–April	RCP8.5 May–October
Niue		SPCZ ENSO TCs	3% (–14 to 31%)	2% (–13 to 14%)	10% (–14 to 67%)	4% (–15 to 31%)
Northern Mariana Islands CNMI		ITCZ ENSO TCs	10 to 20%	5 to 10%	20 to 40%	10 to 20%
Palau		ITCZ WPM ENSO TCs	3% (–10 to 10%)	8% (–1 to 17%)	3% (–15 to 19%)	14% (1 to 38%)
Papua New Guinea	Whole country	WPM ENSO TCs	8% (–2 to 18%)	9% (–1 to 31%)	14% (–1 to 35%)	18% (–2 to 51%)
Pitcairn Islands		SPCZ	NMA	–5 to 10%	NMA	–5 to 10%
Samoa		SPCZ ENSO TCs	1% (–11 to 9%)	–2% (–15 to 9%)	2% (–18 to 20%)	–5% (–23 to 13%)
Solomon Islands	Whole country	ITCZ SPCZ WPM ENSO TCs	4% (–1 to 10%)	3% (–8 to 12%)	6% (–6 to 20%)	5% (–11 to 22%)
Tokelau		SPCZ ENSO TCs	NMA	–5 to 10%	NMA	–5 to 10%
Tonga		SPCZ ENSO TCs	4% (–9 to 22%)	1% (–11 to 13%)	11% (–10 to 53%)	1% (–22 to 23%)
Tuvalu		SPCZ WPM ENSO TCs	4% (–10 to 15%)	4% (–7 to 19%)	8% (–25 to 36%)	3% (–26 to 24%)
Vanuatu	Whole country	SPCZ ENSO TCs	1% (–13 to 13%)	–1% (–25 to 14%)	5% (–13 to 30%)	3% (–26 to 34%)
Wallis & Futuna		SPCZ ENSO TCs	NMA	NMA	NMA	NMA

Regional variations in sea-level rise will occur, related to changes in ocean heat content, surface winds, ocean currents and to the gravitational effect of melting ice sheets. However, these variations are likely to fall within 20% of the global average sea-level change. In addition, on decadal timescales, substantial regional changes can be driven by natural variability related, for example, to the PDO/IPO (Section 2.3.2.3). As such, we would expect sea level to vacillate above and below any mean projected change as a result of natural variability. Sea level is projected to rise throughout the tropical Pacific but with slightly higher rates north of ~10°N and in the southwest Pacific. Slightly lower rates of rise are projected between ~ 10°N and 20°S. These differences in relative rates of sea-level rise are, however, small at ~5-6 cm (Figure 2.21).

The effect of sea-level rise is most strongly felt in changes to extreme sea-level events. For example, a 50 cm increase in mean sea level (which corresponds to the low end of RCP8.5 projections for the coming century) can dramatically increase the frequency of sea level exceeding a given threshold (Hunter 2012). Over the western Pacific increases of two orders of magnitude or more have been suggested (i.e. with a 50 cm sea-level increase a 1-in-100 year flooding event would typically occur every year).

Without concerted greenhouse gas mitigation, much larger sea-level rise is likely over multi-centennial timescales. It is thought that Greenland could reach a tipping point when global average temperatures warm by ~2°-4°C. If this threshold were reached, potentially irreversible melting of the Greenland ice sheet would increase global sea level by ~7 m over millennium timescales (Church et al. 2013).

2.4.5 Wind speed

Projected changes in average surface wind speeds are generally small. Wind speeds are projected to decrease near and to the north of the equator, consistent with atmospheric circulation changes such as the slowing of the Walker Circulation. Surface wind speeds are projected to increase in some regions of the south Pacific, linked to a strengthening of the southeasterly Trade Winds.

2.4.6 Cloud cover and solar radiation

Projected changes to cloud cover and solar radiation broadly follow that of rainfall. In most places there is an increase in cloud cover and a decrease in radiation at the surface consistent with the increase in rainfall (Section 2.4.3). Projected changes are, however, fairly small, with changes in surface radiation <10% under any scenario by the end of the century. Despite slight decreases in radiation, potential evaporation is projected to increase in a warmer climate, driven by warming temperature.

Table 2.6 Projected likely range of sea-level rise and median values (cm), relative to 1986–2005, for mid (2046–2065) and end (2081–2100) of the 21st century and different RCPs (from Church et al. 2013).

RCP	2046–2065	2081–2100
RCP2.6	17–32 (24)	26–55 (40)
RCP4.5	19–32 (26)	32–63 (47)
RCP6.0	18–32 (25)	33–63 (48)
RCP8.5	22–38 (30)	45–82 (63)

2.4.7 Extremes – heat waves, high rainfall, droughts and floods, tropical cyclones and high sea levels

A warmer climate will bring a greater incidence of daily extremes of high temperatures. The 1-in-20 year event of extreme daily temperatures, for example, is projected to increase in magnitude so that by 2090 under RCP8.5, such events will be 2–4°C warmer than present extremes. There will also be larger rainfall extremes, even in regions where average rainfall is projected to decrease. The current 1-in-20 year extreme daily rainfall event is projected to occur once every 7 to 10 years by 2090 under the RCP2.6 scenario, and once every 4 to 6 years by 2090 under the RCP8.5 scenario in most locations (Australian Bureau of Meteorology and CSIRO, 2014). The projected increased frequency and intensity of extreme rainfall events is, however, unlikely to become apparent in the near term due to high natural variability in tropical regions (Kirtman et al. 2013).

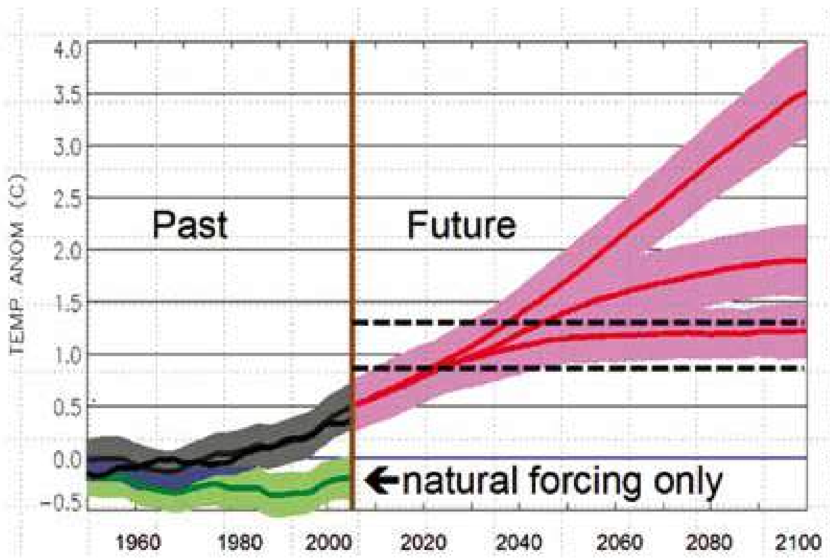


Figure 2.22 Comparison of observed and projected Pacific air temperatures (25ºS–20ºN, 120ºE–150ºW; 11-year running average anomalies from 1961–1990 mean). Black line is observed temperatures, 1950–2005. Grey line is modelled Pacific air temperatures from eight CMIP5 models that include both human-caused (greenhouse gases and aerosols) and natural (volcanoes and solar variability) forcings. Grey shading shows the 5–95% range of values in the models. Green line and shading shows Pacific air temperatures from the same eight models but excluding anthropogenic climate forcings. The red lines show projected changes, 2006–2100, for high emissions (RCP8.5, top), mid-emissions (RCP4.5, middle) and drastically reduced emissions (RCP2.6, lower) (source: CRU air temperature; CMIP5 models).

The Standardised Precipitation Index (SPI) is a measure of meteorological drought, calculated relative to local conditions (Lloyd-Hughes and Saunders 2002). CMIP5 climate models indicate that the average frequency, intensity and duration of 12-month drought, measured by the SPI, will generally follow the projected change in average rainfall. The average incidence of drought is likely to decrease in countries near the equator such as Nauru and Kiribati, and increase at the eastern edge of the SPCZ including the northern Cook Islands, but with little change in other regions such as Samoa. The pattern is stronger in the high emissions scenarios, and strengthens through the 21st century. As with rainfall projections, there is, however, a range of results from different models, especially for changes by 2090 for the very high emissions scenario (RCP8.5). Extreme wet and dry years in many PICTs are also linked to ENSO extremes (Section 2.3.1.1). Although the effect of climate warming on the strength or frequency of El Niño and La Niña events is still unclear, they will continue as a source of rainfall extremes which may well increase in magnitude (Christensen et al. 2013; Power et al. 2013). Recent evidence also suggests that extreme El Niño events (e.g. 1982–1983 and 1997–1998), with their amplified climatic impacts (Table 2.3), might double in frequency during the 21st century (Cai et al. 2014).

Tropical cyclones currently affect all PICTs except for Kiribati, Nauru, Pitcairn and northern Papua New Guinea (Table 2.2). Projecting how the frequency, occurrence and intensity of tropical cyclones may change over this century is limited by the fact that these weather features are not explicitly modelled in current GCMs with their relatively coarse spatial resolution. Climate models can, however, be used in combination with regional downscaled models or large-scale variables to assess if conditions favourable for tropical cyclone development change. Both methods suggest that, globally, the intensity (i.e. maximum wind speeds and rainfall rates) of tropical cyclones may increase by the end of the century but that the global average frequency may either stay the same or decrease by that time; that is, there may be fewer tropical cyclones but those that do occur are likely to be more intense (Knutson et al. 2010; IPCC 2012; Christensen et al. 2013).

As sea level rises over this century, the risk of extreme high sea levels also increases. Higher average sea level will increase the absolute height of seasonal king tides, storm surges associated with tropical cyclones, storm waves and swell waves, and inundation associated with rare tsunamis (Campbell 2006; IPCC 2012).

In summary (Table 2.7), during the course of the 21st century, PICTs will experience warmer air temperatures with more frequent high temperature and fewer low temperature extremes. Although harder to project and lacking the resolution to resolve current topographic influences, total rainfall is projected to generally increase along the equator and in some regions off the equator during their wet season. The frequency of extreme rainfall events is likely to increase. Unusually wet and dry conditions associated with ENSO events will continue to affect PICTs and the magnitude of the associated climate anomalies is likely to increase as is the frequency of very extreme El Niño events. Sea level will continue to rise and thus increase the level of flooding risk associated with naturally-occurring extreme sea-level events. Countries currently affected by tropical cyclones are likely to be similarly influenced in the future with the possibility of fewer but possibly more intense tropical cyclones. Changes in average wind speeds and surface solar radiation are projected to be relatively small.

2.5 Summary

The climate of the Pacific Islands is strongly influenced by the surrounding Pacific Ocean and several important atmospheric features that vary on seasonal, interannual and longer timescales. Key climatic features include the SPCZ (which affects south Pacific countries), the ITCZ (which affects tropical north Pacific countries) and the WPM (which affects western Pacific countries) (Table 2.2). Many PICTs are occasionally exposed to destructive weather events such as tropical cyclones, which currently affect countries away from the equator, mainly in the western Pacific. While seasonal changes are relatively weak in tropical regions, large year-to-year variability occurs associated with ENSO events. ENSO events can cause significant changes to rainfall, sea level and the distribution of tropical cyclones, with different impacts occurring in different regions (Table 2.3). ENSO variability is also modulated on decadal timescales by the IPO/PDO, whereby multi-decadal periods can be dominated by El Niño events while other periods are dominated by La Niña events.

Understanding climate, how it varies from year to year and how it changes over longer periods, requires sustained, homogeneous high-quality observations. Through PCCSP and PACCSAP, the availability of digitised high-quality weather records has been substantially enhanced for many of the PICTs. These observational records show that anthropogenic global warming is already evident for Pacific countries. This is most clearly evident in warmer air temperatures (*high* confidence) throughout the region with a consequent increase in high temperature extremes and decrease in cool temperature extremes. Similarly, there is *high* confidence that tropical Pacific sea level is also rising, although recent exceptionally high rates of rise in the western tropical Pacific are likely to include a large component related to natural decadal climate variability. There are, as yet, no consistent or significant observed trends in total rainfall in the PICTs or in the frequency and/or intensity of tropical cyclones. Rainfall and tropical cyclone activity show very large interannual variability that is still dominated by natural sources of variability, primarily ENSO events (Table 2.7).

Table 2.7 Summary of observed and projected changes in Pacific island climate. Changes with respect to 1986–2005 base period (central values for temperature and sea-level projections).

Climate variable	RCP	Observed	2030	2050	2090
Air temperature	RCP2.6	Significant warming 0.18°C/decade, 1961–2011	0.75°C	0.75°C	0.75°C
	RCP4.5		0.75°C	1.0°C	1.5°C
	RCP6.0		0.75°C	1.0°C	2.2°C
	RCP8.5		0.75°C	1.5°C	3.0°C
Temperature extremes		4-fold increase in frequency of warm days and nights and decrease in cool days and nights, 1951–2011	Becoming more frequent and intense through 21st century and higher emissions scenarios		1 in 20 year extreme daily temperature will be 2–4°C warmer than present extremes RCP8.5
Rainfall	RCP2.6	No significant change–still dominated by natural variability	Becoming wetter across much of region especially near-equatorial Kiribati and Nauru with magnitude of change increasing through 21st century and higher emissions scenarios Drier French Polynesia and Pitcairn Islands		
	RCP4.5				
	RCP6.0				
	RCP8.5				
Rainfall extremes		No significant change–still dominated by natural variability	Becoming more frequent and intense through 21st century and higher emissions scenarios		1 in 20 year extreme daily rainfall will occur every 7–10 years (RCP2.6) or every 4–6 years (RCP8.5)
Sea level	RCP2.6	Significant global +19 cm rise since early 20th century		24 cm	40 cm
	RCP4.5			26 cm	47 cm
	RCP6.0			25 cm	48 cm
	RCP8.5			30 cm	63 cm
Tropical cyclones		No significant change	Similar number or fewer tropical cyclones but those that occur will be more intense		
ENSO events		No significant change but central Pacific ENSOs more frequent than eastern Pacific ENSOs	Continued source of interannual variability; associated rainfall extremes intensify and extreme El Niños (e.g. 1982–83, 1997–98) double in frequency during 21st century		

Projecting what may happen in the future relies on climate models and scenarios of future emissions of greenhouse gases. Some changes to the climate are likely to be consistent across all PICTs (e.g. warmer temperatures and higher sea level), while changes in rainfall are likely to vary with location. Projected changes based on the CMIP5 models (used in IPCC-AR5) are very similar to those produced by the earlier CMIP3 models (used in IPCC-AR4). There are, therefore, no major surprises in this updated assessment of tropical Pacific climate changes due to global warming (cf. Australian Bureau of Meteorology and CSIRO, 2011; Bell et al. 2011). Air temperatures will continue to warm and sea levels to rise (*high* confidence). Higher sea levels will also exacerbate the impacts of extreme sea-level events due to ENSO activity, tropical cyclones and swell waves as, for example, occurred in December 2008 (Hoeke et al. 2013). Rainfall is generally projected to increase in countries along the equator and in the wet season in many countries (*medium* confidence). These changes in rainfall are unlikely to be evident in the short term, due to the high natural variability, and will only become evident (if we continue along the high emissions trajectory) towards the latter part of the 21st century. Extreme air temperature and rainfall events are likely to occur more frequently in the future and be of greater magnitude than present (Table 2.7). The high natural variability of Pacific Island rainfall, due to natural interannual and decadal climate forcings, means, however, that changes in total and extreme rainfall are unlikely to be apparent within the next few decades and will only emerge clearly towards the end of the 21st century.

There are several areas of uncertainty in projecting future climate due to our incomplete understanding of the complex global climate system. There are, for example, unresolved biases in model simulations of present-day tropical Pacific climate including the location of key features such as the ITCZ and SPCZ. An important uncertainty for the PICTs is how ENSO might change as a result of anthropogenic warming. Some GCMs suggest increased ENSO activity while others suggest decreased activity. It seems *very likely*, however, that ENSO will continue to be the dominant mode of interannual climate variability in the tropics (Christensen et al. 2013), that rainfall anomalies associated with ENSO events will be amplified in the future (Power et al. 2013) and that very extreme El Niños (e.g. 1982–1983, 1997–1998) will be more frequent (Cai et al. 2014). There is also some uncertainty as to how the position and intensity of key climate features such as the SPCZ and ITCZ will change. Similarly, there is *low* confidence in how decadal modes of climate variability (IPO/PDO) may change (Christensen et al. 2013). To deal with this uncertainty, risk management suggests that it is wise to plan for both a wetter and a drier (more extreme) future, since we cannot project the direction of change with absolute certainty in some regions. It is *likely* that there may well be a decrease or little change in the frequency of tropical cyclones but those that do occur are *likely* to be more destructive by the end of the 21st century. There is, however, *low* confidence in how the frequency and intensity of tropical cyclones may change for specific ocean basins (Christensen et al. 2013). All these changes are projected to occur against a backdrop of warmer SST.

The different emissions scenarios produce very similar climate projections until about 2030. This means that over the next 20 to 30 years the strength of climate change impacts will be similar, irrespective of human greenhouse gas emissions over that time period. This is because the climate system takes a long time to respond to change. However, changes in the mid-term and to the end of the century will be strongly affected by our emissions over the next few decades: our global actions now will significantly affect the lives and livelihoods of future generations. After 2030, we see greater divergence amongst the scenarios with the most extreme end-of-century effects associated with the very high emissions scenario, RCP8.5. Observed global emissions are currently tracking at or above this high-end scenario making it increasingly difficult, if not impossible, to reduce global emissions to a level which would limit global warming to below 2°C (i.e. equivalent to the RCP2.6 scenario) (Peters et al. 2013).

The human influence on global climate is now 'clear' (IPCC 2013) as is its influence on tropical Pacific climate (Figure 2.22). Climate models are continually being improved as our understanding of climate dynamics increases and their resolution and capacity to correctly model finer scale features (e.g. tropical cyclones) are also improving. It will, however, be several years, even decades, before GCMs and downscaling techniques can provide high-resolution, locally-specific detail with a high level of confidence. We must, therefore, plan for future climate change based on the best available observational records (to identify current climate trends), plausible scenarios of future greenhouse gas emissions and the best available GCMs. A risk management approach is appropriate to deal with the uncertainty in climate projections, where the range of projections that are plausible are all considered, rather than using a single 'best estimate'.

2.5.1 Recommendations

Planning for a future climate different from the past presents many challenges for PICTs. There are, however, several actions which can assist with this transition:

- Maintaining and enhancing high-quality weather and ocean observations throughout the Pacific Islands. Accurate and continuous records of current climate conditions assist assessments of climate vulnerability and sensitivity in natural and managed ecosystems such as agriculture and forestry. Such records also allow identification of recent climate trends and when such trends exceed the natural sources of interannual and decadal climate variability.
- National and international commitment to rescue and digitise additional long-term weather observations known to be available in paper format in various NMS and international archives.
- National commitment (which may involve international assistance) to reverse the decline in recording in recent decades, evidenced by the number of missed observations and loss of reporting stations, largely due to NMS budget constraints and increasing costs of instrumentation
- Sustaining and enhancing uptake throughout PICTs of country-specific seasonal climate outlooks. Knowing that an upcoming season is likely to be wetter or drier than usual or that there is an increased risk of tropical cyclone activity can allow preparatory planning. A variety of information is now available through various web portals. These include the *Climate and Oceans Support Program in the Pacific* (COSPPac, www.bom.gov.au/cosppac/comp/) which provides seasonal climate outlooks (currently for only 10 of the PICTs), the monthly *Island Climate Update* produced by NIWA (www.niwa.co.nz/climate/icu) and *Pacific ENSO Update* produced by the Pacific El Niño/Southern Oscillation Applications Climate (PEAC) Center (www.prh.noaa.gov/peac) which provides a summary of recent conditions and seasonal outlooks.

- Impacts of a changing climate are likely to be first expressed in a greater likelihood of extreme weather events (e.g. floods, severe tropical cyclones). Thus, an obvious step is to integrate disaster risk management and climate change adaptation planning within PICTs. This integration has already been agreed to by many of the PICTs (e.g. Statement of the Joint Meeting of the Pacific Platform for Disaster Risk Management and the Pacific Climate Change Roundtable, 8–11 July 2013, Nadi, Fiji) and its further development and implementation should be actively supported.
- Incorporating climate change impacts into planning for both the short and long term (to the end of the century). Identifying actions that can be implemented now that will increase future resilience, implement 'no regrets' actions where appropriate and use a risk management framework to deal with uncertainties in climate projections.
- Recognising that climate models are continuously improving and that there needs to be regular reassessments of their outputs for the tropical Pacific. This will, over time, increase our confidence in the magnitude and nature of climate changes as they affect the PICTs.

Data sources

ERA-interim: http://data-portal.ecmwf.int/data/d/interim_moda/

HadISST: http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_hadisst

IBtrACS: http://www.ncdc.noaa.gov/oa/ibtracs/index.php?name=ibtracs-data-access

Goddard Institute for Space Studies (GISS) surface temperature analysis: http://data.giss.nasa.gov/gistemp/

Global Precipitation Climatology Project (GPCP) precipitation dataset: http://www.esrl.noaa.gov/psd/data/gridded/data.gpcp.html

Pacific Climate Change Science Project (PCCSP) data portal: Monthly and daily rainfall and temperature (mean, maximum and minimum) - RESTRICTED ACCESS FOR DATA DOWNLOADING: http://www.bom.gov.au/climate/pccsp/

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Photo: Jalesi Mateboto

Chapter 3

Agriculture and climate change: an overview

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Contents

3.1 Introduction

This chapter provides an overview of the impact of climate change on agriculture. The focus is on information available from global studies, much of which has been generated from simulation models based on climate projections, historical data and experimental data (Fezzi et al. 2013). Understanding crop response to climate change has mainly been studied with the major staple crops such as rice and wheat (Gornall et al. 2010; Lobell et al. 2011). However, despite the focus on non-Pacific crops, the information generated from these studies can help to improve our understanding of physiological responses to changes in climate and provide an insight into how crops in the Pacific Island Countries and Territories (PICTs) are likely to respond.

Global studies serve to highlight the complexity of what is involved both through direct impacts, such as crop response to high temperature stress, and indirect impacts, such as the response of a virus disease vector to high temperature. They can help guide research by providing a knowledge base on which research strategies for the Pacific can be developed. They also provide an opportunity to assess whether changes in global food production and supply as a result of climate change will afford any benefits to the Pacific; for example, projections for rice and wheat production are of particular importance for Pacific food security. Climate change is predicted to have a significant impact on both crops with the likelihood of short-run crop failures and long-run production declines leading to higher prices (Nelson et al. 2009). The 2013 Intergovernmental Panel on Climate Change (IPCC) report confirmed that globally, negative effects from climate change are already evident with a decline in net global yields of crops such as wheat, maize, rice and soya beans (Vermeulen 2014).

Despite the focus of this chapter on global studies, where available, information on crops and livestock of relevance to the Pacific has been included (FAO 2008; APN 2010; Wairiu et al. 2012; SPC 2011). The sections on the impact of cyclones (3.5.5) and pests and diseases (3.7) are particularly focused on the Pacific. More detail about the threats, impacts and opportunities for specific areas of Pacific agriculture will be described in later chapters. Chapter 7 focuses on livestock; therefore, the overview/general information provided for livestock in this chapter is limited. Similarly forestry (native forests, plantations and trees outside forests) has been addressed specifically in Chapter 8, because to include forestry here would have resulted in a very complex and lengthy chapter. As crop production in the Pacific has been discussed in three separate chapters, namely staple food crops (Chapter 4), export commodities (Chapter 5), and horticultural crops (Chapter 6) a comprehensive overview of the impact of climate change on crops is provided in this chapter.

3.2 The impact of agriculture on climate change

Food, forage, bioenergy and pharmaceuticals are all provided by agricultural systems. These systems rely on services provided by natural ecosystems, including pollination, biological pest control, maintenance of soil structure and fertility, nutrient cycling and hydrological services. Preliminary assessments show that the value of these contributions to agriculture is enormous and often under-appreciated. A range of ecosystem services, such as regulation of soil and water quality, carbon sequestration, support for biodiversity and cultural services are also provided by agro-ecosystems. Depending on management practices, agriculture can be a source of numerous adverse effects, including greenhouse gas emissions (GHG), loss of wildlife habitat and therefore biodiversity, nutrient runoff, sedimentation of waterways, and pesticide poisoning of non-target species (Vermeulen et al. 2012). The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) used the term 'multifunctionality' to describe the interconnectedness of agriculture's different roles and functions (IAASTD 2009). The complexity of this relationship highlights the importance of agricultural practices that recognize the trade-offs that may occur between provisioning services and other ecosystem services and disservices, and that climate change is likely to affect all the services provided by agriculture and those provided by the natural ecosystem.

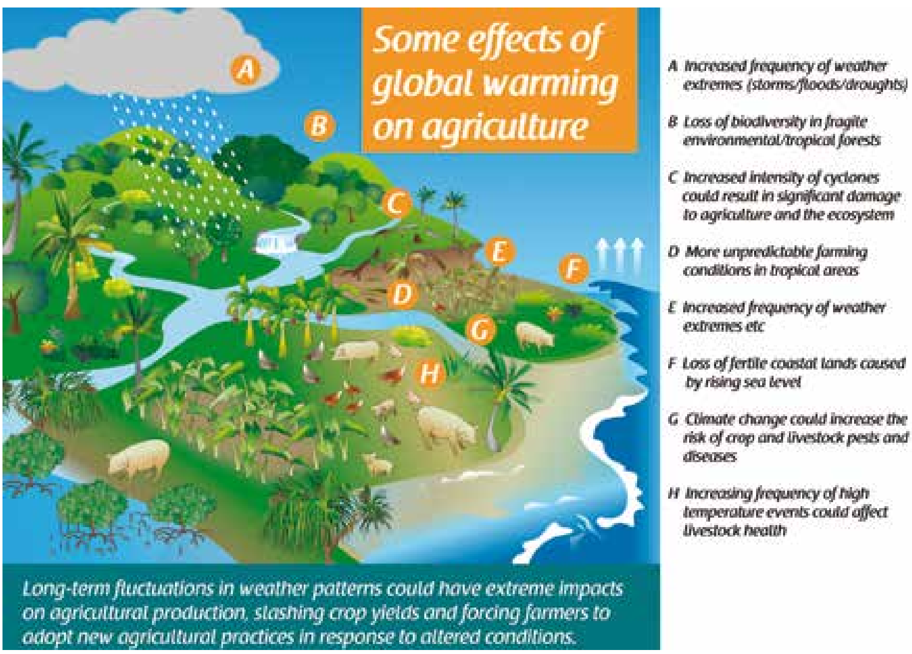
Agriculture contributes to GHG emissions directly through agricultural practices, releasing carbon dioxide (CO_2) largely from microbial decay or burning of plant litter and soil organic matter, methane (CH_4) from enteric fermentation, biomass burning, rice production and manure management, and nitrous oxide (N_2O) from the microbial conversions of nitrogen (N) in soils and manures, to the atmosphere. Only agricultural non-CO_2 sources are reported as anthropogenic GHG emissions, as the actual CO_2 emitted is linked to annual cycles of carbon fixation and oxidation through photosynthesis (Smith et al. 2014). Agriculture is the largest producer of non-CO_2 GHG, contributing 56% of non-CO_2 emissions (USEPA 2011). The United States Environmental Protection Agency estimated that the net CO_2 emission from agricultural soils in 2000 was less than 1% of global anthropogenic CO_2 emissions (as cited in IPCC 2007c). A more recent study reported that CO_2 emissions from the soil in the last 50 years have increased, though the reasons for this increase are as yet unclear (Bond-Lamberty and Thomson 2010).

Enteric fermentation and agricultural soils represent together about 70% of total emissions, followed by paddy rice cultivation (9–11%), biomass burning (6–12%) and manure management (7–8%). Between 1961 and 2010, global emissions from enteric fermentation grew by an average annual rate of 0.70% (Smith et al. 2014). Emissions from synthetic fertilizers had the largest absolute growth rates, increasing on average, 19% per year during the reference period of 2000 to 2010. In 2010, 70% of emissions from synthetic fertilizers were from developing countries, with Asia being by far the largest emitter (Tubiello et al. 2013). The magnitude of direct and indirect emissions and the relative importance of the different sources of emissions vary between world regions (Vermeulen et al. 2012).

3.3 Impact of climate change on agriculture

Weather and climate have a major influence on agriculture. Therefore, over the years farmers have adapted to the vagaries of local climate with its seasonal and annual variability by using different farming practices, traditional knowledge and experienced-derived knowledge. Farmers, from small island states in particular, have learnt to work with highly variable climate and weather extremes. However, changes outside of their sphere of knowledge and experience can have significant implications for agricultural production, creating challenges for food production. Further, the magnitude and intensity of any extreme climatic event are compounded by pre- and post-conditions surrounding that event, so that farmer experience based on familiarity is less valuable in managing the impact of the event.

The impact of climate change on agriculture will be mainly experienced through long-term trends in mean temperature, precipitation, winds, and CO_2 concentrations, and by increasing variability associated with greater frequency and severity of extreme weather events such as drought, floods and heatwaves. Sea-level rise and saltwater intrusion are important for atoll islands and low-lying communities, especially in the long term. Other factors will come into play such as the recovery time between extreme events, the impact of multiple stresses (for example, a combination of higher temperatures and lack of rainfall), and progressive climate change over time. Developing a better understanding of current vulnerabilities to these different climate change threats can help to guide the process for adaptation. Increasing the resilience of current systems by implementing risk management strategies will support communities to manage greater variability, while at the same time strengthening adaptive capacity to manage the slow-onset changes.



http://www.seedbuzz.com/sites/default/files/impact_clim_agri.jpg

The potential impacts of climate change on global agricultural production have been assessed in numerous studies (FAO 2008b; Rosegrant et al. 2008; Lobell et al. 2011; Thornton and Cramer 2012). The projections are for crop productivity to increase slightly at mid-to-high latitudes for local mean temperature increases of 1°–3°C, as productivity at these latitudes is generally temperature-limited, although this will depend on the crop. At lower latitudes, decreases in crop productivity are projected for even relatively small local mean temperature increases of 1°–2°C, because crops at these latitudes are already close to their maximum heat tolerance (Thornton and Cramer 2012). There is considerable uncertainty about such estimates (Challinor et al. 2007); nevertheless, most studies indicate that agriculture productivity in the tropics and subtropics is likely to be adversely affected by climate change in the coming decades.

Models that use historical data between 1980 and 2008, linking crop yields with climate variables such as temperature and precipitation, indicate that yields of maize and wheat production declined by 3.8% and 5.5% respectively over that time period; the decline was less for soya beans and rice. Country-specific differences were evident; in some countries climate trends were offsetting potential gains in yield arising from other factors, such as improved technology (Lobell 2011). At higher latitudes some countries have experienced productivity benefits from higher temperatures; for example, northward shifts in maize area in the U.S. (Hatfield et al. 2011) and the rice area in China (Hijmans 2007).

The livestock sector will experience direct and indirect effects from climate change (Table 3.1). Direct impacts include productivity losses resulting from physiological stress caused by temperature extremes, increases in rainfall variability and frequency of drought. Indirect impacts include changes in the availability, quality and prices of inputs such as fodder, housing and water (Thornton 2010). The more industrial producers can access and use global markets to sustain their supply of fodder and other inputs, (although climate change could impact on this global supply—see Section 3.5.1.2) but this is not an option for small-scale producers. The distribution and incidence of diseases are likely to change because of the impact of climate change on the habits of vectors, for example, the impact of increasing temperature on generation times.[1] However, as discussed in Section 3.7.7, the precise effects are difficult to predict. In the more traditional production systems, livestock farmers are accustomed to less predictable conditions. However, the appearance of as yet unknown diseases or pests will present 'new' challenges, which will have to be managed, possibly with limited resources.

1 Average time between two consecutive generations in the lineages of a population.

Table 3.1 Direct and indirect impacts of climate change on livestock production systems (source: Climate-Smart Handbook, FAO, 2013).

	Grazing Systems	Non-grazing systems
Direct impacts	Increased frequency of extreme weather events • increased frequency and magnitude of droughts and floods • productivity losses (physiological stress) due to temperature increase • change in water availability (may increase or decrease, according to region)	Change in water availability (may increase or decrease, according to region) • increased frequency of extreme weather events (impact less acute than for extensive systems)
Indirect impacts	Agro-ecological changes and ecosystem shifts leading to: • alteration in fodder quality and quantity • change in host-pathogen interaction resulting in an increased incidence of emerging diseases • disease epidemics	Increased resource prices (e.g. feed, water and energy) • disease epidemics • increased cost of animal housing (e.g. cooling systems) •

3.4 Mitigation and adaptation

Agriculture not only has to adapt to climate change but also needs to mitigate climate change through sequestering and/or reducing GHGs, while at the same time meeting the increased demand for food as a result of population growth. Mitigation measures should be both supply-side (changes in land management) and demand-side (reduced waste). Supply-side mitigation measures are the basis of sustainable agriculture, all aspects of which would make a significant contribution to increasing the resilience of production systems.

Despite the focus on climate change and agriculture, most adaptation and mitigation efforts are pursued separately, limiting the potential to take advantage of synergies and to minimise trade-offs across actions designed for either adaptation or mitigation benefits. Further, addressing mitigation and adaptation separately is not an efficient use of funds, and prevents an integrated management approach to agricultural landscapes, which could not only address climate issues but also ensure the provision of food, water and other ecosystem services. The consideration of trade-offs across multiple temporal and spatial scales are critical since some trade-offs will be evident immediately, while others will be apparent later (Harvey et al. 2013). A climate-smart approach to agriculture requires actions beyond the farm level, involving the adoption of a landscape, ecosystem, or ridge-to-reef approach. This integrated approach provides opportunities for generating important synergies for agricultural production, climate adaptation and mitigation, as well as other livelihood and environmental objectives, at both farm and landscape scales.

A recent concept is that of 'climate-smart agriculture' (CSA)[2]. CSA is 'agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes GHGs (mitigation) and enhances achievement of national food security and development goals' (FAO 2010). In developing countries it focuses primarily on enhancing smallholder adaptive capacity and resilience, with, in many cases, mitigation co-benefits.[3] Despite the relatively recent introduction of the term 'climate smart' the concept is founded on practices and approaches that are the basis of sustainable agriculture.

3.5 Nature of effects of climate change on agriculture

The threats to agricultural production from climate change arise largely from changes in temperature and precipitation, both long-term and slow-changing (slow-onset changes), as well as changes in the frequency and intensity of extreme weather events. These extreme events are likely to be more damaging, especially if their timing coincides with a crucial developmental stage in the life cycle of a living organism (such as a crop or livestock species, or a pest or disease vector), and because of their potentially damaging impact on the communities working in the sectors and the supporting infrastructure. The recovery time between events, and the preceding conditions prior to any extreme event, will influence the actual impact of the event. A further consideration is the combined impact of multiple stresses (both biotic and abiotic).

The impacts of long-term (slow-onset) changes are most likely to be felt beyond 2050, and will depend on emission trajectories and the extent of climate change that occurs (Chapter 2). However, significant yield losses for major crops are still projected by the 2050s. Knox et al. (2012) conducted a systematic review of model-based studies of future crop yields in South Asia and Africa. Under high GHG emissions, significant yield variation is indicated for maize (–16%) and sorghum (–11%) in South Asia and wheat (–17%), maize (–5%), sorghum (–15%) and millet (–10%) in Africa. The limited number of studies identified for cassava, sugar cane and yams prevented any meta-analysis from being conducted.

The inherent complexity and variability of natural systems makes analysis difficult using traditional field and/or controlled environment experimentation. It is technically possible to generate future climate changes, such as changes in atmospheric carbon dioxide concentration, temperature, and rainfall in glasshouse and growth chambers, but costs are high and the results may fail to capture the full complexity and variability of the natural system.

2 CSA is a newly framed concept but includes many of the field-based and farm-based sustainable practices already documented and in use.

3 FAO recently launched the 'Climate-Smart Agriculture Sourcebook' which describes the tools available to reach the goals of sustainable production, and at the same time contribute to climate change adaptation and mitigation http://www.climatesmartagriculture.org/en/

The uncertainties that exist with the climate models can be exacerbated when used with farming system models or other biophysical models. It is these models that generate the information on how crops, for example, will perform under certain climate conditions. However, by using a sensitivity approach (i.e. a range of possible climate futures/ scenarios) to model future impacts, a range of different on-farm adaptation options can be effectively evaluated. Such models use data generated at the local or plot level. As yet the direct use of climate model outputs within crop prediction systems remains limited in the Pacific, reflecting the scarcity of local climate records of sufficient length and accuracy. The few studies that have attempted to make crop yield projections across the different regions, including the tropical regions, ignore the impacts of threshold limits and sub-seasonal variability. Crop projection models also do not take into account the impacts of climate change on the functioning of ecosystems, such as the effect on pollinators (Kjøhl et al. 2011) and the balance between pests and their predators (FAO-OECD 2012). However, despite the uncertainties and the gaps in knowledge, the available information, linked with local knowledge, can and must be used to develop sound but flexible response strategies.

Pollinators at work Photo: Scott Groom

The following sections consider the influence of the different climate variables, such as temperature and rainfall, and their interaction, on the growth and development of crops and livestock. Understanding how these biophysical processes are likely to be affected by changes in intensity or frequency of these climate variables provides a basis on which to better understand the potential impact of climate change on Pacific agriculture.

3.5.1 Effect of temperature change[4]

The recent IPCC report (IPCC 2013) stated that global mean temperature change for the period 2016–2035 will likely be in the range of 0.3°–0.7°C, but that relative to natural internal variability, near-term increases in seasonal mean and annual mean temperatures are expected to be larger in the tropics and subtropics compared with mid-latitudes. As discussed in Chapter 2, by 2030 the projected warming in all PICTs is 0.5°–1°C regardless of emission scenarios. For 2050 and beyond, projections vary within the range of 0.5°–2°C, depending on the emission scenario. By 2090, projected warming is likely to exceed 2°C for all emission scenarios except RCP2.6 (very low) and RCP4.5 (low). The region will also see more hot days and warm nights and fewer cool days and nights. An extreme temperature event could see an increase of 2°–4°C over and above the average temperature by 2090 under RCP8.5.

3.5.1.1 Crops

Sustained temperature increases are likely to change the duration of a crop's growing season or where the crop can be grown. Depending on their intensity and duration, short episodes of high temperatures can be very damaging if they occur at a critical time of development, and can affect growth and yield independently of any substantial changes in mean temperature (Challinor et al. 2006).

Temperature is a key determinant of evaporative and transpirative demand, particularly in tropical regions. Where temperatures are already close to the physiological maximum, higher temperatures are likely to increase both the heat stress on crops and water loss by evaporation. High temperature stress can be exacerbated by the high relative humidity found in tropical locations. Saturated air reduces the potential for evaporative cooling and is also accompanied by higher night temperatures. High temperatures will increase the demand for water, and how the plant manages heat stress will be determined by agronomic and genetic factors influencing the plant's potential for evaporative cooling. In the short term, high temperatures affect enzyme reactions and gene expression; in the longer term the impact will be on growth and yield through carbon assimilation (Reynolds et al. 2010). Models indicate that in tropical and subtropical regions temperature increases of only 1°–2°C are likely to depress yields as heat tolerance levels are exceeded (Section 3.3).

Various authors (Porter and Gawith 1999; Wheeler et al. 2000) have suggested that temperature thresholds are well defined. For example, rice grain sterility is induced by temperatures in the mid-30s, and pollen viability in maize is reduced when temperatures exceed 36°C (Gornall et al. 2010). Groundnut, a crop of semi-arid conditions, regularly experiences temperatures of 40°C, but temperatures of 42°C, even for short periods of time, will drastically reduce yield (Vara Prasad et al. 2003). Non-linear heat effects have been reported with crops such as maize, corn, soybeans and cotton. For corn, soybeans and cotton, yields increased up to 29°C, 30°C and

4 All stated temperature change is relative to a baseline of 1986–2005.

32°C, respectively, but temperatures above these thresholds were very damaging, with a far steeper decline occurring beyond the level of optimum yields compared with the incline leading up to the optimum yields (Schlenker and Roberts 2009).

Fruit crops, such as mango and papaya, can be affected by high temperatures at specific stages of their development. High temperatures during panicle development in mango speed up growth and reduce the number of days for effective pollination, which may lead to poor yield. Rising temperatures cause desiccation of pollen and poor pollinator activity resulting in low fruit set and, ultimately, a poor crop (Bhriguvanshi 2010). In papaya, higher temperatures have caused flower drop in female and hermaphrodite plants as well as sex changes in hermaphrodite and male plants. The promotion of stigma and stamen sterility in papaya is mainly because of higher temperatures (Dinesh and Reddy 2012). These two crops are further discussed in Chapter 6.


Papaya production in Fiji Photo: Kyle Stice

A warming temperature will enable crops to be cultivated in locations currently unsuitable; for example, banana cultivation in areas of higher altitude in PNG. However, at the same time, higher temperatures could encourage the spread of black leaf streak disease to higher altitudes. Similarly a warming temperature can also affect the incidence and spread of a disease, as in the case of taro (*Colocasia esculenta*), where a higher night temperature can favour sporulation of the oomycetous fungus *Phytophthora colocasiae*, increasing the risk of taro leaf blight (Chapter 4).

Crop quality can also be affected by a warming temperature. Higher temperatures have been shown to reduce vitamin content in fruit and vegetable crops (McKeon et al. 2006). The failure of transport processes to match accelerated growth rates can also result in macronutrient deficiency (Woolf et al. 1999). Studies have indicated that rice quality traits such as chalk, amylase content, and gelatinisation are affected by higher temperatures (Wassmann and Dobermann 2007). Ethylene production and cell wall softening occurred in papaya and tomato fruits after exposure to high temperatures in the field (Chan et al. 1981; Picton and Grierson 1988). A comprehensive review of the impact of climate change on the postharvest quality of fruits and vegetables is provided by Moretti et al. (2010).

Extremes of temperature will also impact on agricultural farm labour productivity. Most agricultural production in the PICTs is carried out using manual labour, therefore on very hot days it is highly likely that labour output will be affected.

The perceived benefits of increased carbon dioxide could also be offset by higher temperatures, due to the higher energy costs of photosynthesis (Reynolds et al. 2010). Higher temperatures can also reduce yields as a result of increased rates of dark respiration; for example, rice loses yield potential (up to 10% for each 1°C increase in minimum temperature in the dry season) with warmer night temperatures (Mohammed and Tarpley 2009).

3.5.1.2 Livestock

In general, livestock can adapt to small increases in temperature. Heat stress is known to affect the physiology of livestock, reducing production and male and female fertility, and increasing mortality rates. Body temperatures beyond 42°–45°C are lethal in many species. Poultry in particular are highly vulnerable to increased temperatures, especially when associated with high humidity. At temperatures above 30°C appetite is suppressed and animals can reduce their feed intake by 3–5% for every additional degree of temperature; increasing temperature also puts a greater demand on water requirements. Many local breeds in the tropics and subtropics are comparatively well adapted to high temperatures, but any animals that have been introduced to the tropics are likely to be affected by heat stress, particularly where high temperatures are combined with high relative humidity and diets based on poor-quality forage (King et al. 2006).

Studies that evaluate the impact of climate change on animal feed suggest that the availability of maize- and soy-based animal feed could be affected by climate change. The demand for maize and coarse grain for livestock production is predicted to account for nearly 50% of the grain produced in the years 2000–2050 (Rosegrant et al. 2009) but the prospects for maize, especially in conditions of higher temperatures, are not good. Crest Ltd (Fiji) is the main supplier of manufactured livestock feed mixes, especially for poultry. Between 60–70% of their raw ingredients, mainly grains (such as maize, wheat, and sorghum), meat and bone meal, and premixes (feed balancer), are imported. Crest depends on imports of raw feed ingredients for consistency in supply, and quality of the raw ingredients. Therefore, any shortage of maize or other grains would have a significant impact on the availability/reliability of livestock feed in the PICTs (Cokanasiga pers. comm.).

Pastures are expected to decline in quality, with high temperatures encouraging lignification of plant tissues and therefore decreasing forage digestibility. Climate change is likely to support a shift from C_3 to C_4 grasses (Christensen et al. 2004; Morgan et al. 2007); C_3 forage plants yield less but generally have higher nutritive value, while C_4 plants contain large amounts of low-quality dry matter and have a higher carbon–nitrogen ratio (Easterling and Apps 2005; Easterling et al. 2007; Tubiello et al. 2007). The impact this higher proportion of C_4 species in pasture will have on livestock productivity is discussed in Chapter 7.

Over the long term, future disease trends for livestock could be heavily influenced by climate change. Van Dijk et al. (2010) found that climate change, especially elevated temperature, has already changed the overall abundance, seasonality and spatial spread of endemic parasitic worms in the United Kingdom. Increased incidence of intestinal problems in cattle has been reported in Vanuatu, with similar problems (worms and infections) reported by piggery farmers (FAO 2008a). These changes in disease patterns and intensity highlight the importance of close monitoring and effective diagnostic and detection methods.

As with crops, the impact of temperature on livestock production will be influenced by changes in other climate variables and the nature of the production system. The influence of different breeds has been highlighted with the likelihood that local breeds will be less vulnerable to high temperatures than any introduced breeds.

Photo: Mary Taylor

Impact of temperature on livestock will be influenced by the livestock breed and the nature of the production system

3.5.1.3 Summary

The impact of temperature on selected crops and livestock is discussed in more detail in later chapters. These chapters discuss the optimum temperatures for growth and productivity and assess whether projected temperatures will exceed those optimum temperatures. Better understanding of these temperature limits and their timing across growth cycles would enable more confident predictions to be made regarding crop and livestock responses, in particular responses to high temperature events, which are likely to have more impact than a gradually warming average temperature.

This section has also highlighted the challenge in assessing the impact from a warming temperature separately from water availability, and/or increasing CO_2. Further, the impact of warming on crops and livestock, whether as a result of an increasing mean temperature or increasing heatwaves, cannot be considered without taking into account the impact on ecosystem services and pests and diseases (see Sections 3.6 and 3.7).

3.5.2 Effect of change in precipitation

The IPCC (IPCC 2013) reports that changes in the global water cycle in response to warming will not be uniform, and as discussed in Chapter 2, an increase in average annual rainfall is projected for large parts of the tropical Pacific in a warmer climate. The effect of warming on rainfall is likely to be small prior to 2030, and mostly hidden by natural climate variability. After 2030, patterns will emerge, which will be stronger for the higher emission scenarios (RCP6 and RCP8.5), and with time. A warmer climate will also see an increase in the frequency and intensity of heavy rainfall events. The IPCC report also stated that the El Niño-Southern Oscillation (ENSO) will continue to dominate inter-annual variability in the tropical Pacific, and because of the increase in moisture availability, ENSO-related precipitation variability on regional scales will likely intensify.

As further discussed in Chapter 2, many factors affect rainfall projections for any location and as such, confidence in regional rainfall projections is generally low. Given this uncertainty, it is difficult to predict potential regional changes in agricultural productivity. Importantly, percentage change in rainfall should be considered in the context of the current baseline, so that large projected increases, for countries where current rainfall levels are already considered high (such as in parts of the Federated States of Micronesia, PNG and Solomon Islands), are likely to have a significant impact on productivity. Similarly, countries such as French Polynesia and the northern Cook Islands (May–October) could face challenges with the projections of a drier climate (Table 2.4, Chapter 2).

The global water cycle in response to warming

A Higher rates of evapotranspiration from forests, rangeland and cropland

B Increased evaporation from reservoirs, water bodies and wetlands

C Increased variability of precipitatons, more extreme events

D More frequent floods affecting human settlements and cropland

E Sea level rise and salt water intrusion

F Longer periods of low flow affecting water users including industries, electricity generation and irrigation

G Increasing demand for irrigation water

H More frequent and longer periods of soil moisture deficit affecting crops

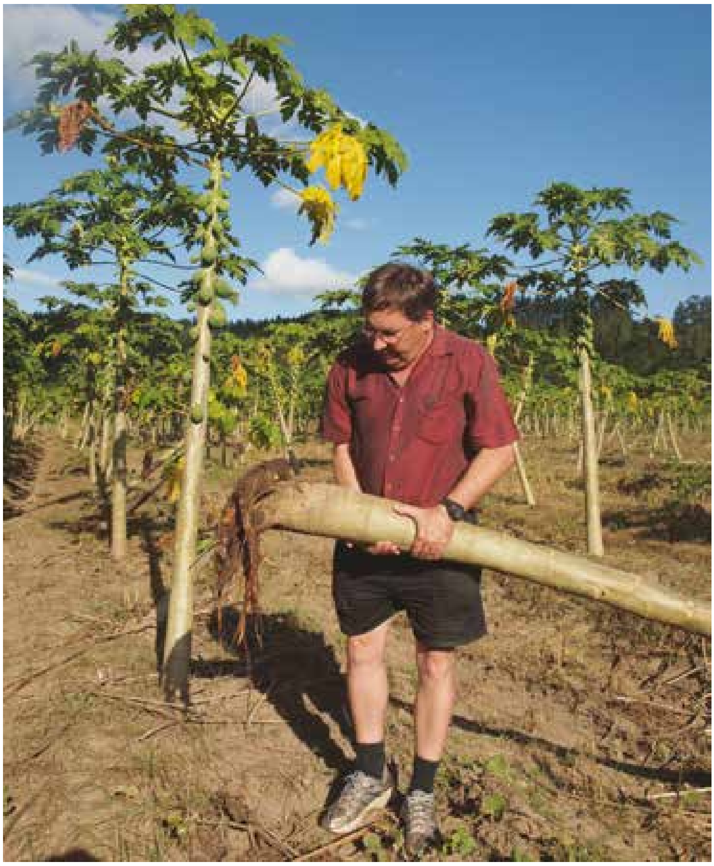
I More pressure on groundwater to compensate for more variable surface water supply

(source adapted from http://www.fao.org/nr/water/art/2013/watercycle_cc.jpg)

3.5.2.1 Crops

Excess water results in waterlogging, and soil saturation and oxygen deficiency (hypoxia) can occur over a few days (Grable 1966). Nutrient uptake is reduced and therefore transient waterlogging can lead to decreased yields if crops are not subsequently re-fertilized (Robertson et al. 2009). Hypoxia can also increase the concentration of toxic ions, metals, fatty acids, phenolic compounds and ethylene found in the soil. In saline conditions, at least a 30% increase in either sodium or chlorine concentrations in the leaves or shoots of 23 of 24 species surveyed occurred with root-zone hypoxia (Barrett-Lennard 2003). Rao and Li (2003) provide a review of the impact of flooding on the growth of vegetable and selected field crops, which include sweet potato, yam and tomatoes (further discussed in Chapters 4 and 6).

Heavy rainfall leading to flooding can delay farming operations, wipe out entire crops over wide areas, damage seedling availability and restrict access to planting material and markets. The 2009 floods in Fiji were reported as the worst since 1931, costing USD 13 million in economic costs in the country's sugar belt. Preceding conditions of several consecutive depression systems over a short period of time coinciding with high tides added to the damaging impact. Continuous torrential rain for two weeks led to most low-lying areas being under water for days (Lal 2010). Extreme events not only cause havoc at the time, but recovery from these events can be both a costly and lengthy process. In 2012, Fiji experienced floods in January and March and costs to agriculture were over USD 9.7 million; damage to the sugar industry was estimated separately at over USD 11.7 million (National Disaster Management Office 2012). High levels of precipitation at critical times such as harvesting can have serious effects; for example, historic wet spells have caused multimillion dollar losses in the Australian sugar cane industry (Vermeulen et al. 2012).



Flood damaged papaya in Fiji Photo: Richard Markham

Total annual rainfall is just one aspect of the impact of rainfall on plant growth. Other important factors are seasonal distribution (timing), variation between years, extremes and intensity. Fruit crops can be very sensitive to timing and amount of rainfall. For example, with mango, rainfall during flowering will adversely affect fruit set, fruit development and yield. Anthracnose can also be a problem with mature fruits in high rainfall (Rajan 2012), and with other important crops such as yams.

Stomatal closure is an adaptive function that increases transpiration efficiency, but reduced transpiration may result in heat stress (Davies et al. 2005). Osmotic adjustments are often observed under water deficit, so that favourable water potential gradients are maintained to support continuous growth (Morgan 2000). If a plant's drought-adaptive strategies fail, growth will cease and damage to the photosynthetic apparatus and other metabolic processes can occur (Ghannoum 2009). A decline in water potential triggers a wide range of physiological processes; some are the result of the changing water status of the tissues while others are induced by plant hormones signalling changes in water status (Chaves et al. 2003). Cattivelli et al. (2008) provide a list of physiological traits and the responses induced by drought stress.

Some crops are relatively tolerant of drought. A study of a large number of cassava genotypes from the core collection held at the International Centre for Tropical Agriculture, Columbia (CIAT) highlighted both the variation in drought tolerance depending on genotype and also the mechanisms used by cassava to tolerate significant water stress. These included effective stomatal control over leaf gas exchange, a reduction in leaf canopy area and an ability to recover quickly once water was available by producing a new canopy of leaves with a much higher photosynthetic rate than unstressed crops. With these mechanisms the yields of water-stressed plants can approach those of a well-watered crop (El-Sharkawy 2007). However, although cassava is a crop that will yield well under drought situations, as discussed in Chapter 4, studies have shown that the cyanide concentration found in tubers and leaves increases under water stress (Burns et al. 2012). However, in examining the effect of soil moisture on growth and linamarin levels in cassava over a five-month period, Vandergeer et al. (2013) found that high concentrations of cyanogens could be reduced by cooking and boiling and by watering plants for two weeks after the drought period. Drought can also exacerbate micronutrient deficiency (e.g. zinc) due to reduced transpiration rates, and also mineral toxicity, such as boron and salinity (Reynolds et al. 2010).

Crop productivity is increasingly vulnerable when more than one abiotic stress is present. Recent studies on maize have shown that tolerance to combined drought and heat stress was genetically distinct from tolerance to drought and heat stress separately, and tolerance to either stress alone did not confer tolerance to combined drought and heat stress (Cairns et al. 2013). Under elevated CO_2 (eCO_2) more water may be needed to maintain the additional leaf area, while in drier areas there could be an increased risk of drought as the 'faster-growing' crop exhausts stored soil water (Reynolds et al. 2010).

Droughts can result in considerable damage to the agriculture sector. El Niño-induced drought conditions in Samoa saw a 5–8% loss of taro production with a corresponding 3–5% increase in food imports (World Bank 2010). Similarly taro growth was also reported as seriously affected by the drier conditions on Aitutaki, Pukapuka and Mauke, in the Cook Islands (FAO 2008a). During the 1997/98 El Niño event, sugar cane losses in Fiji were estimated at USD 52 million (McKenzie et al. 2005). Perhaps the most catastrophic natural disaster experienced in the South Pacific was the PNG drought of 1997–98. During this ENSO-induced event more than 40% of rural villagers suffered from food shortages of varying severity (Bourke 2012).

In 2011, Tuvalu declared a national emergency when a period of no rain led to a water shortage. The vulnerability of the pulaka (swamp taro) to dry conditions was particularly highlighted and salinity problems were exacerbated illustrating the effect of multiple climate-related stresses (SPC 2011). Prior to the 2011 drought, a measurement of the salinity in selected pits (Rao 2010) showed significantly high conductivity values in some of the pits especially when compared with the survey carried out by Webb (2007). The combination of the high temperatures experienced during the drought and the increasing salinity of the pulaka pits adversely affected the growth of the pulaka.

Swamp taro during drought in Tuvalu Photo: Fereti Atumurirava

3.5.2.2 Livestock

Drought conditions will affect livestock directly through availability of water and also indirectly through pasture quality and quantity. Both effects can lead to lowered fertility, and generally increased vulnerability to disease, and hence higher mortality and morbidity. Forage provides some of the water that livestock use and the water content can vary from 0–80% depending on the species and weather conditions. As temperatures increase, so too does the demand for water. For *Bos taurus* water intake at 30°C is 8 kg/kg of dry matter (DM) intake compared with 14 kg/kg DM at 35°C (Thornton et al. 2009). Overgrazing of certain areas can occur in drought conditions encouraging a change in the species composition of the grasses and favouring the development of annual grasses and woody perennial scrub (Chambwera et al. 2011). Some diseases may be exacerbated by flooding and made more complex because of limited access to water (Thornton 2010).

Photo: Vincent Lebot

Bos taurus, Vanuatu; water intake likely to increase with increasing temperature

3.5.2.3 Summary

The impact of precipitation variability on selected crops and livestock is presented in more detail in later chapters. For many PICT locations, rainfall is already somewhat higher than optimal, and for some locations it is already considered excessive. In Solomon Islands, the mean annual rainfall can rise as high as an estimated 8000 mm in the mountains of Guadalcanal and Makira, whereas in northern Guadalcanal, mean annual rainfall levels are in the range 1850 to 3000 mm (Bourke et al. 2006). The extent of this in-country variation highlights the importance of location-specific information. Projections of increasing annual rainfall and increased frequency and intensity of ENSO-related droughts and floods pose a significant threat to those countries and locations where rainfall is already excessive, and where water availability is determined by precipitation, such as in the atoll countries. Adaptation strategies need to take these extremes into account and to ensure that land use (both at the farm and landscape level), infrastructure and farming practices do not exacerbate these extremes of water availability. Diversified agro-ecosystems will be better able to manage these changing environmental conditions, and will offer some protection against these extremes.

3.5.3 Effect of change in atmospheric composition

The IPCC report (IPCC 2013) states that 'cumulative emissions of CO_2 largely determine the global mean surface warming by the late 21st century and beyond'; however, other gases are also important. Converting all GHGs to CO_2 adds the equivalent of another 30–50 ppm CO_2 depending on which gases are included (Dawson and Spannagle

2009). As of April 2014, the monthly mean carbon dioxide measured at Mauna Loa Observatory, Hawaii exceeded 400 ppm (401.30), compared with 398.35 ppm in April 2013[5]. Adding in the other GHGs elevates the figure to around 450 ppm CO_2 equivalent—the concentration level at which it is generally considered that society has at least a 50% chance of stabilising the climate at 2°C global average temperature increase, the goal set in 2010 at the UN Framework Convention on Climate Change (UNFCCC) conference in Cancún (OECD/IEA 2013).

3.5.3.1 Crops

Until recently it was thought that the benefits of eCO_2 would offset some of the negative effects of temperature and precipitation. For example, it was suggested that CO_2 concentrations of 550 ppm could increase the yield of C_3 crops such as wheat and rice, by as much as 40%[6]. However, near-field experiments have indicated that the benefits are significantly less and more likely to be in the range of 8 to 15% (Long et al. 2005), as other production inputs such as water and nitrogen must also be considered (Erda et al. 2005). However, tuber crops seem to be more stimulated by eCO_2 than grain crops (Miglietta et al. 1998; Rosenthal et al. 2012). It is now understood that plants acclimatise to high CO_2 by decreasing the size of their photosynthetic machinery, reducing the stimulatory effect of the CO_2, which results in less use of nutrients such as nitrogen and phosphate (Rasse and Tocquin 2006). Grain crops are able to adjust their photosynthetic machinery because carbohydrate is stored in the leaves, whereas with crops such as cassava, where carbohydrate is transported to the tubers, plants are less able to sense over-production (Ludewig et al. 1998). It is likely that taro will be stimulated by eCO_2 and will behave in a similar manner to other tuber crops. This potential positive impact of eCO_2 on tuber crops is further discussed in Chapter 4. There is observational evidence, that the response of crops to CO_2 is genotype-specific (Ziska et al. 2012). For example, 3–36 % yield enhancement among rice cultivars was observed in free-air carbon dioxide enrichment (FACE) experiments with 200 ppm additional CO_2 (Hasegawa et al. 2013).

In C_4 plants such as maize and sugar cane, eCO_2 could make plants more water-efficient (von Caemmerer and Furbank 2003), because of increased root densities and reduction in the duration of stomatal opening. Enhancing water efficiency may increase yields and would be advantageous at times of water scarcity and warming-induced evaporative demand. The extent to which any benefit from eCO_2 is realized will depend on the type of plant and factors such as water availability, nutrient availability and pests and diseases (Stern 2006). Legumes may be better able to maximise the benefits of eCO_2 by transferring the excess carbon available to the root nodules where it can be used as a carbon and energy source for the bacterial symbionts. Studies in controlled environments have shown that compared with other plant species, legumes show increased photosynthesis and growth under eCO_2 (Rogers et al. 2009). In a study on chickpeas, the yield benefit due to eCO_2 by 2050 ranged from 7% to 20% across sites as compared with the yields under current

5 http://www.esrl.noaa.gov/gmd/ccgg/trends/

6 Ribulose-1, 5-biphosphate carboxylase-oxygenase (RuBisCO) in C_3 crops is not CO_2 saturated.

atmospheric CO_2 concentration; while the changes in temperature and rainfall had either positive or negative impacts on yield at the sites (Wang et al. 2012). However, as Section 3.7.4. points out, the yield benefits gained from eCO_2 can be negated by the eCO_2-enhanced activity of related pests.

Legumes are popular in several countries in the Pacific. For example, dahl, which can be any one of a number of pulses, including chickpea and pigeon pea, is widely consumed in Fiji (Lincoln International 2003). In Fiji, PNG and Vanuatu livestock farmers are encouraged to interplant legumes with their grass pastures, adding nitrogen to the soil, and also providing extra protein for the animals when grazing (Cokanasiga pers. comm.) Peanuts are one of the most profitable crops in PNG, producing around 30,000 tonnes each year and providing a major portion of family income in the PNG Highlands[7]. They are grown in a wide range of local farming systems, including seasonally drier areas and wet coastal regions, and are generally grown from sea level up to 1850 m above sea level. Legumes are particularly suitable for dry areas, with the establishment stage being the only critical stage requiring moisture. They can easily withstand drought (especially cow pea, mung, and pigeon pea), and poor (marginal) soil.

Pigeon peas, Fiji Photo Andrew McGregor

A meta-analysis of 228 experiments found that under eCO_2 (540–958 ppm) protein concentration of wheat, barley, rice and potato was reduced by 10 to 15%, with smaller though still significant reductions (1.4%) in soy (Taub et al. 2008). Leaf nitrogen levels decrease on average by 13% per unit leaf mass under eCO_2 (Ainsworth and Long 2005), affecting the protein value of crops. FACE experiments conducted in the United States (Ainsworth and McGrath 2010) and in China (Erda et al. 2005) show that under the

7 http://malumnalu.blogspot.co.uk/2010/01/high-yielding-peanuts-for-papua-new.html

projected CO_2 concentrations for 2050, protein content and minerals such as iron and zinc in non-leguminous grain crops are significantly reduced. Results from studies carried out on wheat and rice suggest that decreases in essential minerals such as calcium, magnesium, sulphur and nitrogen will occur (DaMatta et al. 2010). Myers et al. (2014) reported that C_3 grains and legumes, when grown under field conditions at the eCO_2 predicted for the middle of this century, have lower concentrations of zinc and iron. C_3 crops other than legumes also have lower concentrations of protein, whereas C_4 crops seem to be less affected. Not only will this impact on protein levels and affect human nutrition, but poorer quality plant material could result in increased consumption of leaf material by insect herbivores (Stiling and Cornelissen 2007). Importantly, differences between cultivars of a single crop highlighted the importance of selection or breeding for decreased sensitivity (Myers et al. 2014).

Cassava contains the cyanogenic glucoside linamarin, which if present at high levels in crops that are either eaten to excess or not processed adequately, can cause neurological diseases such as konzo and, in extreme cases, death (Banea-Mayambu et al. 1997). Recent studies conducted by Gleadow et al. (2013) at Monash University suggest that the concentration of linamarin in cassava tubers does increase with eCO_2 (Chapter 4). An unpublished study by Bain (2010) indicated that the high cyanogen levels were connected to a redistribution of metabolites within the plant rather than an actual increase in cyanogens. These studies on eCO_2 and drought (Section 3.5.2.1) show the physiological changes that can occur with cassava depending on the climatic conditions. As cassava tends to be perceived as a crop better able to manage climate variability than other crops, farmers and consumers need to be aware of the negative impacts that can result depending on the climate conditions. Generally, cassava varieties in PICTs are low in cyanogen content, but there is the possibility that a combination of drought and eCO_2 could raise cyanogen levels significantly.

In summary, carbon dioxide fertilization was considered to be of significant benefit for crop production, but in recent years these benefits have been re-evaluated and projected gains in yield reduced accordingly. However, it would seem that tuber crops behave differently from grain crops, and that yields could be significantly increased; preliminary studies carried out by CSIRO and the University of Monash, which indicate eCO_2 benefits for cassava and taro, are discussed in Chapter 4 (4.6.1.4). In addition the studies on cassava clearly illustrate how eCO_2 can affect not only the yield of the crop but also the nutritional value, highlighting the link between climate change and nutrition, and therefore the health of the community. As discussed in Section 3.7 eCO_2 may also affect pest and disease impacts.

3.5.3.2 Livestock

Changes in atmospheric composition will affect grassland productivity and species composition and dynamics, causing changes in animal diets and possibly reduced nutrient availability for animals (Thornton et al. 2009). The negative impact of eCO_2 on leaf protein as described in the previous section (3.5.3.1) is likely to mean an increase in biomass consumption for those animals relying on plant material for protein, (Gleadow et al. 2012; Gleadow et al. 2013). For tropical pastures (C_4 grasses), the quality rather than the quantity of forage available is often the limiting factor for production.

3.5.3.3 Summary

The impact of eCO_2 on crops and livestock cannot be considered in isolation. Elevated CO_2 is also likely to affect pests and diseases (Section 3.7), and as mentioned in Section 3.5.1.1, any crop yield benefits from eCO_2 could be offset by higher temperatures. The multiple levels of possible interactions between climate variables and biotic components of any production system highlight again the difficulty in predicting the impact of climate change on a specific crop or animal, and emphasize the importance of monitoring and collecting data and development of crop-climate models.

3.5.4 Effect of sea-level rise

The projected increases for sea-level rise are substantially higher than those in previous assessments. Across the Pacific there is considerable spatial variability but very high rates of sea-level rise are observed in the western tropical Pacific where sea-surface salinity is decreasing; in contrast sea-surface salinity is increasing in the southeastern tropical Pacific. Importantly, the effect of sea-level rise is most seen through changes in extreme sea-level events. Over the western Pacific a 50 cm sea-level increase would mean that a 1-in-100 year flooding event would typically occur every year (Chapter 2).

Sea-level rise is of relevance to those communities inhabiting coastal areas and atoll islands. On the atoll islands, freshwater reserves are limited to shallow subsurface lenses susceptible to contamination by salt water; most of the crops grown on these islands have a relatively low tolerance to salinity. Further, the height of atolls above sea level rarely exceeds two metres, making them very susceptible to wave damage and coastal erosion. On low islands and atolls in the Pacific, practically all crop agriculture is concentrated at or near the coast. Sea-level rise can impact on agriculture through coastal erosion with some areas of land under permanent inundation; through high tides and storm surges, which periodically contaminate the freshwater lens; and through the infiltration of salt water into rivers during dry seasons, which can increase the level of salt in the soil.

Coastal erosion, Kiribati Photo: Ruut Kareba

Soil salinity affects plant growth and survival because increasing levels of certain ions, mainly sodium and chloride in the soil solution, effectively decrease water availability (osmotic effect). These same ions can also damage plant metabolism and growth (toxic effect). Osmotic effects are immediate whereas the toxic effects can take days or weeks to decrease growth (Mullen and Barrett-Lennard 2010). As reported by Hu and Schmidhalter (2005) salinity may also cause nutrient deficiencies or imbalances, due to the competition of sodium and chlorine with nutrients such as potassium, calcium, and nitrogen.

Salt tolerance is achieved either by plants withstanding the adverse water relations induced by salinity, or decreasing the movement of toxic ions to the shoots. Of particular concern to the atoll communities is the vulnerability of swamp taro, a hugely important crop in the atolls, both culturally and for food security (Chapter 4). Webb (2007) found that swamp taro grew well in locations where the electrical conductivity (ECe) was 1000 µS/cm (equivalent to about 100 mM of sodium chloride (NaCl); seawater contains about 500mM of NaCl), and tolerated levels around 2000 µS/cm, but levels of 3000 µS/cm and above could be lethal to the plant. As Webb points out, the response of giant swamp taro to salinity is complex. The duration and intensity of any salinity event have to be considered, along with other environmental conditions including shade, soil conditions and planting depth, which makes determining salinity tolerance difficult. Two studies (Webb 2007; Rao 2010) carried out in Tuvalu highlighted the vulnerability of some varieties of swamp taro to the intrusion of saltwater into the swamp taro (pulaka) pits.

Saltwater intrusion, Tuvalu Photo: Fereti Atumurirava

Addressing sea-level rise in atoll islands and low-lying areas where food is produced will be a significant challenge, requiring far more knowledge about salinity tolerant crops and systems than is currently available. Atolls also face the challenges of drought; it is likely that both sea-level rise and drought will require significant investment in adaptive infrastructure.

Apart from the atoll countries and the atoll islands of the larger Melanesian countries, sea-level rise is not a major issue for the region in terms of agricultural production. Although the atoll countries are highly reliant on food imports (see Chapter 9), the cropping systems of countries such as Kiribati and Tuvalu, particularly in the outer islands, continue to make a valuable contribution to household self-sufficiency despite the difficult environment in which they operate. Salinisation of groundwater, storm surges and land lost due to coastal erosion will make it even more difficult for these systems to supply food to growing populations. Any efforts to improve local food production, such as utilising and possibly processing excess crops (e.g. breadfruit) from the outer islands, will need to take into account effects from sea-level rise. As discussed in Chapter 4, increasing salinisation could result in swamp taro production declining in importance in the short term (2030) and disappearing entirely in the medium term (2050).

3.5.5 Effect of tropical cyclones on agriculture

Tropical cyclones, depending on their intensity, can be extremely damaging to agriculture and forestry, influencing production conditions, destroying trees and crops, drowning livestock, altering water supplies, and influencing water-borne transport and ports. As discussed in Chapter 2, globally the intensity of tropical cyclones is projected to increase by the end of the century, but the global frequency may either stay the same or decrease. Damage to crops and vegetation tends to increase exponentially with wind speed; for example, 180km/hr winds are four times more damaging than 90km/hr winds (McGregor and McGregor 1999). Each cyclone, however, is individual in terms of its characteristics and impacts. Category 1 cyclones can cause significant flooding damage, normally associated with a more intense cyclone. Further, the impact of a tropical cyclone is affected by preceding conditions and the potential for damage can be magnified by any clustering of intense weather systems. The level of damage to infrastructure important for the agriculture sector, such as roads and markets, will obviously depend on the pre-cyclone status of that infrastructure and how well it has been maintained. As recommended in Chapter 9, measuring the trade-off between less frequent and more intense cyclones to the region's agriculture would be a useful area of research, and may produce a weighted average of the risk of loss over various time periods.

Losses to agriculture from cyclones are generally well reported. In New Caledonia, the estimated cost of damage to agriculture by Cyclone Erica in March 2003 was USD 13 million (Terry et al. 2008); that same year Cyclone Ami struck Vanua Levu, Fiji resulting in a loss of USD 33 million (McKenzie et al. 2005), mainly due to flood damage to agricultural crops and infrastructure. More recently, damage and loss from Cyclone Evan (December 2012) in Samoa were estimated at USD 87.5 million compared with the total costs resulting from the 2009 tsunami, which were assessed at USD 56 million. Damage and loss costs to the crop subsector were estimated at USD 28.5 million. Crop losses were high because the cyclone struck at a peak production time (highlighting how the timing of these events is an important consideration), causing significant damage to banana and breadfruit crops and coconut plantations. Root crop damage was less but farm equipment, buildings and roads were all seriously damaged or destroyed. Flash flooding in localised areas on Upolu wiped out or heavily damaged a number of farms. Livestock farmers reported the death of animals, destruction of farm infrastructure, and widespread damage to fences due to fallen trees. Estimated recovery costs were almost USD 6 million (Government of Samoa 2013).

Cyclone damage to coconuts, Samoa Photo: SPC

These reports highlight the high costs to the population and the economy resulting from cyclone events and illustrate the urgent need for effective risk management strategies at community, national and regional levels. Addressing cyclone risks and vulnerabilities should be a key focus of resilience building. Periods of intense cyclone activity have existed in the past, such as in the 1870s in several parts of the region. However, what we are seeing now is increased vulnerability to cyclones. As reported in the South Pacific Disaster Reduction Programme Report, losses of soil and vegetation have been exacerbated in recent decades by the expansion of non - sustainable agricultural and logging practices. Human settlements are more exposed to storm surges as they have relocated from being predominantly inland to the coasts. Traditional cropping patterns that mitigated against cyclone impact are often no longer maintained, and traditional food preservation, once a disaster mitigation strategy, has all but disappeared (McGregor and McGregor 1999).

Identifying the limits to risk management and adaptation, beyond which transformative change may need to be considered, is also important. The limits to adaptation should also be taken into account for other extreme events, such as droughts and floods.

3.6 Effects of climate change on ecosystem services

Agricultural ecosystems cover nearly 40% of the terrestrial surface of the Earth (FAO 2009), and are both providers and consumers of ecosystem services. Traditionally, agro-ecosystems have been considered mainly as delivering provisioning services, but as discussed in Section 3.2, they also make important contributions to other types of ecosystem services. It is also important to recognize that agriculture supports the services delivered by the ecosystem, such as pollination and pest control, and that poor management of agriculture will affect the quality of these services. Therefore, not only will climate change impact on ecosystem services but the poor management of agricultural systems can exacerbate that impact.

3.6.1 Pollinators

Over 75% of the major food crops are reliant on pollinator services provided by animals. Pollinators, especially bees, are crucial for global food security. The global economic value of pollination services is estimated to be USD 214 billion per year (Gallai et al. 2009). Considerable variation can be found in thermal sensitivity across the different pollinating species; however, climate change may still result in temporal or spatial mismatches between plant and pollinator with potentially serious consequences (Hegland et al. 2009; Kjøhl et al. 2011). Tropical insects operate within a narrow range of temperature suitability and are relatively sensitive to temperature changes. Therefore, tropical agro-ecosystems are likely to suffer greater population decrease and extinction of native pollinators than agro-ecosystems at higher latitudes (Deutsch et al. 2008).

Ecosystems with high species diversity are often linked to resilience, so agricultural fields located in close proximity to natural habitats may benefit from native pollinators (Klein et al. 2003; Ricketts 2004; Gemmill-Herren and Ochieng 2008). For example, a yield increase of 20% was obtained when coffee production was located within 1 km of forest; a source of pollinators. Coffee quality also improved with a 27% reduction in the frequency of 'peaberries' or small misshapen seeds (Ricketts et al, 2004). Relying on a few pollinator species is more risky than encouraging a range of pollinator fauna with differing optimal temperature ranges.

Some studies recently carried out on bees in the Pacific provide insight into how populations have changed as a result of the warming period that followed the Last Glacial Maximum. The lower elevation species (generalist pollinators) that responded positively to that warming period may continue to persist as temperatures increase. Species found at higher elevations, however, which are already comprised or very small populations with lower genetic diversity, are likely to be heavily impacted by a warmer climate. If these higher elevation species are specialist pollinators, this has implications for the plant species they interact with (Groom pers. comm.). The results of these studies and the potential impact climate change might have on these pollinators and therefore crop production are discussed in Chapter 7.

3.6.2 Crop wild relatives and landraces

Crop wild relatives (CWRs) are a key source for genes and traits for biotic and abiotic resistance useful for climate change adaptation (Maxted et al. 2012). The input of wild relatives to disease resistance has made the present-day commercial production of crops such as sugar cane and tomatoes possible (FAO 1997). Thomas et al. (2004) project that 15–37% of wild plant biodiversity will be threatened with extinction by 2050 due to climate change, although not all will be important to crop species. However, Jarvis et al. (2008) project that 16–22% of CWRs with direct value to agriculture may be in danger of extinction. Davis et al. (2012) projected a 65–98% reduction in bio-climatically suitable locations for indigenous Arabica coffee (*Coffea arabica*) by 2080. Under eCO_2 CWRs produce relatively less fruit and seed than their domesticated relatives (Jablonski et al. 2002).

Little is known about CWRs in the Pacific. Some wild taro populations exist in New Caledonia, PNG, Solomon Islands and Vanuatu (Kete 2008). For example, PNG is the primary centre of diversity for banana, being home to ten wild bananas of which one species, *Musa ingens*, is found only in PNG. *Artocarpus camansi*, the wild progenitor of breadfruit, is indigenous to New Guinea, where it can be found growing naturally or cultivated in home gardens in the lowlands. *Artocarpus mariannensis*, native to Palau and CNMI, is found only in Micronesia, along with hybrids. Wild populations, however, are declining, yet trees of *A. mariannensis* and hybrid cultivars tolerate salinity better than *A. camansi* and *A. altilis*. How climate change will affect CWRs is difficult to predict, but it is likely that any extreme change will have a negative impact. Every effort should be made to gain more knowledge about these species in order to determine how best they can be conserved and used.

A. mariannensis, Peleliu, Palau (l). *A. camansi* Atimaono, Tahiti (r). Photos: Diane Ragone

Not only should CWRs receive attention; so too should the rich species and genetic diversity that exist in landraces[8]. The landraces we see cultivated *in situ* in the centres of crop diversity are the result of natural and farmer-mediated evolutionary pressures. Their ability to adapt to climate change will depend on a number of factors, such as plasticity[9]. Other varieties, (often introduced), are often preferred to landraces on the basis of yield and market desirability. Yet the varieties preferred today might lack the plasticity needed to adapt to a changing climate, unlike landraces (Maxted et al. 2012).

3.6.3 Soil

'Soil constitutes the terrestrial environment's primary recycling and cleansing medium, for it is within the soil that the waste products of myriad plants and animals are decomposed and transmuted into nutrients that ensure the continual regeneration of life' (Rosenzweig and Hillel, 2000). This statement clearly articulates the huge importance of soil. The authors conclude that 'the preponderance of evidence shows that our management of the soil should be aimed at enhancing soil organic matter for the multiple complementary purposes of improving soil fertility and soil structure, reducing erosion, and helping to mitigate the greenhouse effect'.

Organic farmer analysing soil, Samoa Photo: Mary Taylor

The concept of 'soil health' is based on the perception of soil as a complex and dynamic material, whose physical, chemical and biological properties must be within a certain range if they are to support the processes and provide the functions required

8 Traditional varieties of crops—the result of farmer and natural selection.
9 Phenotypic plasticity allows plants to continually adapt to their local environment, and enables growth optimisation for the local environment.

by a healthy crop (FAO 2011). Classical approaches have tended to regard the soil as a complex but inert medium. Modern techniques, which aid in the identification of soil microbes and provide some understanding of their interactions have, in contrast, emphasized the importance of soil biological health. While it may be hard to define the range of acceptable soil parameters, it is clear when soils become degraded and necessary soil functions are no longer fulfilled. Recently the declining yields of taro cultivated for export on Taveuni, Fiji have been linked to poor soil fertility[10].

The soil organic carbon (SOC) pool in cultivated tropical soils can be depleted by as much as 75%. Depletion of this pool negatively affects soil quality and reduces productivity. For most soils in the tropics the critical limit of SOC concentration is 1.1%. An optimal level of SOC stock is essential so that the soil has good nutrient and water holding capacity (Table 3.2), reduced risk of erosion and degradation, improved soil structure and tilth, and importantly, can provide energy to soil microorganisms (Lal 2004). These essential characteristics are necessary for the soil to support a resilient cropping system, highlighting the importance of SOC.

Table 3.2 Capacity of soil with a bulk density of 1.2g/cm^3 to store water as affected by soil organic carbon (SOC) content to 30 cm depth. (source: Jones, 2006a and b).

Change in SOC content	Extra SOC	Extra water		CO_2 sequestered
%	kg	Litres/m^2	Litres/ha	t/ha
1	3.6	14.4	144,000	132
2	7.2	28.8	288,000	264
3	10.8	43.2	432,000	396

Climate change is likely to affect the soil and soil processes in complex ways, including acceleration of the decomposition of organic matter and depression of nitrogen-fixing activities (Rosenzweig and Hillel 2000), and increased erosion as a result of increased precipitation (Kundzewicz et al. 2007). Indirect changes will occur with the impact of climate change on the plants, in particular on root growth and root architecture, because of the role rhizo-deposition plays in moving organic matter from the roots into the soil. The majority of studies suggest that eCO_2 is likely to increase the flow of organic substrates into the soil, through increased root production (Pritchard 2011).

Soil organisms will be influenced directly and indirectly by changes in the climate. The impact of elevated eCO_2 is likely to vary depending on the organisms, with studies showing the general response to be a shift from fungal to bacterial-dominated soil food webs, and a promotion of mycorrhizal and nitrogen-fixing relationships (Pritchard 2011). Increasing precipitation, in contrast to CO_2 enrichment, generally favours the fungal component of the soil food web which could mean increases in soil-borne fungal diseases. Responses to changes in precipitation are influenced by vegetation; for example soil biota are less limited by drought, and probably

10 http://pidp.org/archive/2010/February/02-01-16.htm

more limited by carbon availability in non-forest ecosystems compared with forest ecosystems, where the soil biota population is severely restricted by low precipitation (Blankinship et al. 2011). Wetter soils will tend to favour a high microbial diversity, rapid microbial turnover rates, high rates of decomposition, and more robust populations of soil meso- and macro-fauna compared with dry soils (Wardle 2002).

The effects of warming, however, are highly variable and have only been investigated over relatively short exposure durations (Staddon et al. 2002), therefore failing to capture the long-term responses of soil biological processes that may be found in agricultural fields under cultivation for some time (Pritchard 2011). Some studies suggest that warming will favour a shift from a bacterial- to a fungal-driven food web (Wardle 2002) and that effects will be most significant on the larger soil organisms such as surface-dwelling earthworms (Pritchard 2011).

Understanding how the soil and soil organisms will respond to climate change is a huge task, and as the studies to date have shown, responses can be extremely variable. Strengthening the resilience of the soil can only serve to enhance its buffering capacity and improve its stability. It is worth noting the research by Li et al. (2009) which showed that the incorporation of plant residue into the soil had a greater effect on nematode abundance and diversity than exposure to eCO_2 in FACE-grown wheat and sugar.

Building compost in Kiribati to improve the soil Photo: Richard Markham

In summary, an integrated landscape approach that incorporates climate-smart agriculture, provides the best approach for ensuring the ecosystem services essential for agriculture are nurtured and that any negative impact from agriculture is minimised.

3.7 Effects of climate change on pests, diseases and invasives

Pest damage accounts for an estimated loss of 10–16% in global crop production costing approximately USD 220 billion (Chakraborty and Newton 2011). Post-harvest losses of an estimated 6–12% are additional and particularly high in tropical climates, often due to weak infrastructure (Agrios 2005). In the Pacific, pre-harvest losses for vegetables are estimated to be in the range of 15% (capsicum, beans) to >50% (tomatoes), with post-harvest losses around 10%, as vegetables are consumed soon after harvest. For root crops, losses are estimated at 20–25% pre-harvest and another 15% post-harvest (Jackson pers. comm.).

Fungi and oomycetes are responsible for losses from major crops that would feed 8.5% of today's population (Bebber et al. 2013). Although much of this information on losses is based on limited data that have not been systematically collected, it does provide some indication of the extent of crop loss (Flood 2010). Further, in addition to the huge diversity of organisms that exists, new pathotypes continue to evolve and be disseminated, many of which can be highly virulent and invasive, such as the strains of rusts *Puccinia graminis* and *P. striiformis*, and the new lineage of *Phytophthora infestans*, which has quickly replaced other late blight genotypes (Bebber et al. 2013).

The spread of crop pests and pathogens is facilitated primarily by human transportation; however, evidence suggests that climate change is also likely to be an effective dissemination mechanism. Bebber et al. (2013), in their analysis of data, demonstrate a poleward shift of many taxa, supporting the hypothesis of global warming-driven pest movement. As pest and disease incidence and distribution are influenced by temperature and precipitation patterns, projected changes in the climate are likely to have an impact, with potential for new threats from pathogens or pests that are considered unimportant today, and the possibility of current problems being reduced or eliminated.

The interactions between crops, pests and pathogens are complex and not well understood in the context of climate change (Gregory et al. 2009). Many of the projections available for crop yield under a changing climate ignore the impacts of pests and diseases, despite the knowledge that plant diseases are influenced by the weather and that short-term weather data often guide disease management. Limited empirical knowledge is available regarding climate change impact on pests and pathogens, with projections mostly based on modelling studies. Furthermore, multifactor studies investigating climate change effects on tropical and plantation crop diseases are also lacking (Ghini et al. 2011).

The productivity of agricultural pests and diseases is influenced by temperature and precipitation. Generally insect ecology, epidemiology and distribution will be affected by temperature; for example, increased temperatures will accelerate generation time[11]. Plant pathogens tend to be more affected by humidity and rainfall patterns (Jarvis et al. 2010); however, temperature will also influence the survival of

11 Length of time between different life cycles.

inoculum, rate of disease progress, and the length of any epidemic. Temperature and precipitation will also affect leaf wetness, which will influence pathogen infection (Jackson pers. comm.). The impact of a higher minimum temperature and humidity on taro leaf blight disease is discussed in Chapter 4.

Rainfall patterns can influence pests and diseases in a number of ways; for example, through the effect of drought on the resistance of crops to specific diseases and/or the increased pathogenicity of organisms (Gregory et al. 2009). Severe storm events have the potential to support the spread and establishment of pests and diseases in new areas. Epidemics of late blight in potato crops in Canada in 1994–1996 were due to unusual tropical storm tracks moving up the eastern seaboard of the USA (Peters et al. 1999). Rainfall was a contributing factor in the establishment of bacterial crown rot in papaya in the Kingdom of Tonga (Fullerton et al. 2011), and oomycetes in the genera *Phytophthora* and *Pythium* have been shown to cause the greatest damage to roots in poorly drained soil (Rao and Li 2003).

Pests and diseases could become more problematic at the post-harvest and storage stage with a warming climate. Increased reproduction of pests and diseases will lead to a more rapid build-up of insects and fungi in stored produce. Wet and hot spells at harvest time have been shown to increase the concentration of mycotoxins (Paterson and Lima 2010) affecting crops such as peanuts and maize (Cotty and Jaime-Garcia 2007).

In the Pacific region, pests and diseases are highlighted as one of the major problems farmers have to address (HOAFS 2010), yet information regarding many of these pests and diseases is limited, let alone how they will be affected by climate change. Understanding how climate change will affect those pests and pathogens considered to be a significant threat is essential.

Table 3.3 lists the pests and diseases that affect the crops discussed in this publication, and suggests how variable rainfall and a warming climate will impact on these pests and diseases.

3.7.1 Viruses

Virus vectors are relatively sensitive to temperature change and could already be close to their optimal temperature. Therefore, increasing temperatures could see a decline in the importance of some viruses in the tropics. This threshold sensitivity could be particularly significant for *Papaya ringspot virus,* transmitted by various species of aphids (Ghini et al. 2011).

Table 3.3 Effects on pests and diseases in relation to variable rainfall* (source: Jackson pers. comm.).

Crop	Pest & Disease (P&D)	Effects on P&D in relation to variable rainfall			Comment
		Increase in P or D with more rainfall	Decrease in P or D with less rainfall	Impact unknown	
1. Aroids	*Phytophthora colocasiae*	√			Increase at higher altitudes as they warm
	Alomae and Bobone		√		Increase population of insect vectors (*Tarophagus*)
	Papuana beetle			√	
	Tarophagus species		√		Effect of drought on parasitoids (*Cyrtorhinus* egg predator)
	Pythium	√			Both taro and *Xanthosoma*
	Spodoptera litura	√			Negative effects on parasitoid population by cyclones
2. Sweet potato	*Cylas formicarius*		√		Population increases during droughts
	Euscepes postfasciatus		√		Population increases during droughts
	Viruses		√		Droughts may increase begomovirus, whitefly vector
3. Cassava	None				
4. Yams	*Colletotrichum gloeosporioides*	√			Increased disease if cyclones more intensive
	Pratylenchus coffeae		√		
5. Breadfruit	*Phytophthora palmivora*	√			
	Phellinus noxius			√	
	Bactrocera frauenfeldi			√	Complex: Probably rainfall will cause increase, and very high rainfall decrease in populations.
6. Banana & plantains	*Mycosphaerella fijiensis*	√			
	Banana bunchytop nanovirus		√		Increase population of insect vector (*Pentalonia*)
	Fusarium oxysporum f.sp. *cubense*	√			
	Cosmopolites sordidus			√	
7. Coconut	*Oryctes rhinoceros*		√		Probably less impact by *Metarhizium*
	Scapanes australis		√		Probably less impact by *Metarhizium*
	Brontispa longissima		√		Effect of droughts on parasitoids
	FDMT (Vanuatu)		√		Increase population of insect vectors (*Mindus* sp.)
	Bogia (PNG)			√	Pathogen & vector unknown
8. Sugar cane	*Fiji disease virus*		√		Increase population of insect vectors (*Perkinsiella*)
9. Coffee	*Hypothenemus hampei*			√	Increased generations due to temperature
10. Cocoa	*Conopomorpha cramerella*			√	
	Phytophthora palmivora	√			
11. Oil palm	*Ganoderma*			√	
12. Mango	*Bactrocera frauenfeldi*			√	See 5. Breadfruit
	Colletotrichum gloeosporioides	√			
13. Pineapples	Pineapple wilt disease		√		Increase population of insect vector (*Dysmicoccus*), which in turn will be affected by ants
14. Tomato	*Helicoverpa armigera*			√	Higher temperatures will decrease generation times
	Phytophthora infestans	√			Worse in highlands
	Alternatria solani	√			
15. Cucurbits	*Didymella bryoniae*	√			
	Bactrocera cucurbitae			√	See 5. Breadfruit
16. Kava	Cucumber mosaic cucumovirus		√		Influence on aphid vector (*Aphis* spp.)
17. Betel nut	*Brontispa longissima*		√		Effect of drought on parasitoids
	?Phytophthora sp. (Markham)	√			Not proven
	?Viroid (Reef Islands, Solomon Islands)			√	Transmission unknown

N.B *It is assumed that average annual temperature will increase as projected (Chapter 2).

Symptoms of *Papaya ringspot virus* Photos: Grahame Jackson and George Wall

More than 50% of all known plant viruses are transmitted by aphids. For example, *Pentalonia nigronervosa* (banana aphid) is responsible for the transmission of *Banana bunchy top virus* (BBTV). Under eCO_2, aphid species respond differently, highlighting the complexity of relationships between plant and pest. In studies on soya bean, O'Neill et al. (2011) found that eCO_2 reduced stomatal conductance and as a result, leaf temperature increased, which significantly enhanced the population growth of the aphid, *Aphis glycines*. In contrast, Chen et al. (2004), studying spring wheat and the aphid *Sitobion avenae*, found that both plant and insect benefited from eCO_2. Chen et al. (2005), investigating the response of plant, predator and pest using transgenic cotton and *Aphis gossypii*, showed that in this case the predator benefitted from eCO_2. A combination of higher temperatures and rainfall intensity has led to an increase in the numbers of whitefly, *Bemisia tabaci*, the vector of cassava mosaic virus, which can have a significant impact on production and yield (Chancellor and Kubiriba 2006).

3.7.2 Fungi

The challenge of predicting the effect of eCO_2 on unstudied pathosystems is highlighted in a review by Chakraborty et al. (2000). Their studies showed that disease severity increased for six of the ten biotrophic[12] fungi studied, but decreased for the other four. Similarly, for the 15 necrotrophic[13] fungi studied, nine showed an increase in disease, four showed a decrease and the response of the remaining two was unchanged.

The fecundity of *Colletotrichum gloeosporioides*, a significant pathogen in the tropics causing anthracnose in a wide range of crops including yam, mango and papaya, has been shown to increase under eCO_2 (Chakraborty and Datta 2003). Considerable variation does occur in culture and host range; some strains target a single species, such as those infecting mango, whereas others can attack many host species (Hayden et al. 1994). Crop canopy can significantly influence the dynamics of the disease. Within a large and dense canopy, conditions such as high relative humidity, reduced wind flow and limited penetration of solar radiation would favour disease development. A large canopy would also hold more infection sites and significantly more pathogen propagules, which could lead to an increase in population size (Pangga et al. 2011). Higher rainfall is also likely to increase the incidence and intensity of this disease, as will increased intensity of cyclones.

12 Organism that requires a living host to complete development.
13 Fungi that derive their nutrients from dead organic matter.

Higher temperatures will increase the reproduction rate of the root rot pathogen (*Monosporascus cannonballus*) of melons and watermelons (Waugh et al. 2003). Increasing temperatures could, however, see a gradual reduction in black leaf streak disease (Ghini et al. 2008), as the maximum temperature threshold for the fungal disease is exceeded, (assuming it does not adapt to changing conditions). However, with increasing temperatures, the disease may also be able to expand its range and spread to highland areas currently free of the disease, replacing the less damaging yellow Sigatoka.

Anthracnose on yams Photo: Grahame Jackson

A study of powdery mildew on wheat shows how non-climate factors can influence the severity of a disease within a changing climate. Under eCO_2 disease severity was reduced; however, with increasing leaf nitrogen concentrations, mildew levels increased but reduced with increased leaf water content. The authors suggested that eCO_2 caused nitrogen levels to decline and water content to increase and it was in fact the latter that had the greatest influence on the mildew severity (Thompson et al. 1993).

Increases in minimum night time temperature have been linked to the spread of taro leaf blight (TLB), and therefore, the projected temperature increases do present risks for those countries where the disease is currently not present (e.g. Cook Islands, Fiji, Tonga and Vanuatu). For those countries where TLB is present, the disease could increase in severity. This potential for TLB to spread is further discussed in Chapter 4.

3.7.3 Bacteria

Elevated CO_2 concentrations affect the physical and chemical quality of potato tubers, with levels of 550 ppm increasing the occurrence of common scab (caused by a seed- and soil-borne bacterium, *Streptomyces scabies*) by 134% (Singh et al. 2013). Sweet potato scab caused by *Elsinoe batatas* might also be encouraged under eCO_2. *Ralstonia solanacearum* complex bacteria, which cause bacterial wilt of crops such as tomato and eggplant, are highly weather-dependent, with hot and humid conditions supporting their fecundity and spread (Ghini et al. 2008). Tobacco plants growing in Nadi, Fiji can be heavily infected by *R. solanacearum* during the hot, summer months, whereas in the relatively cooler winter months, the bacteria are not detectable (Davis pers. comm).

3.7.4 Pests

Climate change will affect the distribution and degree of infestation of insect pests directly, by impacting on the life cycle, and indirectly, by the impact of climate change on hosts, predators, competitors and insect pathogens. The life-cycle processes affected by climate and weather include lifespan duration, fecundity, diapause[14], dispersal, mortality and genetic adaptation (Reilly et al. 2007).

Radopholus similis is an important nematode pest of bananas in the Pacific, first identified in Fiji in 1891 (Jackson et al. 2003). *R. similis* has over 350 hosts, which include citrus, black pepper, ginger, coconut and other tropical palms (Brooks 2008). Sensitivity to temperature hinders its establishment at high altitudes and latitudes; however, increases in temperature could encourage its spread (Masters and Norgrove 2010). Corm rot in swamp taro corms caused by *R. similis* has also been reported in Yap, Federated States of Micronesia (Murukesan et al. 2005).

A study in Brazil indicated that the incidence of coffee leaf miner and nematodes (*Meloidogyne incognita*) was likely to increase by 4, 32 and 61% in 2020, 2050 and 2080 respectively, under high emission scenarios, due to a greater number of generations per month than occurred under 'normal' climate conditions experienced between 1961 and 1990 (Ghini et al. 2008).

Sweet potato weevil Photo: SPC

14 Diapause is a suspension of development that can occur at the embryonic, larval, pupal, or adult stage, depending on the species.

Drought could increase plant carbohydrate levels such that host plants are more attractive to insects (Ziska et al. 2010). One of the most significant pests of sweet potato is sweet potato weevil (*Cylas formicarius*), and losses of 60 to 100 % in crop yield have been reported during periods of drought. Drought increases weevil feeding but reduces larval survival, therefore, the timing of the drought period could either increase or decrease the damage caused by this pest. The response may also vary with genotype, highlighting the importance of genotype selection and diversity in managing pest problems (Mao et al. 2004).

As demonstrated by the severe outbreak of taro cluster caterpillar or armyworm (*Spodoptera litura*) that occurred six months after Cyclone Val hit Samoa, drought conditions that can exist after a cyclone can increase the feeding behaviour of pests (Jackson pers. comm.).

Taro armyworm *Spodoptera litura* Photo: SPC

The importance of considering how pests or pathogens are affected when making climate change projections for crop performance is illustrated by an example from arable agriculture. Crop biomass is generally predicted to increase with eCO_2; however, nitrogen availability could be a constraint to any potential yield benefits. Legumes respond positively to eCO_2 as does the soil-dwelling *Sitona* spp weevil. Staley and Johnson (2008) found that the root nodules of white clover became more numerous and larger in size with eCO_2 but at the same time larger populations of the weevil were found, resulting in damage to the root nodules and a decrease in the availability of nitrogen for the crop, therefore limiting any impact from CO_2-induced growth. This example also highlights the complexity involved in analysing the impact of climate change on pests in agro-ecosystems, reinforcing the need for system-specific risk assessments that focus on all the components and potential interactions in the system.

3.7.5 Weeds

Weeds are also likely to benefit from the eCO_2 and from improved water-use efficiency associated with eCO_2, but the subsequent effect on crop production will vary depending on the species involved. Most weeds of tropical agriculture originate in tropical areas and therefore are responsive to small increases in temperature. For example, the growth of three tropical leguminous weeds increased significantly with rising day/night temperatures (Flint et al. 1984). C_4 grasses have also showed large increases in growth rates, which would affect pasture quality (Patterson, 1993). However, as a study on a C_3 crop, rice and a C_4 weed, barnyard grass, showed, this is not always the case. In this study, eCO_2 (extra 200 ppm) improved rice productivity, such that the authors concluded that 'rising atmospheric CO_2 concentration could alter the competition between rice and barnyard grass in paddy fields in favour of rice' (Zeng et al. 2011).

The effect on weed management is also likely to be influenced by changing climate conditions. The high leaf starch concentrations observed in C_3 plants grown under eCO_2 might interfere with herbicide activity, but on the other hand, warmer temperatures would favour increased uptake, translocation and effectiveness of many herbicides (Reilly et al. 2007).

3.7.6 Invasive species

Climate change will affect the distribution, spread, abundance and impact of invasive species, which could have serious consequences for agro-ecosystems (Gritti et al. 2006). Invasive species have characteristics such as broad environmental tolerances and short maturation time, which help their invasiveness and ability to adapt to climate change.

Climate change can strengthen the invasive nature of a species in several ways: through the establishment of new and suitable environments; through bringing about a change in the hierarchy of an ecosystem so that different species become dominant; and through stressing the ecosystem so that invasive pathways are created (Masters and Norgrove 2010). Cyclones create opportunities within an ecosystem that quiescent invasive species can exploit, resulting in a significant expansion of territory and invasions of ecosystems. Surveys of Niue after Cyclone Heta found that invasive plant species, already present on the island, had become more abundant and had expanded their range before native flora could recover (Space et al. 2004).

Table 3.4 summarises the extent of known alien species (the majority of which are flora species) in the Pacific, that are known to have spread and had a negative impact on the ecology, those that are potentially invasive, and others that have been introduced but without record of their spread or impact.

Invasive pests in a new environment are limited more by climate than by biotic interactions, and therefore it could be argued that some invasive species will be at a disadvantage in such a 'new' environment, but no evidence exists to support this argument. Invasive species do not merely have the capacity to replace native species; they can also change relationships between predators and pathogens, for example, by acting as reservoirs for pathogens and increasing pathogen pressure.

Table 3.4 Number of alien species, classified into three categories – introduced (no impacts or spread recorded); invasive and potentially invasive (source: SPREP 2012).

	Invasive	Potentially invasive	Introduced (no impacts or spread recorded)	Total alien species
America Samoa	40	156	1	197
Cook Islands	161	59	3	223
Fiji	33	497	105	635
FSM	22	385	45	452
French Polynesia	201	253	139	593
Guam	40	447	105	592
Kiribati	42	158	16	216
Marshall Islands	66	238	218	522
Nauru	23	261	200	484
New Caledonia	9	462	159	630
Niue	46	287	16	349
Northern Mariana Islands	26	92	1	119
Palau	61	370	35	466
PNG	17	385	112	514
Samoa	56	328	16	400
Solomon Islands	25	316	55	396
Tokelau	3	39	0	42
Tonga	39	378	8	425
Tuvalu	2	73	4	79
Vanuatu	23	172	20	215
Wallis & Futuna	31	225	61	317

3.7.7 Livestock

Climate change may affect the vectors of animal diseases and also those diseases associated with water, which could be exacerbated by flooding and poor access to water. Reviews by Baylis and Githeko (2006) and Thornton et al. (2009) present the various ways in which pathogens, hosts, vectors and epidemiology can be affected by climate, such as temperature and rainfall. For example, higher temperatures may support the development of larger populations of pathogens and parasites that spend some of their life cycle outside their host. On the other hand, any organisms sensitive to temperature increase may be at a disadvantage. The distribution and abundance of disease vectors may be affected by changes in rainfall and temperature. For example, the ability of disease vectors to become or remain infected with viruses, such as bluetongue, has been shown to vary with temperature. The reports in the literature highlight the considerable gaps in knowledge concerning many diseases of livestock that exist now and also with regards to the impact of climate change (Thornton 2010).

3.7.8 Disease management

Climate change will also affect disease management with regards to the efficacy of the various forms of control methods and their use within an integrated pest or crop management strategy. For example, synchrony between the development and reproduction of potential biocontrol agents and invasive species is unlikely to be maintained with an increasing incidence of climatic extremes. Current knowledge is limited; therefore understanding what effects are likely is difficult. A number of studies have, to date, indicated a decline in herbicide efficacy in response to eCO_2 and/or temperature for some weed species, both C_3 and C_4 species (Archambault 2007; Manea et al. 2011). In some cases the mechanisms are understood. For example, eCO_2 results in a greater biomass with the Canada thistle (*Cirsium arvense*), thus reducing the impact of the herbicide (Ziska 2010).

A review by Juroszek and von Tiedemann (2011) considers the various plant disease management tools from quarantine to systemic fungicides and suggests how these will be affected by climate change, and the potential of these tools for adaptation (see Table 3.5).

In conclusion, the authors highlight that farmers have used a wide range of tools over the years to manage plant diseases. Climate change will require not only the continued use of these tools but also ongoing adaptation and improvements which will be guided by an 'improved understanding of drivers of disease cycles, epidemic development and host responses to enable farmers and advisors to respond to a changing climate'. They further emphasise that 'diverse, flexible and resilient crop production systems will be needed, even more than today, that can cope more readily with conditions in a changing environment'.

Table 3.5 Some assumptions on the potential influence of changing atmospheric composition and climate on selected plant disease management strategies/tools[15].

Control strategy	Tool	Expected effects of climate change	Potential of tool for adaptation
Avoidance	Barrier to entry/ quarantine	Change in pathogen dispersal – frequency, abundance, distance, speed	Altered efficacy of quarantine practices
Preventive	Crop rotation	No direct effect – diversity in cropping systems will remain important	Crop species better adapted to local climatic conditions may be required
Preventive	Plant residue management	Potential increase in crop biomass from eCO_2 unless high temperature and drought act as counterbalance	Innovative approaches needed to reduce the inoculum level and saprotrophic colonization
Preventive	Sowing/planting date	Adjustments likely to be necessary – simple and cheap way to manage biotic and abiotic stresses, but disadvantages are also possible	Apparently a powerful tool but could have limitations
Preventive	Host-plant resistance	Temperature-dependent resistance may be overcome by pathogens; changes in plant morphology and physiology with effects on resistance; potentially accelerated pathogen evolution may erode disease resistance prematurely	Altered efficacy of host-plant resistance
Preventive	Cleaning machinery and tools	Presumably no major effects	Phytosanitary methods will remain important
Preventive	Use of healthy seeds and plantlets	Presumably no major effects	Clean planting material will remain important
Preventive	Input levels, e.g. irrigation	Higher temperatures likely to encourage, where possible, increased use of irrigation	Water conservation may demand efficient technologies such as bucket harvesting, drip irrigation
Preventive/curative	Field monitoring and use of decision support systems (DSS)	Presumably no major effects	Will become more important
Preventive/curative	Soil solarisation	Increased temperatures could increase use where appropriate	Altered efficacy, generally positive, unless drought acts as a counterbalance
Preventive/curative	Antagonists, biological control agents (BCAs)	Likely that vulnerability of BCAs will be higher as a result of climate variability	Altered efficacy dependent on product, environment and management
Preventive/curative	Contact fungicides	More frequent rainfall could mean more applications, faster/slower crop growth may shorten/lengthen the time between applications	Altered efficacy dependent on product, environment and management
Preventive/curative	Systemic fungicides	More knowledge required on foliar uptake to make reliable predictions	Altered efficacy dependent on product, environment and management

15 Source: P Juroszek and A von Tiedemann 2011.

3.7.9 Summary

Projecting the impact of climate change on crop pests and diseases and their management is difficult. Interactions between plants, insect pests and pathogens are complex, and it is uncertain how these interactions are likely to evolve as climate changes. In PICTs, the situation is further complicated by limited information on pests and diseases. Most countries have poor records of what are present and their economic significance.

If PICTs are to manage pests and diseases in the face of climate change a meaningful start would be to improve soil health and crop diversity within an integrated pest management framework. Many crop pest and disease problems are linked to intensification of land use and declining soil fertility, and crop diversity is important as it can contribute to broad genetic variation. Improvements to both soil fertility and crop diversity could provide resilience and adaptability to whatever climatic changes occur. The challenges now are twofold: first, to strengthen the capacity of farmers to monitor pests and diseases and to better understand life cycles of major pests and diseases, environmental interactions, and available pest management options; and, secondly, to increase research capacity and research-extension linkages to provide technical support.

3.8 Impact of climate change on water management and agriculture

Survival of Pacific communities is fundamentally linked to the state of their freshwater resources, whether these occur as rivers and streams, underground aquifers, or rainwater collected from roofs. These resources are essential for basic human needs such as drinking, washing and cooking, and are also vital for agriculture in all its forms. Across the region, self-sufficiency (subsistence) and commercial agriculture have been developed and have progressed on the basis of freshwater availability. While irrigated agriculture is relatively minor in the Pacific, agriculture remains the region's predominant user of water, estimated to account for approximately 60% of average annual freshwater withdrawals (ADB 2011).

The dependency of Pacific agricultural production on rainfall exacerbates the vulnerability of this sector to changes in rainfall patterns and to the frequency and intensity of extreme weather events such as droughts or storms. The consequences of such impacts are particularly severe in low-lying atolls, where agriculture is already under stress due to poor soil, limited available land, and water scarcity. Lacking access to rivers and streams, atoll communities rely completely on either rainwater harvested from roofs, thin and fragile groundwater reserves, or a combination of both. The relatively small reserves of freshwater associated with household tanks and thin groundwater lenses are highly susceptible to the impacts of drought. Near-shore aquifers are also particularly vulnerable to the impacts of saltwater intrusion caused by the combination of sea-level rise, increased risk of storm surge, and over-extraction.

Managing the water-related impacts of climate variability and climate change requires a risk-based approach, and adaptation to these impacts requires integration of effective risk reduction strategies across all sectors, including agriculture. By taking an integrated land use approach (such as ridge-to-reef, landscape), sustainable agricultural practices can be a part of the solution in strengthening the resilience of freshwater resources to the impacts of climate change. Improving water-use efficiency through cost-effective technologies and management practices can reduce pressure on water resources while improving agricultural productivity. Appropriate application of fertilizer and pesticides, and the careful management of agricultural wastes such as piggery waste, can dramatically reduce pollutant loads to aquifers, rivers and coastal waters. Water conservation approaches such as eco-sanitation can also have direct benefits to agriculture, as demonstrated by the use of composting toilets in atoll environments, saving precious drinking water while also providing a valuable source of organic material for community gardens.

Water shortage during Tuvalu drought Photo: Fereti Atumurirava

3.9 Indirect impacts of climate change on agriculture and forestry

Increasing frequency and severity of extreme weather will affect pre- and post-production agriculture. More frequent extreme weather events occurring under climate change will damage infrastructure (roads, storage and processing facilities), with detrimental impacts on food storage and distribution. The damage to agriculture infrastructure during Cyclone Evan (Samoa) was estimated at USD 3.5 million (Government of Samoa 2013).

Increasing temperatures will affect the performance of traditional food storage systems and add an extra cost if storage involves air conditioning or refrigeration. Storage rots, as previously discussed, are likely to become more of a threat with increasing temperatures, especially if facilities are damaged or lost.

As is visibly evident after extreme events, transportation systems can be seriously affected, but determining the impact of such events is hindered by a lack of integrated assessments, either nationally or globally (Jaroszweski et al. 2010). Weakened and damaged transportation systems impair the availability of and access to inputs, such as planting materials, fertilizers, pesticides, and the delivery of produce to markets. Failure to deliver produce on time can result in significant financial loss to farmers, which in turn can discourage participation in the agriculture sector. The extent of the damage to infrastructure will be influenced by the quality of the infrastructure and by preceding climate conditions. Recovery time between events will also be a critical factor for the resilience of infrastructure.

Infrastructure damage from cyclone Evan, Samoa Photo: Tolo Iosefa

Repairing damage to infrastructure is likely to mean that farmers have limited funds available to invest in their farms, and income is also likely to suffer if climate conditions result in low yields and poor quality produce. Similarly, government support for agriculture could be reduced because funds would have to be redirected elsewhere. At the consumer end of the chain, spending could also be reduced, with personal income being used to repair housing, for example, or merely because of general uncertainty.

Climate change could also affect the health of the agriculture workforce; human productivity is a function of comfort and the physiological limits of the human body (Kjellstrom 2009). For example, young agricultural workers in El Salvador and Nicaragua have a high rate of chronic kidney disease. Dehydration resulting from manually cutting cane in the sun every day for 6–8 hours for 3–5 months has been recognized as one of the causes (Chambwera et al. 2011). Prolonged spells of hot and wet weather are also likely to increase the incidence and intensity of existing diseases, such as malaria, which affects PNG, Solomon Islands and Vanuatu, and dengue, which is particularly important for Fiji and New Caledonia (Rodgers 2009). The impact of these diseases on the economy of a small country can be significant, as noted by a World Bank study (World Bank 2000), which calculated that the cost of the dengue epidemic in Fiji in 1998 was USD 3–6 million. How climate change affects the wellbeing and health of the Pacific population needs to be considered when assessing the vulnerability of agriculture to climate change.

3.10 Conclusion

Despite the uncertainty that exists regarding the magnitude of climate change, what is certain is that agriculture is facing significant challenges in the coming years from climate change. The findings of the Fifth Assessment Report (AR5) of the IPCC confirmed that climate change is affecting agricultural production now (Vermeulen et. al. 2014). As discussed in Chapter 2, for the Pacific, an increase in mean temperature is confidently projected; however, the impacts on productivity may depend more on the magnitude and timing of extreme temperatures, especially in the short to medium term. Regional rainfall projections are less confident but there will be an increase in average rainfall over much of the Pacific, and after 2030, patterns will emerge, the impact of which will be determined by the emission scenario. As with temperature, it is the extreme rainfall events that are likely to cause the most damage to agriculture in the short to medium term. Mean sea-level rise is also confidently projected, but the impacts from storm surges and the flooding that follows are likely to be greater and less predictable. The projected increased intensity of cyclones poses a very significant threat to those countries vulnerable to cyclones.

The nature of climate change and the lack of data that exist regarding its impact, for example, on pests and diseases, and the time lag that exists between research and development and widespread application, mean that action will need to move ahead of knowledge, with decisions made and reviewed on the basis of emerging research and consensus. It is thus important to recognise and address the problems that exist with current production systems (such as declining soil health and fertility and lack of diversity) now, and ensure that any new initiatives are developed around sustainable, climate-smart practices. The approach has to be learning by doing, putting in place 'no/low regrets' actions that will reduce risks now and also support and promote future adaptation. At the same time research must be conducted to address the knowledge gaps outlined in this chapter, which are further discussed in later chapters. Research must aim to improve our understanding of the uncertainties, to allow more confident decision-making and allocation of resources. Finally, an integrated landscape or ridge-to-reef approach can help to target adaptation and mitigation goals simultaneously, and at the same time ensure improvements in livelihoods, productivity and other ecosystem services.

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Photo: Andrew McGregor

Chapter 4

Vulnerability of staple food crops to climate change

Andrew McGregor, Mary Taylor, R. Michael Bourke and Vincent Lebot

Contents

4.1 Background

This chapter focuses on the potential impact of climate change on Pacific Island staple food crops; that is, those food crops that dominate diets in the Pacific Island Countries and Territories (PICTs), provide a major proportion of energy and nutrient needs and are vital for food security. The production of food staples is the dominant agricultural activity, for both household self-sufficiency and income generation. Factors that impact on staple food production will have a profound influence on livelihoods and the economic wellbeing of the region.

In the region there is no longer a clear distinction between self-sufficiency and cash crops. Purely subsistence gardening is now rare and confined to remote Melanesian custom villages. Self-sufficiency farming is, however, common, particularly in Melanesia, although some traditional crops are also important commercial crops, such as taro and kava. Similarly, no clear distinction exists between self-sufficiency food crops and commercial tree crops. Coconuts contribute significantly to subsistence in all PICTs, and, in the form of copra, have historically been the most important export product. Breadfruit has also been an important starchy staple crop and is now sold into local markets and exported.

4.2 The Pacific Island staple food crops

The order of importance of locally produced staple food crops in terms of total calories supplied is: sweet potato (*Ipomoea batatas*), banana (*Musa* species), cassava (*Manihot esculenta*), taro (*Colocasia esculenta*), cocoyam (*Xanthosoma sagittifolium*), swamp taro (*Cyrtosperma merkusii*), giant taro (*Alocasia macrorrhiza*) and yams (*Dioscorea* spp.). Coconuts (*Cocos nucifera*) and breadfruit (*Artocarpus altilis*) are also important staples. *Abelmoschus manihot* (aibika, bele, island cabbage, slippery cabbage) is included in this chapter because of its widespread use in Melanesia and its nutritional value. Coconuts are also treated as an export tree crop and addressed in Chapter 5.

Much of the data presented in this chapter is from Melanesia, in particular Papua New Guinea (PNG) and Vanuatu, reflecting relative resource differences between these countries and others. For crops of more global importance, such as banana and rice, global studies have provided information. As in other chapters, regional experts have been consulted in sourcing information on staple food crops.

4.2.1 Root crops

Sweet potato, kaukau or kumala, is by far the most important food staple for PNG and Solomon Islands, providing almost two thirds by weight of staple food crops in both countries (Bourke and Harwood 2009).

Sweet potato plot, Papua New Guinea Photo: RM Bourke

Sweet potato is also assuming greater importance in Vanuatu's farming systems, although taro, banana, greater yam (*Dioscorea alata*), strong yam (*D. nummularia*), cassava, and cocoyam remain the most important food crops. Sweet potato is less important in Fiji, where cassava and taro dominate, and in the Polynesian countries where taro, bananas, breadfruit and yams are the most important locally grown staples.

The most important pests of sweet potato are weevils, (*Cylas formicarius* and *Euscepes postfasciatus*), which cause significant damage to crops and affect marketable yield. Twenty different viruses have been recorded, with evidence that some viruses result in reduced yields (Kreuze and Fuentes 2008). Leaf scab caused by *Elsinoe batatas* is the most serious foliar disease and although the fungus does not infect the storage roots, yield losses can be as much as 60% in Melanesia (Lebot 2009).

Table 4.1 Estimated PNG consumption of staple foods (2006) (source: derived from Bourke 2013 p. 4).

Food	Estimated quantity		
	tonnes/year	kg/person/ year	% of total consumption
Sweet potato[a]	2,542,000	416	54.6%
Banana	515,000	84	11.1%
Yam (all species)	322,000	53	6.9%
Cassava	321,000	52	6.9%
Taro	276,000	45	5.9%
Chinese taro (cocoyam)	267,000	44	5.7%
Rice (imported)	184,000	30	4.0%
Wheat flour (imported)	107,000	18	2.3%
Sago	98,000	16	2.1%
Irish potato	22,000	4	0.5%
Rice (PNG grown)	1,000	0.2	0.0%
Total	4,655,000	762	

[a] excludes sweet potato that is fed to pigs in the highlands

Taro, the main root crop in Fiji (dalo) and Samoa (talo) is also important in Vanuatu, Tonga (talo), coastal areas of PNG (taro tru), Palau and the Federated States of Micronesia (FSM). Taro was once important in Solomon Islands and in many locations in lowland PNG until decimated by the disease taro leaf blight (TLB) caused by *Phytophthora colocasiae*. *Pythium* corm and root rot, also a serious fungal disease, can cause yield loss of 10 to 100%.

TLB resistant lines, Samoa

Photo: Mary Taylor

Several pests are of significance, namely taro beetle (*Papuana* spp.), taro leafhopper (*Tarophagus* spp), taro armyworm or caterpillar (*Spodoptera litura*), taro hornworm (*Hippotion celerio*) and taro aphids. Taro beetle is one of the most serious constraints to taro yield and quality in Melanesia. Taro leafhoppers, along with aphids, transmit viruses, the most serious being Colocasia bobone disease virus (CBDV) which is widespread in Solomon Islands and in PNG. Alomae disease causes stunting and can prove fatal, and occurs if CBDV combines with *Taro bacilliform virus* (TaBV) (Lebot 2009). Both armyworm and hornworm can occasionally cause spectacular defoliation to the crop but are usually naturally regulated and do not normally require intervention by growers to control them.

Cocoyam , also called tannia, is popular in Fiji (dalo-ni-tana), Vanuatu (Fiji taro), Tonga (talo futuna) and Samoa (talo palagi), and generally is increasing in popularity, due to its relative tolerance to drought, resistance to taro beetle, and immunity to TLB.

Cocoyam, Viti Levu, Fiji

Swamp taro, Anguar, Palau Photos: Andrew McGregor

Swamp taro is important in atoll locations, due to its tolerance of swampy conditions and some degree of salinity (although this appears to be very genotype-dependent), and is grown as a famine food in some other islands. It continues to be important for food security and has significant cultural value, but its value as a staple food crop is declining.

Giant taro is of some importance in Tonga (kape) and Samoa (ta'amu). In Tonga, giant taro was second to yam as a crop suitable for presentation to nobility (Manner 2011a).

Compared with taro, these other aroids are relatively pest- and disease-free. Cocoyam and giant taro can suffer from *Dasheen mosaic virus* (DsMV), and a study conducted in Nicaragua highlighted the yield losses that can occur when cocoyam is infected with DsMV (Reyes et al. 2006). Cocoyam can also suffer from *Pythium*.

Giant taro, Samoa Photo: Tolo Iosefa

Domesticated yam (*Dioscorea* spp.) cultivars remain a pivotal crop in drier lowland locations in PNG, Vanuatu and Tonga. In New Caledonia, although sold in markets in relatively high quantities, yams are considered an important subsistence and ceremonial food (Gaillard and Manner 2010), and at least 65% of Kanak farmers' work time is devoted to yam cultivation. Yams are also an important crop in FSM, especially in Pohnpei and Yap. 'Wild yams' include mostly *D. nummularia*, *D. transversa*, *D. pentaphylla* and any other member of the genus that survives without cultivation and untended in bush locations. In western Melanesia these yams are an important 'wild' food reserve. The lesion nematode, *Pratylenchus coffeae*, is the most important yam pest, with damage to tuber quality affecting market value. Of more significance is the fungus *Colletotrichum gloeosporioides*, responsible for anthracnose disease, which causes blackening and dieback of the foliage; *D. alata* is particularly vulnerable (Lebot 2009).

'Wild' yam grown in food garden, Brenwe Malakula, Vanuatu

Photos: Andrew McGregor

Cassava, Lamlu (Middle Bush), Tanna, Vanuatu

Cassava was introduced into the PICTs in the mid to late 19th century, and its cultivation is increasing almost everywhere in the Pacific. In Tanna, Vanuatu, cassava is by far the dominant crop (Lebot pers. comm.). In most countries, exclusively 'sweet' varieties of cassava (i.e. low in cyanogenic glucosides) are planted, and 'bitter' varieties are absent.

Cassava is eaten boiled or roasted or made into 'laplap', the traditional pudding made from freshly ground roots cooked in folded laplap (*Heliconia indica* Lam.) leaves. Cassava leaves are not consumed in PICTs but are fed to pigs.

Enjoying laplap, Vanuatu

Photo: Andrew McGregor

Average nutrient removal by cassava per tonne of dry matter is lower than that for other major crops (Howeler 2002), and therefore it can be grown where no other crop would provide a decent yield. In addition, cassava roots can be stored in the soil, adding to the contribution the crop makes to the resilience of a food production system. Continuous cultivation of cassava, can, however, lead to breakdown of soil structure after two cycles (Lebot 2009). Although generally free of serious pests and diseases, cassava is affected by white peach scale (*Pseudaulacaspis pentagona*) and cassava red mite (*Oligonychus biharensis*) in Fiji and Solomon Islands, and by spiraling whitefly (*Bemisia tabaci*) in Fiji, Solomon Islands, Samoa and Tokelau (Atumurirava, pers. comm).

4.2.2 Bananas

Bananas (used here in a broad sense to include dessert bananas, cooking bananas and plantains) are a staple food grown throughout the PICTs. In 2006 the total world production was 113 million tonnes, of which 980,000 tonnes were produced in Melanesia, Micronesia and Polynesia (Daniells et al. 2011). Their versatility is evident in PNG where they are cultivated in locations with varying rainfall. Bananas are one of the most significant sources of food energy in the region, and are eaten raw and ripe or cooked at various stages of ripeness. Green bananas are rich in resistant starch, and ripe bananas, in particular those with deep yellow or orange flesh, are rich in provitamin A and other carotenoids (Englberger et al. 2006).

Considerable banana diversity exists in the region with some types such as Fe'i, Maoli, Popoulu and Iholena[1] having their centre of diversity located in the Pacific. PNG is the primary centre of diversity for bananas, being home to ten wild bananas of which one species, *Musa ingens*, is found only in PNG. The wild bananas of PNG are threatened by forest clearing for agricultural developments and/or construction of roads and bridges. The value of wild species in providing traits important for climate change adaptation is widely acknowledged; therefore, putting in place programmes with landowners or local communities to protect their areas from destructive human activities is essential (R. Kambuou pers. comm.).

1 Maoli, Popoulu and Iholena are Pacific plantains.

a = Iholena; b= Popoulu; c = Maoli; d = Fe'i

Photos a, b, c: Anne Vezina, photo d: Jeff Daniells

Although bananas require space and light they are generally grown with a range of other crops, such as coconut in Samoa or coffee in PNG (Daniells et al. 2011). Intercropping has been shown to bring benefits. For example, in Uganda farmers are able to obtain 50% more income from intercropping banana and coffee than from growing either crop alone[2].

2 http://www.cgiar.org/consortium-news/coffee-bananas-a-climate-smart-combination/

Musa ingens, Papua New Guinea Photos: Jeff Daniells

Several pests and diseases are of significant importance in the PICTs, namely black leaf streak disease — also known as black Sigatoka and BLSD, (*Mycosphaerella fijiensis*); *Banana bunchy top virus* (BBTV); Fusarium wilt (*Fusarium oxysporum* f.sp. *cubense*); banana weevil borer (*Cosmopolites sordidus*); burrowing nematode (*Radopholus similis*); and scab moth (*Nacoleia octasema*). Bananas from the Cavendish AAA subgroup are extremely susceptible to BLSD (Vanhove et al. 2012).

4.2.3 Rice

There is a high dependency on imported food, particularly rice, throughout the PICTs. This dependency is lowest in Melanesia and highest in Polynesia and Micronesia. In PNG imported rice is estimated to meet 9% of food energy and protein needs (Bourke and Harwood 2009). For Solomon Islands it was calculated that imported grains contributed 21% of the food energy consumed at the national level (Bourke et al. 2006). In Fiji imported grain makes up nearly 60% of the country's food energy needs (McGregor et.al 2009). In FSM, the value of imported rice increased from USD 2,462,000 in 2000 to USD 5,865, 000 in 2007[3].

Melanesian countries, in the face of high levels of grain imports, have adopted policies to promote local rainfed production of rice. Indo-Fijian farmers have long grown rice in Fiji, and the country is now around 25% self-sufficient in rice. A revitalisation

3 Source: International Trade Publication, 2007: FSM SBOC.

programme has been implemented in the country, the main objective of which is to enhance domestic capacity for local padi rice production for local consumption (Prasad and Narayan 2005). Capital structural improvement works for the Northern Division Irrigation, Navua East Irrigation Schemes and rainfed rice-growing areas are planned, with support from China and Indonesia.

Irrigated rice production, Dreketi, Fiji Photo: Andrew McGregor

The large-scale rice production scheme in Guadacanal, Solomon Islands, established in the 1970s, came to an end in 1986 when the rice farm and mill were severely damaged by a cyclone. It was reported that closure would have occurred without the cyclone because of high production costs, almost uncontrollable levels of insect attack and persistently low yields (Juvik 1987). However, a National Rice Sector Policy, 2010–2015 has been released recommending low-input rice farming methods such as 'system of rice intensification' (SRI), with particular interest in rainfed versions. Memorandums of understanding (MOUs) have already been signed with several NGOs to promote SRI. The white paper calls SRI 'the key to the future of rice production in Solomon Islands.' [4]

Despite the current interest, production response to domestic rice production in the past has been minimal. Bourke and Harwood (2009) note that since independence PNG domestic rice production has never exceeded 1% of rice imports. Basically growers lose interest once high levels of assistance are withdrawn because of low yields and returns. As Mike Bourke notes:

There are flushes of interest in rice from different provinces at various times, but these always die out after about three years. Basically a new group of 'recruits' to rice growing discover that it requires a lot of work for very little return, so they drop out and eventually there are no

4 http://sri.ciifad.cornell.edu/countries/solomonislands/index.html

more potential recruits in that area. We saw a big flush of interest in rice growing in the early 2000s when prices for all export commodities, including coffee, were particularly low. Lots of observers got excited, but there was virtually no rice production in any of these locations by around 2005. But even then, the quantities produced were miniscule compared with kaukau and other crops. PNG villagers live on kaukau, cassava, banana, sago, Xanthosoma taro, a bit of taro tru (Colocasia), with approximately 20% of calories in rural locations typically coming from imported rice, flour, oil, etc. Much more calories in urban locations (approximately 50%) are derived from these imported/processed foods, and less in the more remote locations (pers. comm. June 2013).

Rainfed cultivation necessitates strict weed control in order to achieve reasonable yields and, unless the crop is established on rich soil cleared from the forest, high levels of nutrients in the form of NPK fertilisers are required, which very few small holders can afford. On newly cleared land, two successive crops can be obtained but then soil fertility and weed infestation become major constraints. Rainfed rice cultivation can be a threat to the environment, due to the chemical inputs often required to maintain productivity. In Vanuatu, experiments with rice cultivation have revealed risks associated with high winds (> 20 knots) causing lodging, and damage from rats and birds (Lebot 1987).

The following pests have been reported in Fiji and Solomon Islands: brown plant hopper (*Nilaparvata lugens* Stål), leaf roller (*Marasmia exigua*), and armyworm (*Mythimna separata*) (Atumurirava pers. comm.)

4.2.4 Breadfruit

Breadfruit, the archetypal Pacific food tree, is widely cultivated in PICTs, and is of particular importance in many atoll countries, such as the Republic of the Marshall Islands (RMI). In RMI production of taro and sweet potato has fallen dramatically with increased access to imported staples, but breadfruit is still commonly grown. In urban Majuro, more than 40% of households grow some breadfruit and pandanus (FAO 2010).

Seeded (diploid) and seedless (triploid) forms are cultivated, with the greatest diversity of seedless forms found further east in Polynesia (Ragone 1997), but throughout Oceania many unique cultivars of breadfruit exhibiting diversity in many attributes can be found (Morton 1987; Ragone 1997)[5]. Honeybees visit the male inflorescences of the fertile seeded varieties of breadfruit, as well as *A. camansi*[6] and *A. mariannensis*[7], to gather pollen. Bees also collect the white drops of latex that ooze from the fruit surface. The sap is used as propolis (sealant made from plant saps and resins) in their hives.

5 For example, there are 132 cultivars documented from Vanuatu (Walter 1989), 70 from Fiji (Koroveibau 1967; Morton 1987), 50 from Pohnpei (Raynor and Fownes 1991; Ragone and Raynor 2009), more than 30 from Tahiti (Wilder 1928) and over 40 from Samoa (Ragone et al. 2004).

6 *A. camansi* — wild, seeded ancestral form of breadfruit.

7 *A. mariannensis*, native to Palau and the Mariana Islands and cultivated throughout Micronesia for its edible fruits and seeds.

Photo: Diane Ragone

Bees visiting male inflorescences of flowers of *A. mariannensis*

Breadfruit can be cooked and eaten at all stages of maturity, is high in carbohydrates and also a good source of minerals and vitamins. It is often the primary component of traditional agroforestry systems, grown with crops such as taro (Ragone 2006). In Tahiti, French Polynesia, breadfruit flour is available. Manufacturing is 100% artisanal, and operations began in February, 2013[8]. In Northern Marianas, the government is working with food companies and universities to develop gluten-free flour from breadfruit, based on small-scale breadfruit holdings[9].

8 http://en.tahitipack.com/tahiti/breadfruit-flour-uru-p-294.html

9 http://www.islandsbusiness.com/news/northern-mariana-islands


Photos: Diane Ragone (l) and Jim Wiseman (r)

7 year old *A. altilis* x *A. mariannensis* hybrid, Meinpadahk, (from Pohnpei) (l), Two *A. altilis* fruits, variety Puurea from Raiatea, French Polynesia (r)

The fungi *Phytophthora palmivora* and *Phellinus noxius* cause rots with *P. palmivora* affecting the fruit and *P. noxius* affecting the trunk and root, and eventually killing the tree. *Bactrocera frauenfeldi*, known as the mango fly, can also attack breadfruit. Coconut scale (*Aspidiotus destructor*) has also been reported in Fiji, Solomon Islands and Tuvalu (Atumurirava pers. comm.).

4.2.5 Aibika

Abelmoschus manihot, a perennial shrub, known as aibika, bele, pele, slippery cabbage or island cabbage, is extensively grown in the lowlands of Melanesia. It was once described as 'truly the traditional vegetable for all Melanesia' (Barrau and Massal 1954). Aibika, grown by 62% of the PNG rural population, is the third most important vegetable after corn and pumpkin tips, out of more than 60 vegetables grown and eaten in PNG. Significant diversity exists in New Caledonia, PNG, Solomon Islands and Vanuatu, and collections exist in all countries. Production and consumption is not as widespread in Polynesia and Micronesia, but there is growing awareness of and interest in its nutritional value. A recent ACIAR-funded project on nutritionally rich leafy vegetables[10] found aibika to be the most common leafy green vegetable in gardens in Samoa.

10 Feasibility study on increasing the consumption of nutritionally-rich leafy vegetables by indigenous communities in Samoa, Solomon Islands and Northern Australia.

Aibika collection, Vanuatu Photo: Mary Taylor

Aibika is affected by a number of diseases, with collar rot being the most important. The incidence of the disease increases with high rainfall and poorly drained soil, and can cause serious losses. Large differences in susceptibility to collar rot were found in varieties in East New Britain (Pett and Woruba 1994), and ridging or mounding is recommended for high rainfall areas to reduce losses (Preston 1998). Aerial parts of the plant can also be affected by a stem and tip rot caused by *P. nicotianae* var. *nicotiniae*. Aibika jassid, (*Amrasca devastans)*, is a serious insect pest in PNG, with three adults per leaf sufficient to cause severe damage, and in some cases plant death (Sutherland 1984–5). Leaf roller (*Sylepta derogate*) and tip borer (*Earias vittella*) are also serious pests, with 100% defoliation possible with leaf roller. *Nisotra basselae*, flea beetle, a very important pest in the Solomon Islands and PNG, will attack both young and old leaves. Damage from all these pests is more severe in drier weather (Preston 1998).

4.2.6 Staple food crops and nutrition

Rice and wheat flour have a number of advantages compared with the staple food crops of the Pacific. The costs of feeding a family can be cheaper, they are easier to use and store, and have higher concentrations of carbohydrates. However, they usually contain more fat, are more energy dense, are significantly higher in sodium, and contain virtually no vitamins A and C. A comparison of nutrients in 100 g edible portions of boiled taro and rice can be found in the SPC Pacific Food Leaflet on taro, clearly showing the nutritional benefits that can be gained by consuming taro, giant taro and swamp taro (SPC 2006). These crops also contain higher levels of β-carotene equivalent than rice, an antioxidant that has been shown to play an important role in improving protection against cancer, heart disease, hypertension and stroke (Lako et al. 2007). In addition and importantly, their glycaemic index compared with a food such as rice is much lower, an important consideration for those prone to and suffering from diabetes (Foliaki and Pearce 2003).

4.2.7 Staple food crops as cash crops.

Throughout the region the value of staples for home consumption usually significantly exceeds the value of staple food sold, and this contribution to the household income is not insignificant. In PNG 90% of the rural population live in areas where income is derived from the sale of fresh food, an income second only to that derived from the sale of Arabica coffee (Bourke and Harwood 2009). Household income and expenditure surveys (HIES) indicate that the value of staple food production for sale is increasing across the region (McGregor et al. 2009).

4.2.8 Staple food crops as export crops

For some countries, export of root crops has become an important source of income for rural households. Taro is now Fiji's second largest agricultural export after sugar, with an annual taro export volume in the last few years around 10,000 tonnes; some 17,000 people are directly or indirectly dependent on these exports for their livelihood (McGregor et al. 2012). Taro was Samoa's largest export commodity and primary source of farm income until TLB devastated the industry in late 1993. Tonga currently exports significant volumes of root crops in both fresh and frozen form. From 2004 to 2008, Tonga exported an average of 2729 tonnes of root crops each year, around 7.5% of total production (Ha'unga and Taufatofua 2010).

4.3 The impact of climate change and variability on staple food crops

In addition to the complexity of projecting future climate for specific locations on individual islands, there is the challenge of predicting how particular crops and cropping systems will respond to different climate variables. As Lebot (2013) notes, the extent to which climatic change has already affected and may in future affect agriculture and food systems is being vigorously debated, often without clear conclusions being forthcoming. Not only are we moving to 'new' climate regimes but there is the complexity of multiple stressors and the impact of the recovery time between events. Much uncertainty also exists in the climate projections, the crop model projections and the difficulty of predicting the adaptation pathway that human society will follow.

Most research has looked at the major food crops grown in continental environments. For example, Lobell and Field (2007) found that despite the complexity of global food supply, simple measures of growing season temperatures and precipitation explain approximately 30% or more of year-to-year variations in global average yields for six of the world's most widely grown crops (wheat, rice, maize, soybeans, barley and sorghum). Measuring such impacts becomes more difficult for an archipelago environment where variables such as ENSO have a major influence (Moya and Malayang 2004). Separating out the impact of the micro environments also presents a major challenge for the predictive ability of broader spatial scale models when applied to small island situations. Again, as noted by Lebot (2013), the temperature and rainfall operate within a microclimate where the crops are grown, and this can change significantly between the windward and leeward sides of the same island. A vulnerability assessment study conducted in the Sabeto Valley, Fiji, found that areas lying in close proximity to each other can experience different weather further reinforcing the difficulty in predicting climate at the micro level (SPC/USAID 2013).

Some understanding, however, of how staple food crops will respond to the projected climate conditions can be gained by assessing whether future climate projections will provide conditions outside of optimum production conditions, that is, crop physiological thresholds. This is just the first step. The resilience of these crops cannot be separated from their cropping systems and from the farmers and communities who manage those systems.

4.4 Optimum conditions for the production of staple food crops.

The following section discusses the optimum bioclimatic cultivation conditions for the selected staple food crops and indicates, where known, the responses of these crops if conditions are not favourable to growth and production.

4.4.1 Sweet potato

Locations with high sunshine, an average temperature of 24°C or more, and well distributed annual rainfall of 1000 to 2000 mm are required to obtain the highest yield potential for sweet potato (Lebot 2009). Lebot reports that average yields in temperate countries tend to be higher than in tropical developing countries due more to differences in management than to climate factors.

4.4.1.1 Temperature and rainfall

Spence and Humphries (1972) found that sweet potato produces the greatest increase in storage root weight when grown at a constant soil temperature of 30°C, combined with an air temperature of 25°C at night. Tuber formation is impaired when air temperature exceeds 34°C (Bourke 2013); however, such a temperature is rare in countries where sweet potato is an important staple food crop. The temperature in major growing areas in the PNG highlands can fall below the minimum threshold (10°C), particularly during drought periods, with severe consequences for food security. Substantial areas of production are sub-optimal in terms of rainfall. As noted in the Solomon Islands Smallholder Study (Bourke et al. 2006):

Sweet potato, which is the main staple crop for most people in the SI, is vulnerable to extended periods of wet weather. This was demonstrated by the wet conditions of Sept–Oct 2004, which adversely affected sweet potato production in some areas, for example on the Weather Coast of Guadalcanal, resulting in food shortage.

Despite the low tolerance to high moisture conditions, farmers manage to grow sweet potato in locations with high to very high rainfall, (up to 5000 mm/year), using mounds or drains to reduce soil water levels (Bourke and Harwood 2009).

Newly planted gardens in PNG Photo: RM Bourke

4.4.1.2 Tolerance of extreme climate events

The low growing habit of sweet potato helps the crop to withstand cyclones. Once established, it is also reasonably tolerant of drought, but not to flooding or sea surge. In the highlands of PNG, where sweet potato is the dominant staple, it is susceptible to frosts that accompany ENSO-induced droughts. Sweet potato can play a key role in the recovery of food supplies after a disaster, as a crop can be produced in cool and dry (monthly rainfall around 100 mm) conditions and also when it is hot and wet (monthly rainfall around 200 mm), though faster growth and higher yields are obtained when it is cool and dry. Allen (1997) noted the dramatic change to a sweet potato-dominated cropping system after the droughts of 1941 and 1997 in PNG.

4.4.2 Cassava

Most lowland areas in PICTs are optimal for cassava in terms of temperature but somewhat sub-optimal in terms of rainfall. Cassava, outside of the Polynesian countries, is an important food crop in locations with a wide range of rainfall conditions, and can be planted all year round in locations with no marked seasonality.

4.4.2.1 Temperature and rainfall

The optimal temperature for growth is 25°–29°C but a wide temperature range of 12°–40°C is tolerated. Cassava thrives with annual rainfall of between 1500–2000 mm/year and maximum solar radiation (Lebot 2009). Higher rainfall levels can reduce root growth, but despite this, it remains an important food crop in some very high rainfall locations, such as the PNG lowlands with rainfall around 6000 mm/year.

4.4.2.2 Tolerance of extreme climate events

Cassava is considered highly tolerant of drought, and can be grown where precipitation is 500 mm/year (FAO 2010). However, variation in starch quality can occur depending on the severity of the water stress conditions and stage of plant maturity (Lebot 2009). Drought can reduce yield depending on timing and duration of the drought period, with the impact being greater for immature plants. Under drought conditions, the cyanide concentration found in tubers and leaves can increase, although there is evidence that providing adequate moisture prior to harvest can reduce these levels (Chapter 3). Cassava is particularly susceptible to waterlogging and to high winds (>30 knots) which can cause lodging of the plants. Lodging results in severe root damage which is rapidly translated into root rots and loss of the whole plant. However, farmers anticipating the arrival of a cyclone can cut off the stems above ground level, reducing the damage to the roots. Moreover, the crop can be planted at any time of the year and some varieties can be stored in the ground for two to three years, providing some insurance against more intense cyclones.

4.4.3 Aroids

The lowland windward sides of PICTs usually offer excellent climatic conditions for taro production, although for some varieties disease has become a limiting factor. Cocoyam is more tolerant to drought and sensitive to waterlogging, therefore is better suited to intermediate climate zones in terms of rainfall.

4.4.3.1 Temperature and rainfall

For taro, the preferred temperature for maximum photosynthesis is 25°–35°C, with 30°C optimum. Aroids generally have relatively high water requirements, with taro being particularly demanding. High rainfall is required during the first 20 weeks after planting (WAP), corresponding to maximum leaf development (Lebot 2009). Taro can be highly tolerant of waterlogging, depending on the variety, with some traditional taro cropping systems, for example in the Cook Islands and Palau, using planting in ponds. Taro cannot survive prolonged moisture stress, which seldom poses a problem in traditional food gardens, but can be a serious problem with commercial monoculture production.

Traditional taro planting in Palau Photo: Andrew McGregor

Cocoyam can be cultivated across a wide temperature range, 13°–29°C. In Puerto Rico, 24°C is suggested as the mean annual temperature for successful cultivation. Optimum rainfall is given as 1500–3000 mm per year with an absolute minimum of 1000 mm and an absolute maximum of 5000 mm (Manner 2011b).

The temperature range given for giant taro is 23°–31°C, but the plant is likely to have the same preferences as taro, with 30°C being the optimum temperature. The lower limit for mean annual rainfall is 1500 mm with 5000 mm as the upper limit, although it is not tolerant of waterlogging (Manner 2011a). In PNG giant taro is grown successfully across locations with rainfall of 2000–4000 mm per year.

Swamp taro can be cultivated between 23°–31°C, although temperatures of 38°C (the maximum temperature of the hottest month) have been recorded. For rainfall, a mean annual range is not really applicable; a continuous water supply is required either from rain or other sources to maintain the marshy, swampy land preferred by swamp taro (Manner 2011c).

4.4.3.2 Tolerance of extreme climate events

Taro is highly susceptible to cyclone damage, particularly when there is associated flooding. A mature corm growing in standing water for a few days will rot. The thin leaves and stems are susceptible to tearing in strong winds, although young plants, relatively low to the ground, can have a better survival rate (Iosefa pers. comm.). Even when the corm survives, the quality is likely to be poor and not marketable. Starch starts to break down to support the post-cyclone new growth (suckers and new leaves) resulting in watery corms of poor starch quality. Good rainfall after a cyclone can enhance survival rates; however, an extended dry period is more common following a cyclone[11]. A severe cyclone can upset the pest and disease balance. Six months after Cyclone Val (1992) struck Samoa a severe outbreak of taro caterpillar or armyworm (*Spodoptera litur*a) occurred; disruption to the ecological balance by Cyclone Val is also likely to have contributed to the rapid spread of TLB (McGregor et al. 2011).

Cocoyam is less susceptible to high winds than taro; the cormels will remain edible for up to four weeks after harvesting. The crop can be harvested after 6-12 months, or left standing in the ground for up to 20 months (Lebot 2009). Cocoyam is more tolerant of drought than other aroids, and is also more resistant to pests and diseases. For example, taro beetles do not dig into the soil to reach the cormels, therefore pest damage does not occur.

Saltwater intrusion, Tuvalu Photo: Fereti Atumurirava

11 The assessment report for Cyclone Tomas in Fiji noted the following with respect to taro: For a Category 4 cyclone, losses approaching 100% can be expected for mature (> 5 month) taro planted as a monoculture, unless harvested almost immediately. Taro as a monoculture is the farming system now practiced by most Taveuni farmers. If taro is grown as part of a traditional mixed farming system, a reasonable percentage of mature taro can be expected to survive even with a major cyclone such as Tomas. Seldom is a whole traditional mix-cropping food garden destroyed by a cyclone. The swirling nature of the gusts may mean that a particular garden may miss the full brunt of a cyclone. Furthermore, the bush surrounding some gardens will act as a windbreak. This is not the case with taro from Taveuni, but would be the case in parts of mainland Cakaudrove (McGregor et al. 2010).

Swamp taro can survive a cyclone with limited wind damage but is susceptible to saltwater intrusion (although susceptibility seems to depend on genotype), a likely occurrence post cyclone, as swamp taro pits are usually in low-lying atoll locations and therefore highly vulnerable to sea-level rise and extreme high tides. Drought will also exacerbate the impact from salinity.

Giant taro is susceptible to cyclone damage; the plants collapse, but the corms will support new vegetative growth. Giant taro can be quite tolerant of extended periods of drought. A reduction in leaf area occurs but the plant will resume growth when rainfall resumes.

4.4.4 Yams (*Dioscorea* spp.)

Optimum conditions for yam production in PICTs are found in seasonally dry climates, such as inland East Sepik, or on the leeward side of Vanuatu's northern islands. It is also an important crop in locations with moderate rainfall well distributed throughout the year, such as the northern islands of Milne Bay Province in PNG.

4.4.4.1 Temperature and rainfall

Most yam species generally require temperatures of 25°–30°C for normal development. While warm temperatures promote vegetative growth in yams, a marked reduction in mean temperature, which usually occurs in the cool season, is required to promote tuber bulking. Yams are tolerant of dry conditions hence planting usually occurs during the dry season. However, well-distributed rainfall of around 1500 mm during the total growth cycle (approximately 8–10 months) is required to achieve optimum yields (Lebot 2009).

4.4.4.2 Tolerance of extreme climatic events

Cultivated yams are highly susceptible to cyclones, as they are generally trained to grow over trellises and supports. The tuber will quickly rot if it is broken or damaged prior to maturity. Loss of planting material is the major impact with a gap of two to three years needed to get back into full production, although the good storability of yams does help to minimise this impact. *D. esculenta* is the most robust of the cultivated yams in the Pacific, with a yield potential close to 100 tons/ha. It also likes sandy soil, is drought tolerant, immune to anthracnose and tolerant to viruses. However, its taste (sweet) and texture (moist) is not as popular with consumers as other yams and probably explains why it is not more widely cultivated (Lebot pers. comm.). Wild yams, in contrast to cultivated yams, are resistant to cyclones. Strong fibrous vines use forest trees and the forest canopy for support and protection from strong winds. Wild yams, unlike their domesticated cousins, if left un-harvested will regenerate and thus provide a food bank in times of disasters.

Wild yam, Vanuatu Photo: Andrew McGregor

4.4.5 Root and tuber crops and salinity

Aroids generally have a low tolerance to salinity. The FSM damage assessment report carried out in response to the tidal surges of December 2008 showed that the majority of swamp taro patches in the outer islands were affected and as a result many communities said they would cease cultivating taro (Susumu et al. 2009). However, a study carried out by Rao (2010) in Tuvalu indicated that some varieties of swamp taro were less susceptible to salinity than others. Preliminary research carried out in the Secretariat of the Pacific Community Centre for Pacific Crops and Trees (SPC CePaCT) on the salinity tolerance of different varieties of swamp taro from Kiribati *in vitro*, does indicate some genotype influence, but as pointed out by Webb (2007) the response of swamp taro to salinity is very complex.

Sweet potato varieties conserved at the SPC CePaCT obtained from the International Potato Centre, (CIP) in Peru, have demonstrated salinity tolerance in Asia. These varieties are currently being evaluated in the Pacific; studies conducted on an atoll in Palau have shown that reasonable yields can be obtained with some varieties (del Rosario pers. comm.). Similarly a study in Thanh Hoa Province, Vietnam, in which 530 varieties of sweet potato were studied, also demonstrated that salinity tolerance could vary with genotype (van Kien et al. 2013). Highlighting again the importance of diversity, studies carried out on cassava varieties obtained from different regions of Africa (arid, saline zone compared with high rainfall area) showed that some genotypes were more sensitive to salinity than others (Carretero et al. 2007). For yams, *D. esculenta* appears to be the most commonly found yam in the atolls; however, there are no reports in the literature of proven salt tolerance for this species.

4.4.6 Bananas

4.4.6.1 Temperature and rainfall

Bananas are generally considered as a tropical perennial crop that grows throughout the year in warm and moist regions. Much of the information available from global studies on the tolerance of bananas to climate change does refer to Cavendish-type bananas.

The optimum temperature for foliar development is 26°–28°C, and for fruit development, 29°–30°C. Prolonged periods of temperature below 20°C will affect the rate of maturation and significantly slow growth (Stover and Simmonds 1987). Extended periods outside the range 20°–30°C will reduce production per hectare. Larger bunches and a longer vegetative period are found with temperatures in the range of 20°–25°C, whereas with temperatures of 25°–30°C, smaller bunches will develop over a shorter cycle. However, total yield per hectare through time is generally stable in the optimum temperature range of 20°–30°C. Damage to plant tissue and distorted flowering emergence and bunch filling can occur with temperatures above 35°C and below 10°–15°C. Plants will recover if extreme temperatures do not persist beyond two to four days; however, bunches that have emerged during a period of stress may not fill properly (Thornton and Cramer 2012). Fruit quality is also affected by temperature, with increasing mean daily temperature linked to the yellowness of ripe fruit (Bugaud et al. 2007).

Minimum rainfall requirements depend on a number of factors, such as variety and species grown, soil type, planting location and sun exposure. The ABB cooking types (for example, Bluggoe) are increasingly popular because of their vigour, ease of cultivation and drought resistance. For commercial cultivars 500 mm is adequate as long as the rain is evenly distributed throughout the year and the soil is fertile (Nelson et al. 2006). However, an annual rainfall of 2000–2500 mm evenly distributed throughout the year is considered optimal (Vanhove et al. 2012), although actual water use will be influenced by the potential evaporation. Bananas cultivated in forested situations or in deep, fertile soil will tolerate seasonal rainfall.

Bananas are very sensitive to available soil water, detecting slight water deficits at higher soil water levels than other crops. Rate of leaf emergence and bunch size is affected by lack of moisture during or after flowering; yield also declines because of the increased length of the vegetative period with sub-optimum moisture levels (Thornton and Cramer 2012). Yield losses of up to 65% with East African highland bananas (AAA genotype) have been recorded when the annual rainfall was below 1100 mm (Van Asten et al. 2011). Fruit quality, in particular firmness, is favoured by higher rainfall (Bugaud et al. 2007). Tolerance to waterlogging is limited but enhanced if the plants are healthy and disease-free. Forecasts using models have shown that bananas will fail if rainfall exceeds 4000 mm per year (Van der Bergh et al. 2012).

However, despite these apparent rainfall requirements bananas are an important staple food crop in many locations in PNG where the mean annual rainfall ranges from a minimum of 1000 mm/year to a maximum of 6000 mm/year (Bourke and Harwood 2009). Poor nutrition is the major constraint with banana cultivation in the Pacific; improving nutrition would enhance resilience (Markham pers. comm.).

The widespread cultivation of bananas across a range of different environments and conditions reflects the resilience that can be found in diversity. The tetraploid (ABBB) Kalapua group, tolerant to dry conditions, are found growing in the lowland areas of Central Province, the Markam and Ramu valleys of Morobe and Madang provinces and in the Gazelle Peninsular of East New Britain Province. The giant Kalapua is also resistant to drought in Vanuatu and Eastern Polynesia (Lebot et al. 1993; Lebot et al. 1994). AAB cultivars do well in the highlands, suggesting tolerance of cooler temperatures and higher rainfall. Fe'i bananas are also very robust, and are immune to BLSD, and also the weevil borer (*C. sordidus*).

Giant Kalapua Photo: Jeff Daniells

Musa species are tolerant of salt spray, but considered susceptible to salt intrusion and salinity. In countries, such as Iran, Egypt and parts of India where salinity is a limiting factor for banana production, research has been conducted to determine whether genotype-dependent tolerance exists and also whether salinity tolerance can be induced. At the National Research Centre for Banana, India, in studies using salt-affected fields (EC = 3.56mmhos/cm), the variety Saba produced normal fruit and bunch development, whereas poor finger and bunch development were recorded with the varieties Robusta and Nendran[12] . Results from research in Iran on inducing salinity resistant clones through irradiating Dwarf Cavendish plants suggest this approach has potential for establishing salinity resistant banana (Miri et al. 2009). In PNG, two varieties, Yawa (Pisang Awak) and Daru, can be found growing well in coastal areas and atoll environments of the country, and are considered to have some degree of salinity tolerance as well as drought tolerance (Kambuou pers. comm.).

4.4.6.2 Tolerance of extreme climate events

Steady winds will cause leaf shredding, leaf drying, distortion of the crown and if the winds are extreme, complete or partial toppling of the plant will occur, especially if the bananas are fruiting and also if the roots and corm have been damaged by pests, such as the banana weevil borer or burrowing nematode. The post-cyclone period can see an increase in BLSD as it provides a perfect environment for the release of conidia. Damaged leaves remaining on the soil also act as a source of new infection (Kagy pers. comm.).

Cyclone-damaged bananas Photo: Jeff Daniells

12 (http://www.nrcb.res.in/achievements2.html)

Cavendish-type bananas are intolerant of flooding or waterlogging that often accompanies cyclones. Observations made in the Philippines after typhoons suggest that some of the FHIA hybrids both survive typhoons better and recover more quickly (Markham pers. comm.) The impact of cyclones on bananas is evident from reports that circulate after cyclones hit the region. Cyclone Evan, which struck Samoa in December 2012, brought huge damage to the island, including food crops, of which bananas and breadfruit were particularly badly hit[13] . Cyclone Larry in 2006 showed the vulnerability of commercial banana production systems to cyclones when more than 80% of Australia's banana crop was destroyed[14].

4.4.7 Rice

Rice production in PICTs, with the exception of a few locations in Fiji, is rainfed. The optimum climatic conditions for rainfed rice are according to the International Rice Research Institute (IRRI)[15].

Rainfall

- 200 mm of monthly rainfall for lowland rice and 100 mm for upland rice; and,
- 125 cm during vegetative stage.

Temperature

- Best suited to regions with high humidity and prolonged sunshine;
- Mean temperature around 22°C throughout the growing period;
- Tolerates day temperature up to 40°C;
- Minimum of 10°C for sprouting; and,
- Optimum of 22°–23°C for flowering and 20°–21°C for grain formation (with temperatures above 21°C respiration is accelerated and grain filling period is reduced).

4.4.8 Breadfruit

Deep, fertile, well-drained soils are preferred for breadfruit; however, some varieties are adapted to the shallow sandy soils of coral atolls. Several reports highlight the ability of breadfruit to grow on a wide range of soils from those of atolls to high altitude locations (Barrau and Massal 1954; Goodman 1972). Breadfruit is well adapted to the wet tropics, with optimum conditions being temperatures ranging from 21°–32°C, an annual rainfall of 1500–2500 mm and adequate drainage (Ragone 1997, 2006). Cooler temperatures often result in low yields and increased plant mortality (Lebegin et al. 2007).

13 http://www.abc.net.au/news/2012-12-15/an-samoa-declares-state-of-emergency/4429364
14 (http://www.smh.com.au/news/national/thousands-of-jobs-gone-with-bananas/2006/03/20/1142703270076.html)
15 http://irri.org/our-work/research/rice-and-the-environment

Breadfruit trees are prone to damage from high winds; however, trees are seldom uprooted by cyclones, with damage usually confined to outer branches. Clark (1992) describes the impact on breadfruit of the Category 4 Cyclone Ofa that struck Samoa in February 1990:

Observations three months after the cyclone were that trees still standing and even many blown over had refoliated. Many trees in villages had dead or damaged limbs pruned off and had a new flush of leaves up to the trunk and remaining branches. Shoots coming from the roots of fallen trees took a few months to come up to a size ready to replant. There was an abundance of these to replace fallen trees. Most trees flowered later and were bearing a heavy crop of immature fruit by October (p. 71).

Breadfruit requires relatively high levels of rainfall but can survive droughts of 3–4 months after the tree is established (Elevitch and Wilkinson 2000). Prolonged droughts have destroyed trees in the Micronesian atolls, and caused damage to trees in Guam, Pohnpei, Samoa, the Marquesas and other high islands (Ragone 1997).

On low-lying atolls repeatedly inundated by storm and ENSO-generated tides, breadfruit trees are often uprooted and destroyed. Trujillo (1971) has reported that most varieties of breadfruit do not tolerate salinity, whether in groundwater, soil or in salt spray. However, in many of the Pacific atoll states and low-lying coastal areas breadfruit grows in a relatively saline environment in terms of both groundwater and salt spray. Wild relatives of breadfruit and hybrid cultivars may be more tolerant of salinity than *A. altilis* (Ragone 1997). 'Mejwaan', a seeded variety of the Marshall Islands, is not harmed by brackish water or salt spray. In Kiribati, the seeded variety 'Te Maitairika' has shown tolerance to saline conditions and the seedless variety 'Te bukiraro' may be more susceptible to salinity than the seeded varieties. Preliminary data under laboratory conditions indicate that Ma'afala has some salinity tolerance (Ragone pers.comm). However, comparative studies of varieties grown in the same soils have not been carried out.

Research in progress at the Breadfruit Institute (BFI) and the University of British Columbia have quantified the average amount of sodium in the fruit of each of 94 different varieties in the National Tropical Botanic Garden (NTBG) collection and tentatively identified varieties that are sodium accumulators or sodium excluders. The next phase of the research will confirm salt tolerance and exclusion data; demonstrate the localisation of salt within hyperaccumulator tissues; carry out *in vitro* experiments to understand salt tolerance and exclusion; and select and propagate salt-tolerant varieties (Ragone pers. comm.).

4.4.9 Aibika

In PNG aibika is cultivated in both the seasonally dry lowlands and the wet lowlands. Cultivation is possible in the highlands but growth is relatively slow and insect damage can be severe. Aibika has been found growing at 2110 m in PNG, which was considered the 'extreme upper altitudinal limit' for this crop (Bourke pers. comm). Aibika will grow on a wide range of soils but growth is poor on the highly alkaline soils of the coral atolls, because of micronutrient deficiencies and drought. Growth is also affected when the temperature declines during the cool season in the southern islands of Vanuatu, New Caledonia and Tonga. Aibika is susceptible to drought which considerably reduces its leaf area when rainfall falls below 150–200 mm per month. Genetic improvement for drought tolerance is a priority for improvement (Preston 1998).

4.5. Observed climate impact on staple food crops over the last 30 years

The response of staple food crops to climate variability over the last 30 years can provide some insight into future responses under projected climate change conditions. However, while it is clear that climate and climatic events do have an impact on staple food crop production it is difficult to attribute specific impacts to climate change. In discussions and consultations throughout the Pacific, examples such as changes in the fruiting pattern of breadfruit, or mango and citrus, are suggested as responses to climate change, but data, both meteorological and agronomic, are not available to support these anecdotal observations. Examples can also be provided which suggest stability in food production systems. In Vanuatu, 30 years ago farmers planted *D. alata* when *Erythrin*a spp started flowering (first week of August) so that there would be sufficient vegetative canopy for when anthracnose strikes; today farmers are still planting their yams in the first week of August. There has been no change in yam yields or disease to encourage any change in this traditional practice (Lebot pers. comm.).

An assessment of crop response to ENSO events can be used to indicate the potential impacts of climate events on crop production, food security and livelihoods. Extreme El Nino events are associated both with periods of very high rainfall and very low rainfall. Bourke and Harwood (2009) summarise the lessons learned from the cycle of ENSO events in PNG as it relates to staple food crop production:

- Minor ENSO events (every five to six years) may cause local frosts at high altitudes and minor food shortages in the highlands from high rainfall.
- Significant ENSO events (every 12 years) will have a major impact because of drought and high rainfall, mainly in the highlands. Widespread frosts may also occur.
- Very significant ENSO events (every 30 years) will have a very major impact throughout the country. Repeated and widespread frosts will occur, completely disrupting food production at higher altitudes. Large bushfires may occur.
- The impact of the 1997 event (severe drought) was worst further away from the equator and in the poorest and most isolated parts of PNG.

- When an ENSO event of the severity of 1997 occurs, little can be done to maintain food production. Communities in the highlands are unable to protect field crops against repeated severe frosts for months at a time.
- Conversely, much can be done to assist recovery after a drought. In 1997 impressively large areas of food crops were planted with the arrival of adequate rain.
- Overall, food security in PNG is threatened more often by too much water than by too little water. Food supply problems caused by excessive rainfall are insidious, delayed, difficult to identify and do not affect the whole country at the same time. Food shortages caused by drought are immediate, spectacular and widespread.
- People in areas that have a regular dry season use agricultural systems that are adapted to a lack of water for part of the year. They are adversely affected only by very severe ENSO events.
- People in areas that do not have a regular dry season use agricultural systems that are adapted to deal with excessive water, thus they can be severely impacted by drought.

4.5.1 Root and tuber crops

Taro leaf blight (TLB) had a devastating impact on the Samoan taro industry in 1993. At the time taro was Samoa's most important food security crop and by far the most important export industry. Bourke and Harwood (2009), note that the first major change to PNG agriculture since 1940 was the replacement of taro by sweet potato as the staple in Bougainville and other lowland locations. Taro was by far the most important food crop on Bougainville prior to World War II, but now the crop is rarely grown (Connell 1978). Prior to the introduction of sweet potato, taro provided an

Taro leaf blight disease Photo: Andrew McGregor estimated half of PNG's food energy from staple foods, whereas now taro contributes only about 4% (Bourke and Harwood 2009). There has been a similar transformation in Solomon Islands, where sweet potato has replaced taro as the main staple food. In all cases TLB has been a contributing factor.

Meteorological records are not available to directly link increasing minimum temperature with the incidence and spread of TLB; however, results from studies (Trujillo 1965; Putter 1976)[16] , directly link temperature and humidity with variation in the sporulation of the oomycete, and observations of weather patterns at the time of outbreaks, particularly in Samoa, pointing to the influence of minimum (night) temperature on TLB outbreaks. Further, in PNG, TLB is less severe a few hundred metres above sea level and is rarely found above the altitude of 1300 m (Bourke 2010), suggesting sensitivity of the oomycete to a small rise in temperature.

4.5.2 Bananas

Long-term temperature data runs from highlands stations in PNG are limited; however, the data that do exist show similar trends to lowland station data. At Aiyura in Eastern Highlands Province (1640 m), maximum temperature increased by 0.75°C (0.3°C per decade) over a 25-year period (1977–2001), but the daily minimum did not increase over this period. From the mid-1980s communities could grow bananas in Tambul (2300 m) in the Western Highlands Province. Prior to that period, bananas could not be grown, suggesting that the increasing maximum temperature supported banana production at the higher altitude (Bourke 2010).

Throughout the region farmers and the community at large discuss how there have been changes in the intensity, duration and timing of seasonal rainfall patterns. Such information is inevitably anecdotal because of the low number of rainfall stations and the lack of long-term (50 years plus) data necessary in order to reveal clear trends. In PNG 650 rainfall stations operated 'for any length of time' between 1910 and 1970 (McAlpine et al. 1983). By the time of the severe 1997 drought, less than 30 stations recording rainfall on a regular basis existed, mostly on agricultural research stations and airports. The number of stations has probably fallen even further today.

The impact of long periods without rainfall on bananas is evident. The recent (2013) drought in RMI was reported to have affected bananas growing in home gardens[17]. Recently in Western Australia banana production has been affected by both drought and a heatwave highlighting the impact of multiple stressors. Banana production is the lowest in 20 years, with 70% less volume being harvested. The drought had been affecting production but a heatwave has added further problems; bunches that emerged during the heatwave are developing slowly, not ripening and falling to the ground[18].

16 Putter (1976), working in PNG, found that temperature and relative humidity together explained 72.57 per cent of the variation in sporulation, with all these associations being highly significant (P<01).Trujillo (1965) showed that a minimum night-time temperature of 21°C and a relative humidity of 100 per cent provided optimum conditions for the TLB. With RH less than 90 per cent, no sporulation occurs and zoospores rapidly lose their viability.

17 http://www.abc.net.au/news/2013-05-06/an-australian-aid-for-drought-affected-marshalls/4672534

18 http://cc.rsoe.hu/?pageid=news_read&hirid=1047

4.5.3 Rice

Peng et al. (2004) analysed six years of data from 227 irrigated rice farms in six major rice-growing countries in Asia, responsible for more than 90% of the world's rice. They found that rising temperatures, especially night temperatures, severely affected yields, causing losses of 10–20% of harvests in some locations (Redfern et al. 2012). The sample analysed did not include any data from rice-producing locations in the Pacific region.

4.5.4 Breadfruit

Any information regarding breadfruit response to a changing climate is anecdotal. Observations from FSM, Samoa, American Samoa, and French Polynesia report that the seasonality (time and duration of flowering and fruiting) of breadfruit is changing. More frequent occurrences of longer dry periods are causing fruit drop and/or smaller fruit, although poor soil fertility could also be a contributing factor. Similar observations are reported from Kiribati (Kairo 2007).

4.5.5 Aibika

No change in altitudinal range has been associated with increasing temperatures at higher altitudes in PNG. However, over the past 40–50 years, aibika has been declining in importance, replaced by introduced crops such as cabbage (highlands), choko tips (intermediate zone) and chinese cabbage (lowlands mainly) (Bourke pers. comm.). The reason(s) for this decline is not clear. In Guadacanal Plain (Solomon Islands), a change in the dynamics between populations of two major pests, slippery cabbage flea beetle (*Nisotra basselae*) and jassid (*Amrasca devastans*), has been observed by farmers and researchers, with jassid becoming dominant in areas where these pests used to co-exist. Local communities consider this change is due to recent changes in the climate, mainly increasing intensity from the sun and more rainfall in areas generally considered as drier locations (Vaqalo pers. comm.).

Jassid damage (left); flea beetle (*Nisotra*) damage (right) Photos: Grahame Jackson

4.6 Projected vulnerability of staple food crops to climate change

As discussed in Chapter 3, vulnerability to climate change and climate extremes is considered in terms of exposure and sensitivity, potential impact and adaptive capacity. The consequences of exposure and sensitivity result in a potential impact that can be modified by the adaptive capacity of the species, ecosystem and the community. The exposure is dependent on the climate conditions, which have been discussed in Chapter 2.

4.6.1 Sensitivity, potential impact and vulnerability

4.6.1.1 Increasing temperature

As discussed in Chapter 3, the focus of international research on climate change has been mainly on cereal crop yields. Hay et al. (2003) note that for the Pacific region the projected temperature increase is likely to have a minimum impact on crop production. However, as Wairiu et al. (2012) point out, the physiology of crops may be influenced in ways not yet identified, and the range of interactions possible within a production system adds to the complexity of determining potential impacts. How climate change will affect pests and diseases creates another area of uncertainty. As their behaviour, dissemination and spread are influenced by climate conditions, the changing climate will impact on the pest and disease spectrum of Pacific crops, and if the crops under attack are climate stressed, that impact is likely to be more severe. However, an analysis of the information currently available, which will be presented in the following sections, does suggest that Pacific root and tuber crops will be less affected by projected climate conditions than cereal crops.

The potential impacts of overall increases in temperature on the specific staple crops are discussed briefly below. Generally the projected temperature increases (0.5°–1°C regardless of emission scenario) up to 2030 will not affect production, based on what is currently known for optimum crop production conditions. Between 2030 and 2050, temperatures will be influenced by the emission scenario with projections of 0.5°–1°C (very low scenario) to 1°–2°C (very high scenario) increases by 2050, and beyond 2050, the temperatures again vary significantly depending on the emission scenario[19]. Specific impacts are difficult to predict based on current knowledge, but obviously temperatures approaching 2°C and beyond will create significant physiological stress for many of the staple crops. RCP2.6 and 4.5 would constrain average global warming to approximately 2°C, but this is looking unrealistic as currently observed increases in atmospheric CO_2 are tracking at or above RCP8.5 (Chapter 2).

Probably of more significance is the impact of extreme heat days and heatwaves which could have implications for production prior to 2050 depending on their intensity, timing and duration. As shown with studies on global crops (Chapter 3), a non-linear relationship exists between warming and yield. The combination of increasing

19 As explained in Chapter 2, these changes are in relation to the 1986–2005 baseline.

temperature with other variables (biotic and abiotic) is a further consideration. The availability of water during and around the times of heat stress will have a significant influence on how crops respond. Healthy crops subjected to minimum biotic stress will be more resilient. How insect pests, in particular virus vectors, will respond is also difficult to predict. Temperature increase could either cause a decline or an increase in viruses depending on the temperature sensitivity of the vectors, which would affect the numbers of generations, their dissemination and spread.

Sweet potato

Tuber production is reduced significantly at temperatures above 34°C. The maximum temperature in lowland locations in western Melanesia is currently around 32°C. An increase of 1°–2°C (very high emission scenario) by 2050 would affect production in lowland locations in PNG and Solomon Islands, and other countries where temperatures are currently around 32°C (e.g. the Federated States of Micronesia), within one or two generations, which would have major food security implications. Beyond 2050, the food security implications under all emission scenarios except RCP2.6 could be serious. Extreme heat events would also be expected to have impacts in countries with temperatures around 32°C. The impact would depend on the timing and duration of the event, as well as soil moisture levels.

In highland locations, the temperature impact is expected to be minimal by 2050 even under the very high emission scenario (RCP8.5); however, if the very high emissions scenario continues through to 2090, then production in these locations would also be affected.

Depending on whether temperature increases favour or disadvantage virus vectors, yields could be negatively affected.

Cassava

While the optimum temperature for cassava tuber growth is 25°–29°C, it will tolerate a wide temperature range of 12°–40°C. Thus increases in average temperature, even up to 2°C and beyond, are not expected to have a significant impact on cassava production. Extreme heat days would also be expected to have little impact, but as with all crops the ability to manage heat stress will be influenced by precipitation.

Taro and other aroids

Modelling studies suggest that projected changes in mean climate conditions will have little effect on taro production, with the exception of extremely low rainfall (Wairiu et al. 2012). However, such models do not consider increasing minimum night-time temperature and its influence on the spread of TLB. A rise in minimum night-time temperature increases the likelihood of TLB spreading to locations currently free of the disease (Cook Islands, Fiji, Tonga, Vanuatu and higher elevation areas of PNG). Extreme heat days are likely to pose a threat in this regard. In the long term, as 30°C is the optimum temperature for taro, temperature increases of 2°C and beyond could impact on production, and similarly with the other aroids, possibly with the exception of swamp taro.

Yam

It is likely that yam production will remain unaffected by changes in temperature in the short term. However, as a marked reduction in mean temperature is required for tuber bulking, the projected temperature increases in the long term and extreme heat events, depending on timing and duration, could be significant. Data from the southeastern rainforest zone of Nigeria indicated that yam production would become increasingly difficult if the trends of decreasing rainfall and relative humidity and increasing temperature and sunshine hours evident over the past 30 years (1978–2007) continued (Nwajiuba and Onyeneke 2010).

Bananas

Much of the information available on the sensitivity of bananas to climate change has been derived from models, in particular, an Ecocrop model set up with the climatic parameters for Cavendish-type bananas (Ramirez et al. 2011). With the projected rise in temperatures, the upper altitudinal limit for banana cultivation in the highland tropics will increase, and opportunities could also exist for countries like New Caledonia and Tonga to increase their banana cultivation as conditions become more suitable. However, an EcoCrop modelling study on selected subtropical production areas showed that improvements in suitability cannot be assumed, with only two of the nine regions studied having better suitability and three showing lower suitability in response to increasing temperature (Van der Bergh et al. 2012). However, this work was based almost entirely on commercial Cavendish-type dessert bananas (genome AAA). Many of the cooking bananas and plantains in PICTs have a genome composition of AAB, or ABB and although their physiological tolerances have been much less studied, observations in the field suggest they are more tolerant to drought and temperature extremes.

Up to 2030 the projected mean temperature rise of 0.5°–1°C is not likely to result in any significant reduction in banana yields at low altitudes, and could in fact support banana cultivation at higher altitudes. However, temperatures in excess of 35°C (heatwaves) are likely to affect flowering and bunch filling. By 2050 and beyond, temperature could be a significant constraint on banana production at low altitudes, especially if warming proceeds according to the very high emissions scenario (RCP8.5), where 1°–2°C will be reached by 2050, and 2°–4°C by 2090.

Optimum temperature for development of black leaf streak disease (BLSD) is 27°C and the disease is reduced by very high (>36°C) or low (<12°C) temperatures and low humidity (Stover 1983; Jacome et al. 1991). However, Ghini et al. (2008) suggest that increasing temperatures will favour the spread of BLSD to highland areas in the tropics currently free of the disease and allow it to replace the less damaging yellow Sigatoka. Currently commercial companies are tending to shift production from wet areas to drier areas to reduce the cost of managing BLSD (Markham pers. comm.), as drier climates reduce the impact of the disease (Ramirez et al. 2011).

Sensitivity to temperature prevents the establishment of *Radopholus similis*, a significant nematode pest of bananas at high altitudes and latitudes. Studies carried out in Central Africa showed that increasing the soil temperature resulted in greater root damage by nematodes. Currently the nematodes are limited to elevations below 1300 m, but a warming temperature could support survival and reproduction of *R. similis* at high altitude (Masters and Norgrove 2010). Banana weevil borer is a significant pest in some PICTs, such as New Caledonia. It is very low or absent at altitudes above 1300 m; however, temperature increases of 2°C are likely to result in greater losses due to the weevil borer. Increases in temperature could also see the spread of *Banana bunchy top virus* (BBTV) by favouring the banana aphid's expansion into higher altitudes (Thornton and Cramer 2012). Anecdotal evidence from Africa suggests that the aphid suffers high mortality from rainfall, with the spread of BBTV appearing to be associated with dry seasons and droughts (Markham pers. comm.).

Breadfruit and aibika

Increasing temperatures are unlikely to have much impact on breadfruit at least to a 2°C increase, although fruit drop and smaller fruit are likely to be a problem if heat stress is accompanied by low rainfall.

Increasing temperatures are unlikely to affect aibika unless accompanied by low rainfall, in which case growth would be affected, as would pest and disease incidence and severity.

Rice

In tropical regions increasing temperatures are expected to be a constraint to rice production. The following studies describe the impact:

- Temperatures above critical thresholds not only reduce growth duration, but also increase spikelet sterility, reduce grain-filling duration, and enhance respiratory losses, resulting in lower yield and lower-quality rice grain (Fitzgerald and Resurreccion 2009; Kim et al. 2011).
- One or two hours of high temperature at anthesis can result in a large percentage of grain sterility (Nguyen 2005).
- High night temperature has an adverse impact on respiration, membrane stability, antioxidant capacity and yield of rice plants (Mohammed and Tarpley 2009).
- Significant increases in temperature, for example, 5°–10°C over a short duration, can seriously affect yield rice yields (Wassmann et al. 2009).

- Rice grain sterility is induced by temperatures in the mid-30s (Gornall et al. 2010).
- Night temperature has a greater negative effect on rice yield, with a 1°C increase above critical temperature (>24°C) leading to 10% reduction in both grain yield and biomass (Peng et al. 2004; Welch et al. 2010).

In the past, rice production in Solomon Islands and PNG has been plagued with serious pest problems, particularly brown planthopper. Some research has indicated that brown planthopper may be adversely affected by occasional extremely high temperatures, which would limit its survival and distribution (Piyaphongkul et al. 2012).

4.6.1.2 Changes in precipitation

As discussed in Chapter 2, an increase in average annual rainfall over large parts of the tropical Pacific is predicted for a warmer climate, with impact prior to 2030 being minimal. After 2030, more distinctive patterns emerge, which will become progressively stronger with time and for higher emission scenarios (RCP6 and 8.5). Projected rainfall increases for those countries such as PNG, parts of Solomon Islands, Palau and the FSM will need to be considered in the context of rainfall that is currently high. For PNG, Bourke (2013) suggests an increase in mean annual rainfall of 8% would be beneficial in drier locations; in wetter areas, some reduction in the production of most crops is likely but the impact would be small. An increase of 25% in mean annual rainfall would be beneficial in drier locations (1000–2000 mm/year); however, it would have a significant damaging effect on crop production in locations where rainfall is already high to very high.

Total annual rainfall is just one aspect of the impact of rainfall on plant growth. Other important factors are seasonal distribution, variation between years, and importantly, extremes (intensity and duration). A period of lower rainfall is often desirable to break a cycle of disease build-up, especially in locations closer to the equator where little seasonal change in temperature occurs. Bourke and Harwood (2009) note that TLB is worse in locations (such as PNG) where there is no annual dry period.

As with temperature, rainfall must also be considered together with other climate variables. As discussed in Chapter 3, tolerance to combined drought and heat stress is genetically different from tolerance to drought and heat stress separately. For pests and diseases where drought could increase the frequency or intensity of any attack or infection, the addition of higher temperatures could mitigate that effect if the pest or pathogen is temperature-sensitive; if temperature sensitivity is not a factor, then the combination of drought and higher temperatures could result in escalating populations of pests and/or pathogens.

The potential impacts of an overall wetter environment on specific staple food crops are discussed briefly below.

Sweet potato

An increase in mean annual rainfall might cause some reductions in tuber yield, particularly on heavy clay soils. Excessively high soil moisture, however, particularly during initiation (6–10 weeks after planting) reduces tuber yield and is a major cause of food shortages in the PNG highlands (Bourke 1988). Where rainfall is already very high, most growers will find it difficult to counter a significant rainfall increase — an increase in rainfall, particularly between October and March, would result in yield reductions in many locations. A wetter climate could also increase problems with sweet potato scab.

Taro and other aroids

Overall wetter conditions would generally favour taro production and extend the areas available for successful cultivation. However, the vulnerability of susceptible taro varieties to TLB will be increased if higher levels of humidity are associated with higher night temperatures. Increased rainfall would also favour the spread of *Pythium* (which would affect both taro and cocoyam) and probably taro armyworm or caterpillar (Jackson pers. comm.) .

Cassava and yam

Overall it could be expected that a wetter environment would favour cassava and yam production compared with other root crops. However, higher rainfall will increase the incidence and intensity of yam anthracnose disease, possibly resulting in epidemic developments with serious implications for yam production. Increasing rain intensity and waterlogging can also lead to rot and potentially death of the plant (Lopez-Montes 2012).

Yam anthracnose disease Photo: Grahame Jackson

CSIRO, in collaboration with the Ministry of Primary Industries (MPI), Fiji, the University of the South Pacific (USP) and SPC, developed a cassava module within

Agricultural Production Systems sIMulator (APSIM)[20]. This module has been developed and tested on data collected from field trials in Fiji for two varieties of cassava (non-branching and branching), and was applied to two sites on the eastern and western sides of Fiji with different precipitation levels. Using the module, mean tuber yield was calculated for a 30-year period centred on 1990 (i.e. a baseline) and a 30-year period centred on 2030. Based on simulations using three different future climate change scenarios (warmer through to warmer/drier conditions), tuber yields were projected to decline by up to 9% by 2030, and up to 18% by 2050. In addition to declines in yield, the year-to-year variability was shown to increase by up to 19% by 2030 and up to 28% by 2050 (the increase in variability is driven by more frequent lower yielding years). The yield declines were less severe on the eastern side of the island where annual rainfall is high and waterlogging can sometimes serve to reduce yields. Similar production losses (2–12%) have been simulated for sites in PNG, Solomon Islands and Vanuatu, although these results are prospective and will require further validation. Production impacts are highly variable between countries largely as a result of different soil characteristics (Crimp et al. 2012). CSIRO is now working with MPI, Fiji and the Vanuatu Agriculture Research and Training Centre (VARTC) to develop model crop and cropping system responses within the APSIM framework for taro, and to further refine the cassava models. Field trials and data collection are ongoing in both countries.

Bananas and plantains

The impact of changes in rainfall on bananas is harder to project, but greater irregularity and decreasing rainfall will increase the length of the crop cycle and the seasonality of bunch production. Some banana production areas could have problems with waterlogging. Bananas will grow within a reasonably wide range of rainfall, and therefore in the short to medium term, projected increases in rainfall are unlikely to affect production. In the longer term, beyond 2050, and especially with countries lying between latitudes 5°N and 5°S, the projected rainfall increases could affect production, assuming that 4000 mm rainfall per year is the threshold for the banana varieties cultivated in the Pacific (Van der Bergh et al. 2012). As with temperature, the projected increase in number of heavy rain days is more a cause for concern in the short to medium term, with the potential for waterlogging to affect bunch yield. Higher rainfall is also likely to increase pressure from BLSD and also from Fusarium wilt. Race 1 Fusarium is present in PNG, Northern Marianas and FSM; Race 2 in Tonga, and Tropical Race 4 is in Irian Jaya (Jackson pers. comm.).

An increase in rainfall could favour production, where lack of rainfall is currently a constraint. In contrast, production could become more difficult in those locations where less rainfall is projected, such as French Polynesia (Chapter 2). However, in Vanuatu bananas have become increasingly popular in areas exposed to drought, especially the ABB varieties and the giant 'Kalapua' (ABBB) (Lebot pers. comm.),

20 APSIM (the Agricultural Production Systems Simulator) is a farming systems computer model that simulates the effects of environmental variables and management decisions on production (crops, pasture, trees, livestock), profits and the environmental variables (e.g. soil erosion).

highlighting not only the importance of diversity but also that despite crops having optimum requirements for growth, their ability to yield in less than optimum conditions has to be considered and compared with other crops in the farming system.

Breadfruit and aibika

Increased rainfall is likely to exacerbate damage by *Phytophthora palmivora*, affecting fruit quality.

Photo: Jim Wiseman

Breadfruit damaged by *Phytophthora palmivora*

The situation with *Bactrocera frauenfeldi* (known as the mango fly) is more complex and less certain as more rainfall is likely to cause an increase in populations, but very high levels of rainfall are likely to decrease populations (Jackson pers. comm.).

Drought will reduce growth of aibika and drier weather, will generally increase attack from the *Nisotra* beetle, jassid and leaf roller. Extremes of rainfall are likely to provide conditions that will encourage increased incidence and severity of pests and diseases of aibika. Increased rainfall will favour collar rot, and stem and tip rot.

Rice

More high-intensity rainfall events will increase land degradation problems already associated with growing rainfed rice, particularly on sloping land. Globally, stress caused by drought is perhaps the biggest threat to rice production. As noted by Mohanty et al. (2012) from the International Rice Research Institute (IRRI):

Drought stress is the largest constraint to rice production in the rainfed systems, affecting 10 million ha of upland rice and over 13 million ha of rainfed lowland rice in Asia alone. Dry spells of even relatively short duration can result in substantial yield losses, especially if they occur around flowering stage. Drought risk reduces productivity even during favourable years in drought-prone areas, because farmers avoid investing in inputs when they fear crop loss. Inherent *drought is associated with the increasing problem of water scarcity. In Asia, more than 80% of the developed freshwater resources are used for irrigation purposes, mostly for rice production* (p. 126).

4.6.1.3 More intense extreme events

As stated in Chapter 2, cyclones are projected to be less in number but more intense in activity. The damage caused by a cyclone to crops and vegetation tends to increase exponentially with wind speed. For example, the South Pacific Disaster Reduction Programme (SPDRP) report on Disasters and Agriculture in the Pacific Islands indicated that 180 km/hr winds are four times stronger than 90 km/hr winds (McGregor and McGregor 1999). Therefore, the predictions of increasing intensity of cyclones, rather than frequency, need to be seen in this context. An increase in the frequency and intensity of very hot periods and very wet periods is also projected. Any extreme event will be a threat to staple food crops with the impact depending on the intensity, timing and duration of the event. In addition, the climate conditions before any extreme event, and the timing between extreme events and therefore recovery time, will influence impact. As evident from recent drought and flooding events in the region, the damage to staple food crops, can be significant.


Breadfruit nursery before and after flood, Fiji Photos: Andrew McGregor

From the discussions earlier in this chapter, it is clear that certain crops are more tolerant of extreme events than others. For example, cocoyam and yams will tolerate drought more than taro. Most crops are susceptible to high winds, except for sweet potato, though some crops, such as breadfruit, are not permanently damaged.

Of importance also is the impact of extreme events on pest and disease outbreaks. There is very limited information regarding how climate change will influence pest and disease incidence and distribution, so projections are difficult. For sweet potato, drought would affect the impact from sweet potato weevil, increasing feeding from the weevil but reducing larval survival, therefore the timing of the drought would be significant (Chapter 3). Droughts could also increase sweet potato begomovirus by favouring the whitefly vector (Jackson pers. comm.) A severe cyclone can disturb the pest and disease balance, as evident in Samoa with taro armyworm or caterpillar and TLB outbreaks after cyclones. Drought is likely to increase the population of the vector responsible for the transmission of CBDV, because of its negative impact on the parasitoids of that vector (*Tarophagus* species) (Jackson pers. comm). Drought could favour the expression of virus diseases in both *Dioscorea alata* and *D. rotundata* (Lopez-Montes 2012). Droughts could also encourage increased populations of, and therefore damage by *P. coffeae* to banana (Jackson pers. comm.).

4.6.1.4 Elevated carbon dioxide

As discussed in Chapter 3, studies on the benefits of elevated carbon dioxide (eCO_2) for crop production indicate that at concentrations of 550 ppm yield increases in the order of 8–15% could be obtained; however, that assumes all other inputs, such as water and nitrogen, are not limiting factors. Elevated CO_2 could lead to decreases in important minerals such as calcium and magnesium. Reduced nutritional quality would affect human nutrition and livestock production and could result in increased consumption of leaf material by insect herbivores. The behaviour of aphids has been shown to be affected by eCO_2 though the response depended on the aphid species studied.

Tuber crops appear to be more stimulated by eCO_2 than grain crops (Miglietta et al. 1998; Rosenthal et al. 2012). CSIRO have established controlled environment experiments in Perth, Australia, with CO_2 concentrations set at 400 ppm, 500 ppm, 700 ppm and 900 ppm. Preliminary results show that a positive growth response occurs with modest changes in CO_2 (baseline to 500 ppm), a negative growth response between 500 ppm and 700 ppm and a positive response after 700 ppm. This apparently bi-modal response may account for differences that have been reported in past studies (Crimp pers. comm.).

A number of studies have looked at the impact of eCO_2 on the cyanogenic glucoside linamarin in cassava. Increases in levels are found in both the leaves and the tubers, but the effect is more pronounced in the leaves (Crimp pers. comm.). Generally cassava varieties in the Pacific are low in cyanogen content, but there is the possibility that a combination of drought and eCO_2 could raise linamarin levels significantly. However, as discussed in Chapter 3, there is evidence that suggests high concentrations of cyanogens can be reduced if plants are watered for two weeks after the drought period.

4.6.1.5 Sea-level rise and salinity

Global mean sea level will continue to rise during the 21st century. There is considerable spatial variability across the Pacific but very high rates of sea-level rise are observed in the western tropical Pacific (Chapter 2). The impact of sea-level rise on extreme sea-level events is of significance.

Root and tuber crops

Increasing storm surges and, in the long term, increases in mean sea-level rise, will affect root and tuber growth in the atolls and low-lying coastal locations. As discussed in Section 4.4.5, countries are already reporting losses in swamp taro due to salinity toxicity, and this trend is likely to continue and intensify. Some genotypes of swamp taro, sweet potato and cassava appear to be more tolerant of salinity than others, but more field data are necessary for confirmation.

Bananas

There are no reports of bananas suffering from salinity, but this could be the result of the seemingly more tolerant varieties being cultivated in the atolls and coastal environments (Section 4.4.6). It is unlikely that sea-level rise will have any impact on banana cultivation.

Breadfruit

Breadfruit trees can be quite tolerant to salinity, but with ageing trees, saltwater incursions further weaken the trees increasing their susceptibility to disease. Salt intrusion has been reported as a contributing factor to the 'trunkrot' disease experienced in Kiribati[21]. The problem occurs especially in seeded breadfruit and rarely in seedless varieties. Hence, increasing sea-level events, such as storm surges, are likely to weaken old trees, making them more susceptible to disease.

4.6.1.6 Climate change and the nutritional quality of staple food crops

Transpiration rates are reduced under drought conditions, which can lead to micronutrient deficiencies. If soils are already deficient in these nutrients, for example, zinc, then that deficiency will be exacerbated in the plant. Plants grown at eCO_2 have lower levels of nitrogen and protein (Gleadow et al. 2010; Myers et al. 2014). As discussed in Chapter 3, a meta-analysis which examined 228 experiments found that under eCO_2 concentrations (540–958 ppm) protein concentrations of barley, rice and potato were reduced by 1–15% (Taub et al. 2008). Climate change has been shown to affect the post-harvest quality of fruits and vegetables. For example, high temperatures can reduce the vitamin content (Chapter 3). Studies on banana in Martinique have shown fruit is firmer with higher rainfall, and cooler temperatures result in yellower fruit (Bugaud et al. 2007).

21 http://www.pestnet.org/SummariesofMessages/Crops/Fruitsnuts/Breadfruit/Trunkrot,Kiribati.aspx

4.6.1.7 Summary of projected vulnerability

The projected vulnerability of the various staple crops, discussed above, for medium- and long-term time frames is summarised in Table 4.2.

Table 4.2 A summary of the observed and projected impact of climate change and climate variability on Pacific Island crops.

Crop	Climate change/climate variability impact in recent decades	Projected climate impact to 2030[22]	Projected climate impact to 2050[23]
Sweet potato	ENSO-induced droughts have had a major impact on production, particularly in PNG	Impact in countries where temperature is currently around 32°C. As tuber yield is already vulnerable to high rainfall, it is difficult for growers to counter a significant rainfall increase	Significant impact in countries where temperature is currently about 32°C; serious impact with high emission scenario. Increasing vulnerability to high rainfall. Impact on pests and diseases unclear — drought is likely to increase problems with weevil and begomovirus
Cassava	No clearly discernible direct impact	Expected to be minimal — but possible problems with waterlogging and susceptibility to high winds (>30 knots). Possible yield benefits from eCO_2	Impact from waterlogging and susceptibility to high winds. Future climate pest and disease interactions unknown. Possible yield benefits from eCO_2
Taro	ENSO-induced droughts and cyclones adversely affected production. Likely connection between incidence of TLB in Samoa and increasing minimum night-time temperature	Overall wetter conditions could expand areas suitable for taro production. Cyclone damage with increased intensity. Likelihood of TLB spreading to countries where disease is currently absent. Increasing rainfall would increase incidence and spread of other pests and diseases. Possible yield benefits from eCO_2	A continued spread and increase of TLB and other taro pests and diseases expected. Impact on virus vectors unclear. Cyclone damage with increased intensity. Very high temperature increases (>2°C) could affect production. Possible yield benefits from eCO_2
Cocoyam	No clearly discernible direct impact.	Expected to be minimal	No direct impact predicted, although future climate pest and disease interactions are unknown. Very high temperature increases (>2°C) could affect production

22 Temperature rise of +0.5° to 1°C regardless of emissions scenario.
23 Temperature rise will vary from +0.5 to 1°C (RCP2.6) to +1° to 2°C (RCP8.5).

Swamp taro	Swamp taro pits which are found on atolls affected by saltwater intrusion.	Continued loss to sea-level rise expected. Droughts will exacerbate salinity problems	Could disappear from atoll environments
Giant taro	No clearly discernible direct impact	Expected to be minimal	No direct impact predicted, although future climate pest and disease interactions are unknown. Could be affected by more intense cyclones. Very high temperature increases (>2°C) could affect production
Yams	Impact from ENSO-induced droughts and cyclones. No clearly discernible direct impact on wild yams	Domesticated yam production more severely impacted by cyclones. No impact on wild yams expected. Increased rainfall will worsen problems with anthracnose	Projected temperature rise could affect tuber bulking. Domesticated yam production increasingly affected by cyclones and wetter conditions (anthracnose). No impact on wild yams expected. Pest and disease interactions unknown.
Rice	Globally, rising temperatures, especially at night, have caused yield losses of 10–20% in some locations. No information available for Pacific	Increasing temperature expected to decrease overall rice production in tropical locations (75% of world rice production). Rice production in PICTs likely to become even less viable in terms of productivity. Extreme events could significantly affect global supply available for export	Severe global shortages in rice available for export. The high price of imported rice expected to enhance the comparative advantage of Pacific Island rice production and other staple food crops
Breadfruit	Apparent changes in fruiting patterns due to changes in rainfall	Expected to be minimal though cyclone damage likely to increase	Expected to be minimal though higher temperatures could reduce fruiting and fruit quality. Cyclone damage will worsen with increased intensity of cyclones. Possible increase in pest and disease problems

Aibika	No apparent impact from any change	Minimal impact likely from increasing temperature, but extremes of rainfall will increase pest and disease problems. Increase in frequency and intensity of drought will affect growth	More problems with pests and diseases from extremes of rainfall
Bananas	Cultivation at higher altitudes with warmer temperatures	Favour cultivation in currently sub-optimal locations and at higher altitudes. Higher temperatures could affect flowering and fruit filling. Higher temperatures could increase nematode and weevil damage, and possibly BBTV. Higher rainfall could increase BLSD and Fusarium wilt. Increase in cyclone damage	Increased pest and disease pressure (Fusarium wilt, nematode and weevil). Rainfall impact on BLDS could be lessened by higher temperature. Heat stress effect on flowering and fruit filling. Increase in cyclone damage

4.7 Resilience and adaptive capacity of staple food crops and cropping systems

PICT staple food crops have varying degrees of resilience to changes in the climate and climate variation, including extreme climate events, based on their physiological tolerances. The extent to which this resilience can be influenced by the genotype under cultivation has been discussed in previous sections. However, the traditional resilience and adaptive capacity of agriculture in PICTs is also strongly influenced by the cropping systems used and the farmers and communities who work with those systems to produce food.

As discussed in Chapter 1, traditional disaster mitigation was founded on multi-crop food gardens protected by either primary or secondary forest. Smallholder cash crops are often integrated into traditional farming systems, as McGregor et al. (2011), describe for Vanuatu:

This system involves a household growing a cash tree crop, usually coconuts which might be under-grazed with cattle or inter-cropped with cocoa. Around 70 per cent of households produce their own coconuts; most of these make copra, at least on an intermittent basis. Coconuts also provide a major source of subsistence. A household growing coconuts, will invariably maintain a separate traditional multi-crop food garden. The food garden will usually be located some distance from the village and beyond the coconut/cocoa plantation. The proportion of cash cropping to food gardening depends on the land and labour available, *altitude and the household's adherence to traditional systems. The 2009 Agricultural Census indicates that the average household has approximately two ha of cash crops. According to the Census, each household will have an estimated 0.5 ha of productive food garden (in their first, second or third year) and more than three times that area will be fallow or contain residual crops such as kava and bananas* (p. 65).

Such agricultural systems have enabled countries like Vanuatu to keep pace with a high population growth rate, even on the most densely populated islands. Bourke (1999) attributes this achievement in the case of Vanuatu to the following factors: the adoption of new, more productive staple crops[24] ; the adoption of more productive cultivars of existing foods; shortening of the fallow period; extending the cropping period; improved fallow species; and the rehabilitation of ancient irrigated taro ponds.

Historically Pacific farmers have adapted their food production systems to extremes of climate variability. As discussed, some staple food crops, such as banana, sweet potato and the aroids are relatively resilient to changes in climate conditions. The inter-specific diversity found in the traditional farming system also provides resilience as can be seen by the response of Samoan farmers to the TLB disaster. The significant substitution of other traditional staples for taro lessened the overall impact of the disaster. Paulson and Rogers (1997) described the adjustments that took place in the agricultural sector after TLB destroyed the taro crop:

By June 1995, two years after the taro leaf blight first appeared in Western Samoa, the taro zone in the two main villages had been almost completely abandoned and was under fallow vegetation. Most households had redirected their efforts to the area nearest the village. This area of old gardens, secondary growth and senile coconuts had been transformed into well-tended mixed gardens producing a variety of food and tree crops. All gardens had several varieties of banana and at least two varieties of ta'amu (Alocasia macrorrhiza). Most had yams, cassava, and several varieties of breadfruit, and a variety of minor crops and useful plants. Most farmers were intercropping coconut and cocoa seedlings in the mixed gardens. There was much experimentation, with land managers visiting each others' gardens for ideas (p. 177).

The strength of Samoa's traditional farming system did much to avert a catastrophic situation. In the mid-19th century blight destroyed the Irish potato crop and caused the Great Irish Famine, and in Bougainville starvation accompanied the arrival of TLB just after WW2. However, the degree to which traditional farming systems are retained varies throughout the region. For example, on the Fijian island of Kadavu the virtual disappearance of yams from the cropping system has left many people dependent for food on cash earned from kava (the impact of projected climate change conditions on kava dieback is unknown). On the west side of Viti Levu, most rural people now depend on a single monoculture crop, sugar (Chapter 5).

24 Aelan taro (*C. esculenta*) and soft yam (*D. alata*) were traditionally the most important food crops, supplemented by strong yam (*D. nummularia*), breadfruit, bananas, and other minor crops. However, over the past 50–60 years, other new crops have become increasingly important. The most prominent of these has been cocoyam (*Xanthosoma* spp.) and cassava. Cassava (*Manihot esculenta*) is robust, does not require much care and can grow on poor soils. Cocoyam has greater drought tolerance and is less susceptible to cyclones. Other new crops that have gained importance are sweet potato and Wailu yam (*D. rotundata*). Village growers appreciate sweet potato (*Ipomoea batatas*) because of its short production period and resistance to cyclones (Vanuatu Land Use Planning Office 1999).

It is clear that the Pacific traditional system of production can provide a significant level of resilience to climate variability. It would seem sensible therefore, when considering how to reduce vulnerability and enhance resilience, to consider this system closely and see how it can be further strengthened, how it can be used as the foundation on which to develop commercial production, and what are the key components of the system imparting resilience that should be promoted.

4.7.1 Productivity vs. resilience: is there a trade-off to be made?

Some of the major cash crops of the region (cocoa, coffee, palm oil and bananas), and at least some of the starchy staples, especially yams and edible aroids, are derived from wild species ecologically adapted to grow in the forest, yet in commercial production maximum yields are obtained when the plants are grown in full sun, benefitting from optimum rates of photosynthesis. However, abundant supplies of water and nutrients must be available, or crops will be scorched or show other signs of stress, and will give reduced yields (Beer 1987). Such monocrops are inherently more vulnerable to water stress or extremes of temperature under 'normal' conditions, and this vulnerability is likely to be exacerbated by climate change and increasing climate variability.

The trade-off between the resilience provided by shading and maximum productivity is particularly clear in the case of cocoa (Wessel 1985). Smallholder producers in PNG, Vanuatu and Samoa tend to grow cocoa under the shade of coconuts or of specially planted shade trees, such as *Gliricidia sepium* or *Erythrina subumbrans*. Although yields are low by global commercial or local research station standards, growers obtain yields that are useful as a cash supplement to their livelihoods.

Banana is slightly different, in that it is a plant of forest clearings. Similar considerations probably apply to the swamp-adapted aroids, *Cyrtosperma* spp., because natural swamps tend to form in forest clearings exposing the plant to full sun. Aroids are by origin shade plants and therefore require attention to inputs when grown in the open. Yams present a slightly different case again in that, as forest plants, they commence growth in the shady interior but the vines tend to scramble through and over trees, into the sunshine. This situation is simulated in most production systems by staking the vines, but the roots are probably exposed to sub-optimal conditions of water, and possibly temperature-related stress.

4.7.1.1 Combining tree-crops and starchy staples

The forest origins of these key Pacific crops suggest that resilience can be strengthened by re-incorporating them within traditional agroforestry systems, as suggested earlier in this chapter. Although maximum achievable yields of the starchy staple crops may be lower than those achieved in a monocrop situation with high inputs of water and nutrients, the understorey crops in an agroforestry system will receive some protection from drying winds and excessive heat, and their yields may in practice not be much lower, on a per plant basis, than those achieved by most farmers in open fields. Further, because of the complementary architecture of the plants, the total return to the farmer is likely to be higher (as in the banana/coffee system from Uganda[25]). The resilience of the system is also likely to be greater, due to the mitigation of any temporary water or heat stress experienced by the understorey crops (as demonstrated for coffee in Mexico [Lin 2007]), and because any extreme weather event is less likely to catch both tree and understorey crops at their most vulnerable stages.

If the benefits of combining crops and trees are accepted in principle, the kinds of combinations and arrangements that are optimal, from a resilience or productivity perspective, are less apparent. Truly traditional systems, with numerous species grown together, sometimes in a near-random pattern, achieve a very high level of resilience; however, they are hard to manage for increased productivity and probably few or none of the species in the mix are provided with their own optimal growing conditions.

Multiple species agroforestry plot Photo: SPC

This has led to the development of more formal, structured, intercropping or agroforestry systems, in which plants of the same species (or similar architecture) are planted in rows, alternating in various patterns. Such arrangements allow each component crop to be provided with optimum agronomic conditions and at the same time management operations are simplified.

25 In the Arabica coffee-growing region around Mt. Elgon, annual returns per hectare averaged USD 4,441 for coffee and banana grown together, compared with USD 1,728 and USD 2,364 for monocropped banana and coffee, respectively. In Robusta-growing areas in South and Southwest Uganda, annual returns per intercropped hectare averaged USD 1,827, compared with USD 1,177 and USD 1,286, respectively, for banana and coffee alone http://www.cgiar.org/consortium-news/coffee-bananas-a-climate-smart-combination/

Intensive production of traditional root crops in Tonga Photo: Richard Markham

4.7.2 Enhancing the adaptive capacity of traditional Pacific staple food crops

Improving soil health and crop diversity, also important components of traditional farming systems, can make a significant contribution to resilience and at the same time enhance the resilience and adaptive capacity of the system as a whole, to better manage future challenges.

The following sections discuss diversity (4.7.2.1) and soil health (4.7.2.2). Two case studies are presented, which highlight the importance of diversity in strengthening the resilience and adaptive capacity of staple food crop production systems. An example is also given to illustrate how a relatively resilient traditional staple food crop (breadfruit) can be grown commercially, building on traditional farming practices but integrating information and knowledge gained from scientific research (4.7.2.3).

4.7.2.1 Broadening the genetic base of traditional Pacific Island crops

Most of the aroids grown across the Pacific originated in Melanesia, therefore the genetic diversity of these crops declines from west to east. A narrow genetic base also increases the risk from pests and diseases, as illustrated by the decimation of the Samoan taro industry in 1993 following the TLB outbreak[26]. Breeding can be used to achieve a wider genetic base of crops, and to target a specific need, such as TLB resistance, which is in effect, a reactive response. A proactive response consists of

26 The resulting annual loss in taro production from 1994–1999 was valued at Samoan Tala (WST) 25 million (or AUD 11 million). For five to six years following the arrival of TLB, little taro was consumed in Samoa, a distinct difference from the 1989 census records which showed that almost 96 per cent of agricultural households grew and consumed taro. Taro was also by far Samoa's largest exporter earner. Samoa suffered an annual loss in foregone domestic taro consumption valued at WST 11 million and a taro exports valued at WST 9 million (McGregor et al. 2011).

providing farmers with large volumes of crops and varieties for evaluation and selection, basically enhancing the farmers' portfolio and crop genepool, thereby buffering risks from abiotic and biotic stress. This approach has been used in Vanuatu by the Vanuatu Agriculture Research and Training Centre (VARTC) and by the Kastom Gaden Association Planting Materials Network in Solomon Islands.

A reactive response: breeding for taro leaf blight resistance

The projected climate conditions increase the likelihood of TLB spreading to locations currently free of the disease, such as Cook Islands, Fiji, Tonga, Vanuatu and higher elevation areas of PNG. Further, the relatively limited genetic diversity found in the taro genepools, especially in Cook Islands, Fiji[27] and Tonga, means very little resilience to the disease currently exists[28] .

Conventional methods to control TLB in Samoa failed. The introduction and use of TLB-resistant varieties enabled Samoan farmers once again to cultivate taro, but these were less than ideal in terms of Samoan taste preferences. To meet the requirements of TLB resistance, taste and a shelf life which would support a resumption of the export trade, a breeding programme[29] was established which incorporated a high level of grower participation, ensuring trials across many locations and quick uptake.

This breeding programme, informed and guided by scientific knowledge, farmer experiential knowledge and farmer trials, as well as consumer preference trials, eventually led to the introduction of locally bred TLB-resistant taro varieties. The cumulative result of the largely publically-funded TLB-resistant crop improvement programme far outweighs the costs[30]; the value of taro production over the period 1994 through to 2010 was 10 times the cost of the breeding and germplasm conservation programme (McGregor et al. 2011). Not to be forgotten are the substantial (not quantified) health and nutrition benefits from consuming taro and taro leaves, rather than processed imported grain. Taking into account expected growth in the domestic consumption, and considering recent trends in the consumption of rice and wheat, the value of taro is projected to be about ST 25 million (AUD 11 million) by 2030. With the projected increase in the markets and continued breeding and extension programme at nominal costs, the projected Benefit Cost Ratio[31] (BCR) exceeds 15 (McGregor et al. 2011).

27 The taro variety 'Tausala ni Samoa' currently exported by Fiji is very similar genetically to the taro variety (Niue), wiped out by TLB in Samoa.

28 The AusAID funded International Climate Change Adaptation Initiative (ICCAI) is currently funding the establishment of taro breeding programmes in Cook Islands, Fiji and Tonga.

29 The initial breeding programme involved University of the South Pacific (USP) plant breeders and the Ministry of Agriculture staff, utilising their own funds. Later external funds were incrementally obtained between 1994 and 2010 from various donor partners which included AusAID (TaroGen project and for support for regional germplasm conservation at the Centre for Pacific Crops and Trees (CePaCT)), ACIAR (DNA finger printing and virus testing protocol development projects), and the New Zealand Ministry of Foreign Affairs (assessment of TLB resistance methodology).

30 Production of taro for the domestic market has increased from virtually zero to 9000 tonnes in 2010. Most of this production was for local consumption, which in 2010 was valued at WST 21 million (AUD 9.3 million). The imputed economic value of this consumption was the value of the rice that would have been imported, had this taro not been available. To this had to be added the value of exported taro. In 2010, taro exports were 330 tonnes valued WST 1.1 million (AUD 0.5 million) free on board (FOB).

31 Compares the benefits (realised and future) arising from the investment of public funds with costs incurred. Both benefits and costs are expressed in present value terms using an appropriate discount rate. A BCR of 15 means the benefits obtained are fifteen (15) greater than the costs incurred - which represents an exceptionally high return on the investment of public funds.

Photo: Tolo Iosefa

Farmers assessing breeding lines from Taro Improvement Programme, Samoa

Certain factors contributed to the success of this programme, namely: a coordinated and sustained response of the funding and implementing agencies; the direct involvement of farmers in the taro breeding programme; the existence of regional genebanks at SPC and USP which helped to access the exotic material for the programme; and the high calibre of the key people involved in the identification of the project and its subsequent implementation.

A proactive response: Enhancing the genetic diversity in farmers' fields

The project implemented by the VARTC aimed to broaden genetic diversity of taro, yams, sweet potato and cassava in village farmers' fields. This successful Vanuatu pilot project was based on evaluating local diversity, incorporating some exotic diversity and then distributing large volumes of planting material for farmers to select from, conserve and use. This approach relies on the interest and enthusiasm of farmers for new diversity, and importantly, on their adopting new diversity without abandoning any traditional varieties. A social and economic assessment of this 'no regrets' strategy of establishing 'reservoirs' of genetic diversity in farmers' fields is difficult, as much of the benefit would occur during future pest and disease outbreaks, and climate-related disasters. The benefits will also depend on the maintenance of the genetic diversity in farmers' fields. Assuming new varieties are maintained, the benefits can be measured in terms of imported grain if there is a catastrophic loss of a subsistence crop. Even quite small increases in grain inputs make these investments worthwhile if they can be successfully implemented[32].

Two years after the new varieties were distributed to 10 villages, monitoring of farmers' fields showed 86% net gain in diversity for yam villages and 61% gain for taro villages. In some situations, traditional cultural practices accelerated germplasm

32 For example a mere five per cent increase in Vanuatu's grain imports, at 2011 prices, would have a cost of approximately AUD 520,000 per annum, while a 25 per cent increase would have a cost of approximately AUD 2.6 million per annum. The probability of Vanuatu having a root crop biological disaster over the next decade that resulted in at least a five per cent increase in grain imports is seen as quite high.

distribution while in others cultural practices acted as a constraint. Screening the germplasm material for distribution and establishing new varieties[33] does require significant upfront costs. However, once the 'new' germplasm is embedded in the local farming system and maintained by the farmers themselves, no additional government or donor resources are required for sustainability.

By enriching farmers' varietal portfolios, protection is provided against future epidemics and biological disasters, which can be expected to increase with climate change. In the event of a biological disaster, these reservoirs would provide a source of immediately available planting material for other parts of Vanuatu, enabling a rapid response to a disaster similar to the TLB epidemic in Samoa.

The two approaches described here recognise that broadening the genetic base of crops such as taro is essential to ensure that such crops are 'ready for change'. Achieving this requires the involvement of farmers and cooperation between countries and scientists to facilitate the exchange of germplasm and information and where necessary the use of modern technologies.

4.7.2.2 Investing in soil health: a 'no regrets' strategy

The uncertainties that surround climate change tend to favour the adopting of 'no regrets' measures (i.e. changes that will be advantageous, whatever the changing climate and other circumstances) as discussed in the previous section with diversity. Many production systems in the PICTs have already become unsustainable, as drivers such as increasing population pressure and urban migration have forced farmers to abandon traditional practices and economic incentives have encouraged them to adopt new ones, without always understanding all the implications. Reduced fallow periods or repeated cropping of high-value crops on the same land, often without rotations or sufficient replenishment of soil nutrients, have resulted in a 'rolling crisis' in industries such as the ginger and taro exports from Fiji. Growers obtain positive returns initially but soon encounter falling yields and quality, and increasing pest and disease problems, threatening the profitability of their farm enterprise. Lacking the techniques to assure sustained productivity, farmers may then clear new land from forests or abandon the crop completely — and the favoured crop will be adopted by farmers in another area, until they run into the same problems.

Targeted research and counter-measures may help to address specific problems, but these problems, such as burrowing nematode in ginger in Fiji, are symptomatic of a broader underlying problem of 'soil health' and are more effectively addressed at the level of the entire production system.

Recent work in export taro production systems in Taveuni, Fiji, while illustrating in conventional terms that inputs of fertiliser on most farms are not sufficient to replenish nutrients removed with the crop, have provided insights into unsuspected

33 The cost of the Vanuatu pilot project was approximately AUD 70,000 (McGregor et al. 2011).

problems associated with nematodes (SPC, unpublished project report 2012). Work in other crop systems has shown that the status of soils can be monitored using the nematode 'community composition' as an indicator (Ferris et al. 2001). In healthy soils, saprophytic nematode species predominate, with sufficient predatory nematodes in the community to keep plant parasitic species under control. As soils are exhausted by repeated cycles of crop production, plant parasitic species come to predominate, resulting in economic damage to the taro that is severe enough, combined with soil-borne root-rots, to threaten the profitability of production and the viability of the export trade.

Experience suggests that all dimensions of soil health are linked more or less closely to soil organic matter. Soils in the PICTs, after repeated cropping under humid tropical conditions, show disastrously low levels of soil organic matter, with correspondingly low levels of nutrient retention, water infiltration and retention (Chapter 3), and biological activity. However, preliminary data indicate that increasing the organic matter content rapidly improves the situation, moving towards restoring all dimensions of soil function (SPC unpublished project report 2012). Increased soil organic content also increases the quantity of carbon in the below-ground carbon pool and thereby has a positive secondary benefit in terms of atmospheric GHG concentrations.

Research carried out in Latin America (Coultas et al. 1996; do Prado Wildner et al. 2003; Eilittä et al. 2003) and Africa (Akobundu et al. 2000; Hauser and Nolte 2002; Vanlauwe et al. 2000) has indicated that velvet bean (*Mucuna pruriens*), grown as an intercrop or planted fallow, is particularly effective in raising soil organic matter and suppressing weeds. Used in farmer participatory trials in Tonga, under the Development of Sustainable Agriculture in the Pacific (DSAP) project, *Mucuna* reduced the need for nitrogenous fertiliser and reduced weeding costs in a subsequent crop of squash (SPC 2009).

Mucuna used to suppress weeds and rejuvenate soil in Tonga Photo: Richard Markham

Initial experiments in Taveuni showed that even a single 6-month planted fallow of *Mucuna*, after repeated cultivation of taro, increased corm weight in taro (so that a greater proportion of roots achieved export grade) and improved various soil health parameters (SPC unpublished project report, 2012). Further cycles of trials are now evaluating the use of various locally available organic residues — seaweed, 'cocopeat' and biochar (from coconut wood or multi-purpose trees), alone or in combination with inorganic fertilisers, to increase soil organic matter.

4.7.2.3 The establishment of breadfruit orchards

The resilience of a crop such as breadfruit and the contribution it can make, fresh and processed, to food security, highlights the importance of this crop. In addition, breadfruit contributes to GHG reduction, as orchard systems can be developed on land already cleared of forests. Its potential as a processed product remains untapped, yet it offers the prospect of producing large volumes of starch with negligible fossil fuel inputs; fresh breadfruit can be converted to high quality gluten-free flour and paste products. Processed breadfruit products provide an alternative to the imported rice and wheat products, on which the food security of many PICTs relies. However, as breadfruit continues to be more of a garden crop, (which does contribute significantly to food security and climate change adaptation at the village level), insufficient volumes of consistently good and known quality, are not available for processing. Strengthening the resilience of Pacific communities to climate change has to include increased effort in the processing of staple food crops, such as breadfruit, for which a prerequisite would be sufficient supply. The Pacific Breadfruit Project[34] has as one of its key objectives the establishment of breadfruit as a commercial smallholder-based orchard crop. Twenty thousand planted trees is the target for the end of 2015; six years after 2015 these trees will conservatively produce around 1600 tonnes of marketable fruit, which could supply the food energy equivalent to 5500 tonnes of boiled rice. The expansion of this project and knowledge in establishing commercial orchards to other PICTs would greatly enhance food and nutritional security in the coming decades.

34 Funded by ACIAR.

Establishing a breadfruit orchard in Fiji Photo: Andrew McGregor

4.8 The increasing comparative advantage of staple food crops

In the short term (to 2030) low vulnerability to climate change exists for staple food crop production based on current knowledge of physiological thresholds and expert opinion. However, uncertainty remains regarding changes to the pest and disease spectrum, and the impact of extreme events, such as heatwaves and droughts. In the medium term (2030–2050) the extent to which the vulnerability of staple food crops will be threatened depends on the emission scenario. Maintaining the 2030 rise in temperature of +0.5°–1°C[35] will mean minimum impact; a temperature rise approaching 2°C will increase risks for staple food crop production. Impacts beyond 2050 are more difficult to project, because of the uncertainties surrounding future emissions and the extent to which adaptations have been adopted and are successful. However, in comparing the vulnerability of the Pacific staple food crops with that of global cereal crops, it would seem that the world's staple food crops will be affected more by climate change than the staples of the Pacific, providing an opportunity for these important crops to substitute for imported grains.

The 2013 IPCC report confirmed that globally negative effects from climate change are already evident with a decline in net global yields of crops such as wheat, maize, rice and soya beans. Further, the report confirmed that 'since AR4 there have been several periods of rapid food and cereal price increases following climate extremes in key producing regions, indicating a sensitivity of current markets to climate extremes among other factors', and that 'changes in temperature and precipitation, without considering the effects of CO_2 will contribute to increased global food prices by 2050,

35 As explained in Chapter 2, these changes are in relation to the 1986–2005 baseline.

with estimated increases ranging from 3 to 4%[36] (Porter et al. 2014). This chapter has focused attention on the impact of climate change on the cost and stability of rice supplies; however, the impact of climate change on wheat is also significant for PICTs, as many imported foods are wheat-based. Strengthening the resilience of and further developing staple food production systems to meet consumer demands (quantity, quality and ease of convenience) would seem the best approach to reduce the impact of climate change on Pacific communities, and to increase opportunities for export market development.

Root crops generally are very efficient converters of solar energy, and they are also less demanding of nutrients than other crops, as illustrated by Lebot et al. (2013). Rice and other grain crops depend on high inputs, removing substantial quantities of nutrient from the soil which must be replaced to maintain yields. The total nitrogen removed through harvested rice products ranges between 192 and 248 kg per ha per year (Sukristiyonubowo et. al. 2012). In contrast the nitrogen extraction rates for root crops are:

- Cassava 69 kg N/ha/year (28 to 36% of that for rice)
- Cocoyam 174 kg N/ha/year (70 to 90% of that for rice)
- Sweet potato 170 kg N/ha/year (69 to 89% of that for rice)
- Taro 139 kg N/ha/year (56 to 72% of that for rice).

This low nitrogen extraction characteristic gives traditional Pacific root crops a comparative advantage in a world with increasing population pressure, climate pressures on agricultural production, increasing scarcity of arable land and in particular, escalating fertiliser and energy costs and nitrous oxide emissions.

The production impact on a particular crop in a particular location is only part of the overall impact of climate on the viability of growing that crop, and therefore livelihoods and government revenue. Climate change also impacts on the interaction between markets, prices and the comparative advantage of economic activities (Stern 2007). Thus it is possible that the productivity of crops in a particular location could decline as result of climate change, while the overall financial viability of growing that crop could be enhanced at least for the medium term by even greater declines in production in other growing locations. This is likely to be the case for a number of staple PICT food crops.

The Agriculture Paper prepared for the Pacific 2020 Report identified increased production of food staples as a major agricultural growth opportunity, which would contribute significantly to sustainable and broad-based prosperity at least for the Melanesian and larger Polynesian countries (AusAID 2006). As earlier discussed some Pacific staples are likely to be more resilient than global staples, especially if the farming systems in which they grow are strengthened. Therefore, a focus on increased production of food staples would enhance food security in an era of relative food insecurity, and make a significant contribution to the nutrition and health

36 Medium confidence.

status of communities. Healthy communities are an important factor in reducing the vulnerability of Pacific agriculture.

The growth opportunity for food staples highlighted in the Pacific 2020 report was seen to exist in two broad areas, namely enhancing household self-sufficiency and supplying the increasing food demand in urban markets.

The implications of climate change on the competitiveness of traditional food staples in these two areas are discussed below. Although the production of some staple crops will be adversely affected by climate change, some could become more competitive being less affected by climate and the cost of inputs than competing products from elsewhere in the world. Thus paradoxically, in an interconnected world, climate change could improve livelihoods for some rural people at least in the medium term.

4.8.1 Enhancing household self-sufficiency

The economic contribution of traditional self-sufficiency in agriculture is large and usually under-estimated. For example, Solomon Islands produces around 430,000 tonnes of staple food annually, conservatively valued at around AUD 65 million in 2005 (Bourke et.al. 2006). To put this value into perspective, the combined export value of copra and cocoa in that year was about AUD 15 million. The Pacific 2020 Report argued that the region has a long-term competitive advantage in the production of traditional self-sufficiency crops based on a combination of three factors: ability to grow; consumer preference; and high cost of imported substitutes. How are the projected changes in climate likely to impinge on these three factors?

4.8.1.1 Ability to grow traditional self-sufficiency crops

The vulnerability of the staples covered in this chapter has been discussed. Although it will become somewhat more challenging to grow staple food crops over time, opportunities exist to buffer the impact of climate change and to strengthen the production systems for these crops.

4.8.1.2 Consumer preferences

It is assumed that underlying consumer preferences for traditional self-sufficiency food will be unaffected by climate change over the forthcoming decades, and could in fact increase as imported food prices affected by climate change continue to increase. Nutrition awareness programmes could also result in altering food choices, as will improved availability of processed, easy-to-use forms of staple food crops.

4.8.1.3 High cost of imported substitutes

As discussed, the impact of climate change on rice production compared with Pacific staples is likely to be a fundamental determinant of the comparative advantage of agriculture in the future. Irrespective of any potential positive or negative impact on rice production from climate change, the main factor of poor returns on labour limiting production in Western Melanesia would remain. If the price of rice and other food grains rose very significantly on global markets, rice production in the Pacific could become more competitive. Conversely, the impact of climate change both on the market price of rice and Pacific production, combined with the 'poor returns on labour' factor, could clearly show the benefits to be gained from increased investment into the production and processing of traditional staples.

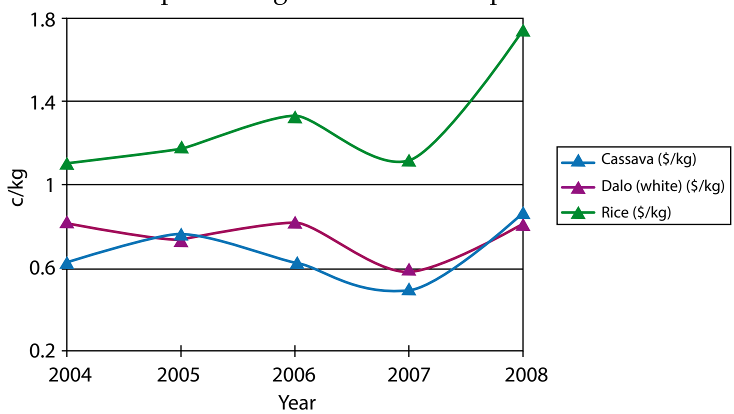

Figure 4.1 Suva Fiji staple food retail prices 2004–2008 (source: McGregor et al. 2009).

At the time of the Pacific 2020 Report, large and rapid increases in the prices of basic foods had occurred worldwide. In PICTs, prices of imported food products such as grains, meats, dairy products and vegetable oil were increasing sharply. Figure 4.1 plots the retail price of rice, taro and cassava in Suva, Fiji over the period 2004–2008, and shows price increases typical for the region, where the price of domestically grown staples increased much less than those of imported food. These price increases created renewed concerns regarding the food security and vulnerability of PICTs (McGregor et al. 2009).

Since the peak of 2008, international grain prices have subsided somewhat, although they are still well above pre-2008 levels. Over the course of coming decades the price of imported rice is very likely to increase sharply in the face of decreasing supply (climate) and increasing demand (population). The FAO's International Rice Commission notes that as world population continues to grow steadily and water resources are on the decline, global climate change can be expected to lead to substantial modifications in land and water resources for rice production as well as the productivity of rice crops grown in different parts of the world (Nguyen 2005). As previously discussed, climate change is likely to have a severe effect on rice yields. Nearly half the world's rice crop goes to market, with most sold in the country in which it is grown. Only 7% of world rice production was traded internationally during 2000–2009. There will be increasing pressure on the residual of internationally traded rice as producing countries try to protect their own food security supply base.

Expanding grain production will be constrained by the increasing cost of energy both for fertiliser and fuel for mechanisation. The need to eventually incorporate carbon price penalties for GHG emissions (methane/nitrous oxide) will be a further constraint. Since the peak of 2008, international petroleum product prices have subsided somewhat, in line with a slowdown in the global economy, although prices are still well above pre-2008 levels. These changing global conditions would suggest a permanent structure shift to the conditions that prevailed in 2008, with imports becoming increasingly more expensive relative to the traditional staples grown in the PICTs.

Even without climate change, world prices for the most important agricultural crops (rice, wheat, maize, and soybeans) will increase significantly by 2050, driven by population and income growth and demand for biofuels. The International Food Policy Research Institute forecasts that the world price of rice will rise by 62% in real terms compared with 2000 prices (Nelson et al. 2009). If climate change is taken into account the world price for rice increases by a further 32–37%. Such a level of price increase has serious food security implications for PICTs.

4.8.2 Supplying increasing urban markets

As discussed in Chapter 1, PICTs are experiencing moderate to rapid rates of urban population growth. Rapid urbanisation has created immense problems and challenges, but has also resulted in a large and under-supplied market for traditional staples and other food products. An indication of the extent to which urban populations are under-supplied with traditional staples can be seen from a comparison of per capita consumption in urban and rural areas. For example, in the rural highlands of PNG the per capita consumption of sweet potato is around 450 kg/head/year and 100 kg/head/year in rural lowland locations (Gibson 2001), which compares with less than 50 kg/head/year in urban areas. Urbanisation in PICTs can be expected to continue apace (as discussed in Chapter 1) and is likely to increase the demand and prices for traditional staples, particularly in the face of escalating prices for imported staples.

4.8.3 Conclusion

The projected increasing real cost of imported substitutes is seen as an incentive for improving and expanding production of staple food crops, focusing the efforts of both governments and communities in strengthening and increasing the resilience of crop production systems. Rural households are likely to grow more food for their own consumption and for sale to increasingly remunerative urban markets. Urban and peri-urban populations in the PICTs can be expected to continue to grow over coming decades. It remains to be seen if climate change will accelerate or constrain this growth. Regardless of the rate of urban population growth, the expected real increase in the price of imported food, particularly rice, will increase the demand for locally grown food. Building on the inherent resilience of Pacific staple food crops and Pacific farming systems and enhancing the adaptive capacity of production systems will ensure that growers are well placed to respond to this demand.

4.9 Enhancing household nutrition

Focusing efforts on increasing the sustainable production of staple food crops would also confer significant nutritional benefits. The nutritional disadvantages of consuming large amounts of rice and foods made from wheat flour are well known (Thaman 1982; Englberger et al. 2007; Hughes 2010). Health ministries and departments and other agencies have campaigned in an effort to change people's eating patterns but as long as imported foods are cheaper and more convenient to use, they will be more attractive than local foods. Cost, guaranteed supply and convenience have been identified as priorities requiring attention in any effort to encourage increased consumption of local, nutritionally-rich foods. Strategies to improve the resilience of Pacific communities to climate change present an opportunity to address this dilemma by investing in the sustainable production and utilisation of local food. Far more effort must go into converting local crops into nutritious convenience foods that are reasonably priced and easy to use, so that they become the preferred food in comparison to imported processed food. The need for sectors to collaborate on addressing the nutrition and health challenge was emphasised by the Framework for Action on Food Security in the Pacific, which was endorsed at the Pacific Food Summit (Vanuatu 2010). Strengthening the resilience of local agriculture in the Pacific can meet both the climate change and the nutrition and health challenges. And to reiterate a comment made earlier, 'healthy communities are an important factor in reducing the vulnerability of Pacific agriculture'.

4.10 Uncertainty, gaps in the knowledge and future research

The level of uncertainty that exists both with climate projections and crop responses to those projections has been discussed. The limited importance of Pacific staple food crops globally, especially the aroids, means that global studies on these crops are minimal. Banana, cassava, sweet potato and yams are covered in the research agendas of the CGIAR[37] International Agriculture Research Centres[38]. Breeding programmes, for example at CIAT for cassava, and at CIP for sweet potato, will help

37 The Consultative Group on International Agricultural Research.

38 The 15 members of the CGIAR Consortium are: Africa Rice Centre (based in Benin); Bioversity International (based in Rome); The Centre for International Forestry Research (CIFOR, based in Indonesia); International Centre for Agricultural Research in the Dry Area (ICARDA, based in Lebanon); International Food Policy Research Institute (IFPRI, based in Washington D.C.); The International Centre for Tropical Agriculture (CIAT, based in Colombia); The International Livestock Research Institute (ILRI, based in Kenya); The International Maize and Wheat Improvement Centre (CIMMYT, based in Mexico); The International Potato Centre (CIP, based in Peru); International Rice Research Institute (IRRI, based in the Philippines); The International Water Management Institute (IWMI, based in Sri Lanka); World Agroforestry Centre (ICRAF, based in Kenya); and WorldFish (based in Malaysia).

in the generation of varieties specifically targeted for various abiotic stress, such as drought tolerance. However, it must be remembered that these centres do not consider Pacific needs and constraints, so for example, sweet potato varieties with drought tolerance could be susceptible to scab disease[39]. Despite such limitations strengthening linkages with external agencies is vital to ensure the region can take advantage of new initiatives and products that will assist in reducing the vulnerability of Pacific agriculture to climate change.

To date there has been limited interaction across the region with the CGIAR, yet the CGIAR is involved in research that could be of benefit to Pacific farmers. Several of the CGIAR Research Programmes (CRP)[40] are of particular relevance to the Pacific; for example, the CRP on Climate change, Agriculture and Food Security (http://ccafs.cgiar.org/), the CRP on Roots, Tubers and Bananas (http://www.cgiar.org/our-research/cgiar-research-programs/cgiar-research-program-on-roots-tubers-and-bananas/) and the CRP on Forests, Trees and Agroforestry (http://www.cgiar.org/our-research/cgiar-research-programs/cgiar-research-program-on-forests-trees-and-agroforestry/).

Linkages with agencies outside the CGIAR system are equally important. The Hawaii-based Breadfruit Institute, in collaboration with the University of British Columbia, is the key agency carrying out a vast amount of work and research on breadfruit. CIRAD, and agencies in other similar regions, such as the Caribbean, are also involved in research that would enhance climate change and agriculture-focused programmes in the Pacific. Establishing a mechanism to strengthen communication beyond the region would improve collaboration and sharing of information.

A greater understanding of the basic crop physiology of most of the staple food crops, particularly the lesser known species such as swamp taro and giant taro, but also for the more important crops of sweet potato, taro and breadfruit, is much needed. Such information would help farmers, extension agents and researchers to better understand the causes of variation in crop performance and to distinguish between changes due to climate factors and non-climate factors.

High temperature events are likely to be a major impact of climate change. How these will affect the staple food crops is relatively unknown. Information on critical temperatures and how their timing across the growing cycle affects the crop will allow for better assessments of vulnerability to heat stress. The response of staple food crops to eCO_2 is far from clear. Collaboration with overseas agencies is essential to unravel the complexities of eCO_2 and its interaction with other factors; similar collaboration will also be necessary to progress the development of models for Pacific crops in Pacific conditions. As described previously, collaboration between CSIRO, Fiji MPI, USP and SPC has delivered some interesting results and this work is now being extended to Vanuatu (VARTC).

39 Sweet potato varieties imported from CIP were found to be vulnerable to scab in trials in Vanuatu.
40 http://www.cgiar.org/our-research/cgiar-research-programs/

Major advantages in yield have been claimed for agroforestry and intercrop systems. Combinations of crops are believed *a priori* to offer greater resilience in the face of extreme weather events and climate change but the research needed to quantify these effects and optimise such systems is highly complex. The influence of each factor (for instance, competition for water or nutrients) changes in interaction with the climate, environment and management regime. Then the crops themselves offer an experimentally challenging combination of species, arrangements and spacing.

One approach for cropping systems research would be to start with systems already in use in the Pacific, such as the rows of taro and giant taro under coconut in Tonga, and aim to improve them incrementally, through formal experiments. Although formal agronomic research could probably increase the productivity and resilience of such systems, especially in combination with the introduction of new varieties, the work would be experimentally challenging. Once models for key Pacific crops are established, they could be used to focus the experimental work on the most important variables. Then social and economic research would help show to what extent similar systems, with appropriate modification of crop species and management practices, might be adopted elsewhere in different climates and cultural settings.

Any research programme on resilient farming systems should include monitoring of financial and economic effects, involving the development of gross margin models that emphasise the returns to effort of household labour. For small holders the returns to effort of family labour are a key consideration in deciding whether to plant a particular crop or adopt a specific cropping system. Such gross margins need to be developed for diverse agroforestry multi-crop systems on a plot basis (McGregor 1999; Vanuatu Land Use Planning Office 1999).

For all the staple food crops, possibly the most uncertainty lies with the impact of climate change on pest and disease incidence and severity. It is unrealistic to expect that projections can be made for each crop and for each pest and disease, so efforts should focus on those pests and diseases of most significance. At the same time, staple food crop farming systems should foster integrated pest management (IPM) approaches. Farmers must be able to monitor any pest and disease problems and be technically supported, possibly through a network of plant health clinics.

The importance of soil health in improving and sustaining the resilience of staple food crop production systems is clear, and has been discussed in Section 4.7.2.2. There are a number of options available for sustainably improving soil health but finding the best approach in terms of improving the soil, increasing crop yield and quality and importantly farmer adoption, which is strongly influenced by associated labour and costs, is not easy. ACIAR is currently investing in this area with a number of projects; however, more investment and efforts are needed. Work on the technical value of organic amendments is, and must always be, closely linked with farmer participatory research to help farmers understand the value of such materials and to investigate which ones can be collected and incorporated into the production system at acceptable cost.

Diversity, both existing and improved, is a very important tool. The SPC CePaCT collections and other collections in the region have crops and varieties in need of scientific evaluation to better identify the level of resilience available in those collections. Resilient diversity in farmers' fields also needs to be investigated. Timely access to diversity requires strengthened planting material distribution systems, involving community, national and regional genebanks. As discussed in Section 4.7.2.1, informal (on-farm) diversity collections are an important buffer to climate variability, yet on-farm/*in situ* approaches to conservation and utilisation have been neglected, and therefore need attention. The extent of diversity required to adequately buffer production systems is also unclear — how much is enough?

Varieties need to be developed that are more tolerant of climatic and environmental extremes. Better understanding of salinity tolerance is required. Breeding programmes to develop these more tolerant varieties should also have nutritional and consumer taste considerations as a priority so that the resulting varieties are not only climate tolerant, but are more readily taken up by farmers and consumers, and have a higher nutritional value per unit of weight harvested. The limited number of propagules available for establishing the next generation is often a constraint to investment into breeding programmes; however, tools are available that allow for the selection of desirable traits, including nutritional characteristics, early in the process.

Traditional staples can be expected to become relatively more efficient than grain crops in the production of calories and starch. It is therefore vital to identify the best methods for commercial processing of staple food crops so that consumers can be supplied with healthy food in a user-friendly form. Improving production systems must be accompanied by increased effort and investment in processing and value-adding.

Better seasonal forecasting and communication of climate information is required so that farmers can plan what to do, and of course this should be linked to a realistic set of adaptation options, not forgetting the underlying importance of inherent resilience through good soil fertility and diversity. Some studies have shown that there is often a mismatch between farmers' needs and the scale, context, format or accuracy of available climate information products and services. However, in contrast, pilot projects in Zimbabwe and Burkino Faso have also proved successful with moderately high adoption rates and benefits reported (Vermeulen et al. 2012).

More could be done in the sharing of knowledge, especially between farmers across the different PICTs. Farmers in some countries have experience of crop production in excessively wet climates, and in contrast, others know how to manage drier climates. The newly established Pacific Island Farmer Organisation Network (PIFON), with its emphasis on farmer-to-farmer exchanges, has an important role to play in this respect. Farmer-to-farmer exchange systems, incorporated into climate change projects elsewhere, have proved to be successful in sharing information and experience; farmer field schools could also be used for this purpose. Looking further ahead, exchanges outside the region would also be useful to learn about 'new' crops that might have to be introduced to manage future climate demands.

4.11 Management implications and recommendations

There are a number of management implications and measures that need to be considered and these are described below; however, the over-riding priority for management is to recognise the huge importance of Pacific staple food crops for future food and nutritional security, and to put in place policies and strategies that acknowledge their value. These crops, compared with many others around the world, are likely to be relatively resilient to the climate conditions projected for the future, and not only can they sustain food security, they also provide an opportunity for economic benefits. Recognising their value is the first step, recognising the importance of traditional approaches and inputs to producing these crops and how these can be improved and strengthened through research is the next step.

Enhancing national and regional self-sufficiency through strengthening the production and increasing the consumption of these crops will be the most effective approach for meeting the climate and non-climate challenges projected for the future. Climate change is too often considered in isolation; decision-makers need to acknowledge that nutrition-related health challenges and climate change challenges are linked, and that by increasing the sustainable production of staple food crops both types of challenges can be addressed.

Cross-sectoral and multi-agency collaboration is crucial if the role of staple food crops is to be considered as significant in addressing the climate change and food security challenge. The need for this collaboration was proposed and described in the 'Framework for Action on Food Security in the Pacific'[41]. The strategies and actions described under Theme 3 of this framework 'Enhanced and sustainable production, processing, marketing and trading and use of safe and nutritious local food', remain as relevant now as they did when the Framework was endorsed at the 2010 Pacific Food Summit in Vanuatu. The Framework recognised the need to reduce the region's dependency on imported rice and wheat products and minimise government import bills. Replacing these imported products with staple food products will improve health across the region and reduce governments' health costs. Improved health and more available funds can only help to reduce vulnerability to climate change. Increased capacity in processing would greatly enhance a country's food security, and national and regional availability of healthy processed products could play an important role in any post-disaster food relief strategy.

41 Towards a Food Secure Pacific: Framework for Action on Food Security in the Pacific, 2011–2015.

As discussed in this chapter, it is important to acknowledge that many of the problems experienced now with climate variability stem from a weakness in current food production systems, often as a result of abandoning traditional practices, or an over-reliance on 'what has worked in the past', and a tendency to consider agriculture as separate from the environment. As recent extreme weather events in the region have shown, contemporary production systems are highly vulnerable, both to cycles of drought and excessive rainfall and to extreme weather (concentrated rainfall and high wind speeds) associated with cyclones and tropical storms. Plots of taro and other moisture-loving crops are often grown on alluvial soils along rivers, where they benefit from generally relatively favourable water and nutrient status, but are subject to flooding or prolonged periods of waterlogging after heavy rains. Other crops are grown on excessively sloping lands, where they are subject to loss of soil by erosion and loss of nutrients by eluviation, as well as gully erosion due to excessive runoff from deforested watersheds above.

Addressing these weaknesses and ensuring that food production systems take into account factors such as soil fertility, crop and tree combinations and integrated pest management, etc. will enhance resilience to climate change and can provide a solid foundation on which commercial systems can be established. Recognising that traditional approaches must often be combined with scientific research is important. Investing in scientific capacity must also include investing in the capacity of users to demand, interpret and apply scientific outputs effectively. Importantly, thinking at the landscape or ridge-to-reef, ecosystem scale will enable better land use planning, more effective research prioritisation and will help to identify opportunities for synergies.

Research must also focus on improving our understanding of uncertainties, to enable more confident decision-making and allocation of limited resources. Coordination and effective monitoring of research is essential, especially as decisions on further actions will be influenced by outputs and outcomes. Technical Advisory Boards or Groups (TAB or TAG) have often been used to guide individual projects; a similar mechanism could be adopted within countries and across the region. A key challenge will be to link research, policy and action across the whole food production system, from field to landscape, or ridge to reef.

To achieve a reduction in vulnerability and an improvement in adaptive capacity will require, in many if not all cases, long-term planning and long-term support. Solutions or impacts will not be realised within a short time frame. As stated by the HLPE[42] (2012), 'addressing food security and climate change requires concerted and coordinated involvement and action of many actors, farmers, private sector, and public actors national and international, civil society and NGOs. It is especially challenging as they are very different, sometimes with conflicting objectives and there is a need to work on the long term perspective while most of them have to consider first a short term outcome. This requires the involvement of all stakeholders'.

42 HLPE: High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security.

4.12 Summary: The likely response of staple food crops to climate change

Crop	Climate change/climate variability impact in recent decades	The impact of climate change over the next two to three decades (2030–2050)	The impact of climate change beyond 2050
Sweet potato	El Niño-Southern Oscillation (ENSO)-induced droughts have had a major impact on production, particularly in PNG	Impact on tuberisation and yield will be greatest in those countries where rainfall is already high, and where temperature is currently around 32°C. Impact on pests and diseases is unclear — possibly increased pressure from sweet potato scab **Overall production assessment impact: moderate**	Increasingly serious impact for those countries where there is currently high rainfall and temperatures, especially with high emissions scenario. The impact on pests and diseases is unclear. **Overall production assessment impact: moderate to high**
Cassava	No clearly discernible direct impact	Impact is expected to be minimal, but extreme rainfall events could cause problems with waterlogging. Cyclone intensity could cause lodging problems which would affect growth. Possible yield benefits from eCO_2 **Overall production assessment impact: insignificant to low**	Extreme rainfall and cyclone events would be likely to increase lodging and waterlogging problems. It is unclear how cassava pests and diseases will be impacted. Possible yield benefits from eCO_2 **Overall production assessment impact: Low to moderate**
Aroids	For taro ENSO-induced droughts and cyclones have adversely affected taro production. Likely connection between incidence of taro leaf blight in Samoa and increasing minimum night-time temperature. For cocoyam no direct discernible impact. Swamp taro pits found on atolls affected by saltwater intrusion. No clearly discernible direct impact for giant taro	Taro leaf blight pressure could increase in those countries where it is already present and could occur in those countries, such as Fiji, Cook Islands and Tonga, where it is currently absent. Problems with other pests (armyworm) and diseases (*Pythium*) could also increase. Countries where rainfall levels are currently a constraint could be more able to grow taro. Increased intensity of cyclones could cause damage depending on stage of crop growth. For cocoyam and giant taro — impact is expected to be minimal. For swamp taro — increasing losses from saltwater intrusion are likely. Taro — possible yield benefits from eCO_2 **Overall production assessment impact: taro (low to moderate), cocoyam (insignificant), swamp taro (moderate to high), giant taro (insignificant).**	Very high temperature increases (>2°C) could affect production especially in countries where temperatures are currently high. Cyclones will continue to cause damage. A continued spread and increase of TLB and other taro pests and diseases would also be expected. For cocoyam and giant taro — temperature (>2°C) would be a constraint to productivity. Swamp taro could disappear from atoll environments. Taro — possible yield benefits from eCO_2 **Overall production assessment impact: taro (moderate to high), cocoyam(low), swamp taro (high), giant taro (low),**

Yams	Impact from ENSO-induced droughts and cyclones. No clearly discernible direct impact on wild yams	Impact from increased intensity of cyclones would be expected and increased rainfall likely to increase incidence and spread of anthracnose **Overall production assessment impact: wild yam (insignificant) domesticated yams (moderate to high)**	Projected temperature rise could affect bulking and therefore yield. Damage from cyclones would occur and increasing rainfall levels would intensify anthracnose problems. **Overall production assessment impact: wild yams (low) and domesticated yams (high)**
Rice	No information available for Pacific. Globally, rising temperatures, especially at night have caused yield losses of 10–20% in some locations.	Increasing temperature expected to decrease rice yields and overall rice production in tropical locations. Rice production in PICTs likely to become even less viable in terms of productivity **Overall production assessment impact: moderate to high**	Severe global shortages in rice available for export. The high price of imported rice expected to enhance the comparative advantage of Pacific Island rice production and other staple food crops **Overall production assessment impact: high**
Breadfruit	Apparent changes in fruiting patterns due to changes in rainfall	Expected to be minimal though cyclone damage likely to increase **Overall production assessment impact: insignificant to low**	Expected to be minimal though higher temperatures could reduce fruiting and fruit quality. Cyclone damage will worsen with increased intensity of cyclones. Possible increase in pest and disease problems **Overall production assessment impact: low to moderate**
Aibika/bele	No apparent impact from any change	Minimal impact likely from increasing temperature, but changes in rainfall will increase pest and disease problems. Increase in frequency and intensity of drought will affect growth. **Overall production assessment impact: low**	More problems with pests and diseases from increased rainfall **Overall production assessment impact: low to moderate**
Banana	Cultivation at higher altitudes with warmer temperatures	Favour cultivation in currently sub-optimal locations and at higher altitudes. Higher temperatures could affect flowering and fruit filling. Higher temperatures could increase pest and disease. Increase in cyclone damage **Overall production assessment impact: low**	Increased pest and disease pressure (Fusarium wilt, nematode and weevil) is likely though the enhancing impact of rainfall on BLDS could be lessened by higher temperature. The heat stress effect on flowering and fruit filling would increase, as would cyclone damage. **Overall production assessment impact: low to moderate**

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Photo: Jillian Greenhalgh

Chapter 5

Vulnerability of export commodities to climate change

Andrew McGregor, R. Michael Bourke, Vincent Lebot and Mary Taylor

Contents

5.1 Background

Most PICTs are reliant on a limited number of export commodities for most of their agricultural export earnings. The region's tree crop commodity exports are copra and coconut oil (PNG, Solomon Islands, Vanuatu, Fiji and minor industries in Kiribati, Samoa and Tonga), coffee (PNG and minor industries in Vanuatu and Tonga), cocoa (PNG, Solomon Islands, Vanuatu, Samoa and a minor industry in Fiji), palm oil (PNG and Solomon Islands), rubber (PNG) and tea (PNG). This chapter focuses attention on the four major tree crop commodities: coconuts (*Cocos nucifera*), coffee (*Coffea arabica*), cocoa (*Theobroma cacao*) and oil palm (*Elaeis guineensis*). Rubber (*Hevea brasiliensis*) and tea (*Camellia sinensis*) are not covered because they are relatively minor export commodities and are only grown in PNG.

Sugar, as a commodity export, has also been included in this chapter, with Fiji the most important exporter of sugar. There is a small commercial industry in PNG for the domestic market, but only 10–15% of production is exported.

For the countries of western Melanesia (PNG, Solomon Islands and Vanuatu) tree crop commodity exports are the main source of income for many rural households. These countries have a competitive advantage in the production of traditional tree crop commodity exports and considerable scope exists for enhancing their contribution to broadly-based rural livelihoods by increasing productivity and improving quality (AusAID 2006). This chapter considers the impact of climate change on the competitiveness of these crops.

Apart from a few niche markets, such as fine flavour, single origin cocoa from Samoa and virgin organic coconut oil-based products, smaller PICTs are no longer significant commodity exporters. It is unlikely that they will return to these exports in the future, regardless of the impact of climate change.

5.1.1 Coconuts

In coastal locations coconuts are of fundamental importance. Coconuts could have justifiably been considered as a staple food crop in Chapter 4. For example, the Smallholder Study in Solomon Islands estimated that around 110 million coconuts are consumed by households annually (Bourke et al. 2006). This equates to around 20,000 tonnes of copra. Coconuts are exported as whole nuts, copra, coconut oil manufactured from copra, or oil extracted directly from fresh coconuts. In remote locations, coconut oil is used for cooking oil, and it is also starting to be used as a fuel substitute for imported diesel. Samoa has experimented with its use for electricity generation on the main island, Upolu.

Coconuts tolerate neglect perhaps better than any other crop. Timing of harvest is not as critical as for most tree crop products and indeed in most PICTs, producers of copra and oil products nowadays simply wait for the nuts to fall, rather than picking from the tree (unless selling the nuts for 'coconut water'). Copra is relatively non-perishable and thus is more tolerant to infrequent and unreliable transportation infrastructure than other crops. The biggest constraint to producing copra is the high labour requirements relative to the price received.

Photos: RM Bourke (left) and Andrew McGregor (right)

Working in a copra drier, PNG and cutting copra, Vanuatu

Copra and coconut oil remain Vanuatu's most important export earner, while in Solomon Islands coconuts have now been surpassed by palm oil as an export earner. In both these countries the coconut industry, despite its decline, remains the largest contributor to rural income generation. In PNG and Fiji the copra industry is of less importance but still continues to provide a meagre source of cash income for households in outer island locations. For a few rural households virgin coconut oil is now becoming important.

In PNG, it is estimated that some 200,000 households grow coconuts, and that copra provides income for 40% of the people living in coastal mainland and island areas (Bourke and Harwood 2009). Copra, taken together with cocoa, is the second most important sector in terms of employment after coffee[1]. In some of the atoll micro-states, such as the Republic of the Marshall Islands and Kiribati, coconut products continue to provide a small but important source of income. The copra industry in Fiji and in the atoll countries is subsidised with the intention of supporting and providing rural livelihoods.

5.1.2 Coffee

In PNG, more than half of the rural population live in households that generate income from Arabica coffee (Bourke and Harwood 2009).

Coffee is not important in other countries in the region, apart from small niche Arabica coffee industries in Tonga and on the island of Tanna in Vanuatu. Small quantities of Robusta coffee (*Coffea canephora*) are grown in some lowland areas of

1 On the production side it is difficult to separate cocoa from copra because they tend to be grown by the same people on the same land, with coconuts producing the shade for cocoa.

Photos: Fairtrade, New Zealand (left) and RM Bourke (right)

Picking coffee and selling parchment coffee in PNG Highlands.

PNG such as East Sepik. Robusta coffee has now largely been replaced by cocoa in recent years in these locations.

5.1.3 Palm oil

Palm oil is now PNG's largest non-mineral export earner, with an FOB[2] value of USD 632 million in 2011, compared with USD 392 million for coffee and USD 132 million for cocoa (Bank of Papua New Guinea 2012). Palm oil has also become Solomon Islands' largest agricultural export earner, with an FOB value of USD 37.6 million in 2012, compared with USD 17.4 million for copra and coconut oil and USD 8.9 million for cocoa (Central Bank of Solomon Islands 2013).

Harvesting oil palm fruit, PNG

Photo: Richard Markham

2 FOB: price loaded on the aircraft or vessel ready for shipping.

5.1.4 Cocoa

Cocoa constitutes an important export industry for PNG, Solomon Islands and Vanuatu, providing a livelihood for large numbers of small holders in lowland locations.

Removing cocoa beans from pods Photo: Richard Markham

In the mid-1990s 850,000 people (27% of the rural population) in PNG lived in households that earned income from the selling of cocoa (Bourke and Harwood 2009). In Solomon Islands over 1600 village-based households grow cocoa (Solomon Islands Ministry of Finance 1997). Cocoa is also an important source of livelihoods in Vanuatu — according to Vanuatu's 2006 Agricultural Census, 4882 households (25% of all households) sold cocoa beans in that year. Declining yields in recent years are the result of a high incidence of pests and diseases and poor crop management. Samoa has a significant industry for domestic consumption and in the past had a major export industry. Fiji has a minor cocoa export industry.

5.1.5 Sugar

Fiji is the only country with a significant export sugar industry. Although the industry has been in decline over the last two decades, it directly employs around 13% of the country's labour force and constitutes about 17% of total domestic exports, valued at approximately USD 94 million FOB in 2012 (Fiji Bureau of Statistics 2012). In PNG there is a significant import substitution sugar industry based in the Ramu Valley, with a small quantity exported in most years.

Fiji sugar cane farms, Bucaisau Photo: Padma Lal

5.1.6 Pest and disease status

The export commodities discussed in this chapter are susceptible to a number of production pests and diseases and post-harvest storage pests. Some already exist in the region and are currently controlled; others have caused serious damage outside the region and therefore are a potential threat to productivity. As discussed in Chapter 3, little information is available regarding the impact of climate change on pests and diseases, and in some cases, very little is known about the actual pests or diseases. Further, pests and diseases can be a major biosecurity constraint in moving planting material around the Pacific and therefore, hinder the introduction of new germplasm to support climate change adaptation. The pest and disease status of these crops is summarised below.

5.1.6.1 Coconuts

In PICTs the major pests of coconut are considered to be the *Oryctes* rhinoceros beetle (*O. rhinoceros*) and the *Scapenes* rhinoceros beetle (*S. australis*). *Brontispa longissima*, coconut leaf beetle, can also be a serious problem. Both adults and the larvae feed on the youngest leaf tissue in the throat of the palm and continuous feeding on young palms can kill them[3]. Both the rhinoceros beetles and coconut leaf beetle are considered to be largely under biological control, so a vital but as yet unanswered question relates to how climate change may affect the balance between these pests and the biocontrol agents. In recent years the level of damage on palms by the coconut rhinoceros beetle, has become severe. A breakdown in the effectiveness of biocontrol agents, *Oryctes rhinoceros nudivirus* (OrNV) and the fungus *Metarhizium anisophilae* (which contributed to the success achieved in controlling this pest in

3 http://www.fao.org/forestry/13374-0bba732bf9dfa85a4f0cd036b5a26f6d0.pdf

the early 1980s and 1900s along with interventions such as sanitation, pheromone trapping, cover cropping and insecticides) is considered responsible for the increased damage[4]. Furthermore, a new genome of *O. rhinoceros*, which invaded Guam in 2007 and recently (December 2013) invaded Hawaii is resistant to the OrNV (Vaqalo pers. comm.).

Coconut foliar decay disease (CFDD), is associated with infection by *Coconut foliar decay virus* (CFDV), and is endemic to Vanuatu. The local cultivar `Vanuatu Tall' is the only cultivar that is fully tolerant, while introduced cultivars and hybrids are affected to different degrees. The virus is spread by *Myndus taffini* (Labouisse et al. 2011).

In PNG a lethal disease known as the Bogia coconut syndrome has recently attracted attention because it has spread to new areas, closer to centres of trade and population. The disease is associated with a phytoplasma very similar to coconut lethal yellowing and in November 2012, was already responsible for the death of 5000 palms[5]. It has also been found well within 20 km of the International Coconut collection held in Madang, which conserves varieties for the whole region. There is a possibility that it also affects betel nut and banana. A new wilt disease of banana has recently been identified which is as devastating as *Fusarium* or bacterial wilt (Davis et al. 2012). Both the pathology and epidemiology of these diseases are poorly understood.

5.1.6.2 Coffee

The major concern with coffee production is coffee berry borer (CBB) (*Hypothenemus hampei*), which has caused yield losses as high as 50% in coffee regions in Indonesia, South America and Southeast Asia. PNG is one of the few remaining major coffee growing areas where CBB is not present though it has been found close to the land border on the Indonesian side and an incursion (into PNG) has been reported (CABI 2014). The absence of CBB to date has provided the Pacific region with a major competitive advantage.

Coffee leaf rust (*Hemileia vastatrix*) is a fungal disease that has had a major impact on coffee production globally over the past 200 years, having a greater impact in higher temperature locations. It was introduced into the PNG highlands in 1986, causing loss of production at lower altitudes (800–1400 m), but is not as yet a serious pathogen in the main producing zone at 1600–1800 m altitude.

5.1.6.3 Oil palm

The most serious disease of oil palm, basal stem rot (BSR) is caused by *Ganoderma boninense*, though other species of *Ganoderma* can also be involved. The disease causes infection of the basal stem roots and the affected palm can be killed (Chung 2011).

4 http://www.pestnet.org/SummariesofMessages/Crops/Plantationcrops.aspx
5 http://www.pestnet.org/SummariesofMessages/Crops/Plantationcrops/Coconutoilpalm/VirusesPhytoplasmas/Bogiacoconutsyndrome,PapuaNewGuinea.aspx

This disease is now a major threat to PNG, where a number of *Ganoderma* spp. have been recorded, mostly in logs (Shaw 1984). The threat will grow as the plants age and are replaced. The Australian Centre for International Agricultural Research (ACIAR) has a major BSR research project in Solomon Islands, with technical support from the PNG Oil Palm Research Association Inc.

Ganoderma disease in logs Photo: Richard Markham

Rhinoceros beetles (*Oryctes* spp.), can also be a problem, attacking palms at night almost as soon as they are planted. Rotting stems of palms provide multiplication sites for the larvae, which can cause problems with replanting[6] and the abundance of breeding sites offered by fallen palms can lead to severe outbreaks in the years following cyclones.

5.1.6.4 Cocoa

In PNG the most serious pest of cocoa is cocoa pod borer (*Conopomorpha cramerella*). The larvae cause the damage, feeding inside the pods, causing seeds to stick together, resulting in undersized seeds and poor quality cocoa beans. As the fruit pulp becomes hard the normal fermentation process is rendered ineffective. Young, green cocoa pods are particularly susceptible[7].

Black pod disease, caused by the fungal disease *Phytophthora palmivora*, can cause major production losses throughout all cocoa growing areas in the region. For example, an assessment carried out in Vanuatu in 2005 indicated that 60% of potential yield was lost due to this disease (Coulter 2005). In Samoa, losses of 60–80% due to

6 http://www.cirad.fr/en/publications-resources/science-for-all/the-issues/oil-palm/what-you-need-to-know/cultivation-harvesting-and-diseases

7 http://www.daff.qld.gov.au/plants/health-pests-diseases/a-z-significant/cocoa-pod-borer

black pod in wet years were reported by Keane (1992). The disease is particularly prevalent in high rainfall conditions where crop sanitation and air flow is poor; good pruning is therefore critical for controlling black pod. Some PNG varieties have a high degree of resistance to black pod disease, particularly when good field sanitation is maintained[8].

Damage caused by cocoa pod borer Photo: Richard Markham

Vascular streak dieback of cocoa is caused by a basidiomycete fungus (*Ceratobasidium theobromae*), known only in PNG and Southeast Asia. It is a windborne leaf-penetrating vascular pathogen that sporulates and spreads during wet weather at night (R. Davis pers. comm.).

5.1.6.5 Sugar

The only significant disease of sugar in the region is Fiji disease (FD) caused by *Fiji disease virus* (FDV) and transmitted by the planthopper, *Perkinsiella saccharicida* Kirkaldy. The disease is controlled by the cultivation of resistant varieties. Ramu stunt disease has caused significant production problems in PNG, particularly in the period 1984–86. Other important pests have been moth stem borer, cicadas and white grub (Bourke and Harwood 2009).

8 http://www.pacificdisaster.net/pdnadmin/data/original/MAL_SLB_Phytophthora_palmivoraExtDFsheet6.pdf

5.2 Optimum bioclimatic conditions and suitability of Pacific Island conditions

As with the staple food crops in Chapter 4, the first step in determining the likely response of these export crops to climate change is to consider the optimum conditions for their production and from this information, assess whether future climate projections will place conditions outside of these physiological thresholds. This section discusses the optimum bioclimatic conditions and indicates, where known, the responses when conditions are not favourable to growth and production.

5.2.1 Coconuts

Coconuts thrive in a tropical environment with a mean temperature of 28°C, a maximum of not more than 34°C and minimum of not less than 22°C (Foale and Harries 2011). A diurnal variation of 6°–7°C is ideal. Preferably the relative humidity should be more than 60%, with no prolonged water deficit or excess soil salinity. Coconuts are favoured by evenly distributed rainfall of 1000–2250 mm annually, but can tolerate higher rainfall if soils are well drained. Good conditions for coconut production are commonly found at elevations below 600 m, although they produce at elevations up to 950 m in PNG.

South Pacific tall coconut varieties evolved in cyclone-prone environments and therefore have adapted to survive in the strongest of winds. The most violent winds can uproot or break mature palms, but only young and senile palms are really vulnerable. A major problem facing coconut industries is the ever-increasing percentage of senile palms. The main cyclone damage to coconut palms comes from the stripping of fronds which causes premature nut fall and damage to young inflorescences, delaying (although not stopping) future nut production.

Introduced hybrid coconut varieties, which are shorter and less elastic, have proven to be far less cyclone tolerant than the tall varieties that have evolved in the region. Labouisse et al. (2007) found considerable variation in resistance to wind across three groups (Dwarf, Tall and Dwarf x Tall) studied in the collection in Espiritu Santo, Vanuatu.

Coconuts can survive drought conditions, hence their ability to grow in atoll conditions. However, prolonged drought significantly delays nut production. They will tolerate short periods of intensive rainfall and longer periods on well-drained soils. Coconuts will also tolerate short periods of saltwater inundation.

5.2.2 Coffee

For Arabica coffee the ideal average temperature range is between 15°–24°C (ICCO 2013). Robusta coffee can flourish in hotter conditions with an optimum of 24°–30°C.

At temperatures above 23°C, the development and ripening of fruit is accelerated, often leading to the loss of beverage quality. Continuous exposure to temperatures above 30°C leads to stress, which is manifest as depressed growth and abnormalities. In regions with a mean annual temperature below 17°–18°C growth is also depressed (Davis et al. 2012).

In general, coffee needs an annual rainfall of 1500–3000 mm, with Arabica needing less than other species. The pattern of rainy and dry periods is important for coffee growth, budding and flowering. Insufficient moisture can cause biennial bearing; wet conditions can delay ripening; small rainfall events can initiate flowering. This makes coffee more directly susceptible to climate change and climate variability than other tree crops like coconuts and oil palm. PNG highland locations in the altitude range of 1600–1800 m offer ideal conditions for the production of Arabica coffee, as do upland locations on Tanna in southern Vanuatu.

Wind can affect growth by reducing leaf area and, if extreme, can damage leaves and buds and exacerbate the shedding of developing flowers and fruits. Hot winds will increase evapotranspiration and therefore water requirements will be higher (DaMatta and Ramalho 2006). However, most of the region's coffee is not grown in cyclone-prone areas.

5.2.3 Cocoa

Climatic factors, particularly temperature and rainfall, are important determinants of cocoa productivity. Cocoa is tolerant of high temperatures and moderately high rainfall. Variations in the yield from year to year are attributable more to rainfall than any other climatic factor (ICCO 2013), as the trees are very sensitive to soil water deficiency.

Wood and Lass (1985) summarise the climatic conditions for optimum cocoa production as:

- a mean maximum temperature of 30°–32°C with a mean minimum temperature of 18°–21°C;
- rainfall of 1250–3000 mm per annum and preferably between 1500–2000 mm, with a dry season of not more than three months with less than 100 mm rain per month; and
- no persistent strong winds.

Wood and Lass also report on research from Trinidad which demonstrated that a constant temperature above 31°C leads to a loss of apical dominance and numerous flushes with small leaves produced by the axillary buds. However, this does not occur with diurnal temperature variation.

The climate in PNG's cocoa-producing areas is more uniform than the cocoa areas of West Africa and South America (Wood and Lass 1985). In areas such as the Gazelle Peninsula, East New Britain and Bougainville, rainfall tends to be well distributed with no dry months. Further, temperatures vary only slightly and tend to be one or two degrees higher than those in other major cocoa-producing countries. Similarly, in PNG sunshine hours show comparatively little monthly variation and are, in total, generally higher than other producing areas (Wood and Lass 1985). Bourke (2013) reports that the mean annual rainfall in the main producing areas is 1800–3000 mm on the Gazelle Peninsula and 2500–3000 mm in northeast Bougainville Island, although there is some production in locations where the annual rainfall is 3000–4000 mm/year, for example, on Karkar Island in Madang Province. The relative uniformity of the PNG climate could mean that PNG cocoa is less resilient to changes in temperature and rainfall. A similar situation prevails in Solomon Islands with respect to temperature. Malekula, the main production area in Vanuatu, is cooler and tends to be drier. Malekula is also subject to cyclones.

5.2.4 Palm oil

The oil palm growing areas of PNG (particularly West New Britain) and Solomon Islands (western Guadalcanal) provide optimum climatic conditions for the crop such that some of the highest yields in the world are obtained in these locations.

Oil palm plantation, Solomon Islands. Photo: Clement Hadosaia

Palm oil is an equatorial crop that requires high temperatures and reasonably wet conditions. The reported ideal conditions for growing oil palm are:

- Hartley (1988): annual rainfall of 2000 mm or greater, evenly distributed, without a marked dry season, and preferably at least 100 mm in each month; a mean maximum temperature of about 29°–33°C and a mean minimum temperature of about 22°–24°C; and sunshine of 5–7 h/day in all months with solar radiation of 15MJ/m^2 per day.
- Goh (2000): annual rainfall of 2000–2500 mm; relative humidity above 85%; low vapour pressure deficit; no extreme temperatures or wind speed; adequate sunshine hours and solar radiation of 16–17 MJ/m^2 per day.

Other requirements include high soil fertility and no limitation to root development (Corley and Tinker 2003).

Oil palm is highly susceptible to cyclones and is therefore unsuitable for cultivation in locations where wind speeds exceed 90–140 k/hour (Goh 2000). Furthermore, as oil palm is intolerant of severe drought it is only moderately suited to locations with a dry season of two to four months and unsuitable where the dry seasons extend from five to six months. Oil palm is therefore not commercially viable in Vanuatu and Fiji. In Vanuatu the possibility of developing oil palm plantations has been considered since the 1950s and a five-hectare trial was established on the Saraoutou station on Santo in 1969. Calvez (1983) noted that:

The ten varieties introduced flowered in 1972 when Cyclone Wendy caused them very severe damage. Between 1974 and 1975 the production rose from 8 to 24 tons of bunches harvested per year and in 1976 and 1977 it reached 28 tons. In 1978 a slight fall in production was associated to two years of dry weather and a minor cyclone in January 1979. Although this depression hardly damaged the other crops, it caused the oil palm yields to decline to 14 tons. The production reached 20 tons in 1982 but was down to only twelve in 1983 as a result of Cyclone Jody. This sensitivity is an unacceptable risk when considering an investment in this crop. Another problem associated with Vanuatu's latitude is the seasonal yield factor which becomes more pronounced when the crop is grown away from the equator. Another one-ha trial established at Tagabé agricultural station on Efate, confirmed the poor adaptation of the species to Vanuatu climatic conditions.

5.2.5 Sugar

Sugar cane productivity and juice quality are profoundly influenced by the climate conditions that prevail during the various growth stages of the crop (NETAFIM 2013). The 'ideal' climate to maximise cane sugar production is detailed below:

- Long, warm growing season with a high incidence of solar radiation and adequate moisture (rainfall).
- Fairly dry, sunny and cool, but frost-free season for ripening and harvesting — moisture percentage drops steadily throughout the life of the sugar cane plant[9].

9 From 83% in very young cane to 71% in mature cane, while sucrose increases from less than 10% to more than 45% of the dry weight.

- Total rainfall between 1100–1500 mm is adequate provided rainfall is abundant in the months of vegetative growth followed by a dry period for ripening. During the active growth period, rainfall encourages rapid cane growth, cane elongation and internode formation. During the ripening period high rainfall is not desirable because it leads to poor juice quality, encourages vegetative growth, formation of water shoots and an increase in tissue moisture. It also hampers harvesting and transport operations.
- Photosynthetic efficiency in sugar cane increases in a linear fashion with temperatures in the range of 8°–34°C (Gawander 2007). Cool night and early morning temperatures (14°C in winter and 20°C in summer) significantly inhibit photosynthesis the next day.
- High humidity (80–85%) favours rapid cane elongation during the main growth period; 45–65% with limited water supply is favourable during the ripening phase.
- Sugar cane is capable of high photosynthetic rates and the process shows a high saturation range with regards to light. Tillering is affected by intensity and duration of sunshine. High light intensity and long duration promote tillering while cloudy and short days have an adverse effect. Sugar recovery is highest when the weather is dry with low humidity, bright sunshine hours, cooler nights with wide diurnal variations and very little rainfall during the ripening period. These conditions favour high sugar accumulation.
- The absence of cyclones.

Fiji's climate in the sugar growing areas satisfies most of these conditions. Average annual rainfall ranges from 1700–3000 mm, of which 75% falls between September and April (Gawander 2007). The coinciding of the wet season with the end of the ripening period and the harvesting period, however, is not ideal. For nearly a century a sugar mill was in operation at Nausori in the wet zone of southeastern Viti Levu. However, while cane yields were high, sugar extraction rates were low. The mill closed in the early 1960s with farmers converting to crops such as rice, taro and vegetables better suited to wet conditions.

Fiji's sugar growing areas are also prone to cyclones. Up until around the 1970s harvesting was usually completed by November, when the cyclone season commences. However, in more recent times the harvesting has often extended into the end of the year due to a combination of various issues. Sugar cane, as a grass, is reasonably tolerant to cyclones; however, during severe cyclones some losses occur to mature canes, mainly from flooding rather than wind damage. Cyclones are often followed by drought, which can severely affect yields. Cyclone Oscar in late February 1983 is such an example. To quote the South Pacific Disaster Reduction Programme Report (1999):

This late cyclone that brought with it extensive flooding was followed by a severe drought. Average cane yields fell from 55 tonnes in 1982 to 37.3 tonnes per hectare in 1983, and total *sugar production fell from 487,000 tonnes to 276,000 tonnes. Much of the crop that would have been ratooned the following year had to be replanted. Had normal rains followed the cyclone, the losses would have been modest and mostly confined to low lying areas where there was prolonged flooding (McGregor and McGregor 1999).*

More insidious than the direct impact of cyclones is the accentuation of soil erosion resulting from the poor land use practices of farmers growing cane on excessively sloping land. The direct and indirect effects of soil erosion, including increased sedimentation and reduced clearance of flood water during heavy rain, add to the problem (Lal 2010).

Sugar cane production on sloping land, Fiji Photo: SPC

Sugar cane is particularly vulnerable to severe droughts that occur during the growing period. The 1997/98 El Niño-induced drought saw sugar production fall from over 500,000 tonnes in 1997 to less than 250,000 in 1998. The implementation of a large-scale replanting programme restored production to around 350,000 tonnes in 1999 but the decline in production continued thereafter, due to other problems in the industry (Lal 2008).

5.3 Observed climate impact over the last 30 years

Determining whether a change in production is due to climate change is difficult, particularly in archipelagos where climate conditions change over short distances. There is also a dearth of decentralised (localised) metrological data, which hinders any changes in productivity being linked with climate change. For example, in PNG, the only highland station for which good quality long-term climate data is available is Aiyura (1640 m) in Eastern Highlands Province (Bourke 2010). Further, changes in agricultural productivity in most countries over the last 30 years have been strongly affected by changing farming practices. For example, sugar yields in Fiji have declined significantly as a result of farmers not adding lime to the soil, the increasing length of the ratoon cycle and the increased incidence of cane burning (Landell Mills Commodities Studies 1991; Lal and Rita 2005). Separating out the impact of such variables from the impact of climate is a difficult task. Some anecdotal information from PICTs exists, mainly reporting on changes in flowering and fruiting of tree crops.

5.3.1 Coconuts

There has been no discernible impact of climate change on coconut production other than observations that coconuts are now fruiting at higher altitude and palms are dying due to sea-level rise and saltwater inundation.

Bourke (2013) reports for PNG:

In late 1970s, coconut palms grew up to 1800 m altitude, but only bore small nuts as high as 1320 m. Twenty years later in 1999, existing palms were bearing up to 1450 m. Another 10 years later (in 2009), palms were bearing at 1560 m. Knowing the temperature lapse rate in the highlands of 5.2°C per 1000 m increase in altitude, these recordings of the upper altitude at which coconut bears indicate that the temperature increased by more than 1°C over the 30-year period 1979 to 2009 (p.6).

In Fiji, Samoa and Vanuatu several severe cyclones associated with ENSO cycles have caused considerable damage to coconuts, particularly to the increasing population of senile trees. The damage caused to the Tall varieties by Cyclone Evan (Samoa, December 2012) was quite significant.

5.3.2 Coffee

The major PNG drought in 1997 increased rather than decreased coffee production in the following year. This was an unexpected rise in production but as explained by Hombunaka and von Enden (2001), the timing of the drought and the periods of rainfall that follow the drought are important considerations in determining the overall impact of drought on coffee yield.

The most apparent impact of climate change on coffee production in PNG, to date, has been through coffee leaf rust (CLR). As reported by Bourke (2013), CLR was detected in the PNG highlands in April 1986 and rapidly spread to higher temperature, lower-altitude coffee-producing locations, resulting in reduced yield. Bourke concludes:

The main impact so far has been at lower altitudes (below 1400 m) where the disease has reduced yield in some marginal growing areas. However, low prices in recent years and deteriorating market access from poorly maintained roads have probably been greater contributing factors to loss of production in these areas.

However, CLR as yet has had minimal effect in the main coffee-growing regions at 1400–1800 m elevation.

5.3.3 Cocoa

Annual rainfall in excess of 2500 mm can lead to high incidence of fungal diseases, particularly black pod disease, which does contribute to the low yields obtained, but lack of pruning may be equally important. In PNG, vascular streak dieback is highly correlated with rainfall, with the disease occurring at greater severity when annual rainfall exceeds 2500 mm. PNG's most damaging cocoa pest, cocoa pod borer, was first discovered in East New Britain in 2006 (Curry 2010) and although the pest has spread to other parts of PNG, there is no indication of a relationship between climate and the incidence and spread of cocoa pod borer.

5.3.4 Palm oil

Much has been written about the impact of clearing forests for palm oil expansion on climate change. However, very little has been written on the impact of climate change on the production of palm oil itself. Oil palm is a hardy crop, which is well adapted to high rainfall, high levels of soil moisture and high temperatures. Palms can tolerate inundation for up to several weeks with no apparent ill effect. However, they cannot tolerate cyclones. There has probably been no direct climate change impact to date on palm oil production in the main global production areas, including the Pacific Islands. It is likely that climate change has probably favoured oil palm relative to other competing tree crops such cocoa.

5.3.5 Sugar

The climate in Fiji over the last 30 years has been characterised by some extreme ENSO episodes, with associated cyclones, floods and droughts. These events have had a major negative impact on sugar production at a time when the industry has faced significant problems, such as land tenure and declining prices in preferential markets (Gawander 2007; Lal 2010).

In 2009, flooding was reported to be the worst experienced in Fiji since 1931, resulting in USD 13 million in economic costs in the country's sugar belt (Lal 2010). Preceding conditions of several consecutive depression systems over a short period of time, which coincided with high tides, increased the intensity of flooding and associated damaging impact. Continuous torrential rain for two weeks led to most low-lying areas being under water for days (Lal 2010). The effect of the floods on those households dependent on the sugar industry was serious. Flooding caused an additional 25% of families to fall below the basic needs poverty line, when compared with the effects of other drivers of change in the Fiji sugar industry.

The floods in 2012 caused significant damage with some fields suffering 100% loss. Replanting was necessary also because waterlogging affected the seed cane. The impact was greater because two episodes of flooding occurred within a period of a few months, highlighting again how climate impacts can be affected by the recovery time between events. Such outcomes of natural disasters are a product of interaction across a complex web of factors: the timing, duration and intensity of the flooding.

Extreme events not only cause havoc at the time, but recovery from these events can also be a costly and lengthy process. High levels of precipitation at critical times such as harvesting can have serious effects, which often continue beyond the time of the event. For example, historic wet spells have caused multimillion-dollar losses in the Australian sugar cane industry (Vermeulen et al. 2012).

5.4 Projected vulnerability to climate change and climate extremes

As discussed in earlier chapters, vulnerability to climate change and climate extremes is determined by considering exposure and sensitivity, potential direct and indirect impacts and adaptive capacity.

The projections for temperature rise and how future emissions will influence these projections have been discussed in Chapter 2. The projection to 2030, regardless of the emission scenario, is for a 0.5°–1°C increase in temperature; beyond that date, the emissions scenario will determine whether the rise stays within that range (very low emissions) or escalates. A very high emission scenario will result in warming of around 1°–2°C by 2050 and 2°–4°C by 2090. Rainfall projections are less precise as discussed in Chapter 2; however 'warmer will get wetter' and 'wet will get wetter' are generally accepted principles. An increase in rainfall would have serious implications for those locations which already experience excessive rainfall. In the short term (to 2030) extreme events (drought, heatwaves and cyclones), their timing, duration and intensity will have the most impact. An extreme temperature event could see an increase of 2°–4°C over and above the average temperature.

5.4.1 Increasing temperature and changes in precipitation

The potential impacts of overall increases in temperature and changes in precipitation on export tree crops and sugar are discussed briefly below.

5.4.1.1 Coconuts

Research in Sri Lanka indicates that rising temperatures and rainfall changes could reduce coconut yields by reducing pollen quality and/or germination, thereby affecting fruit formation and nut development, leading to a smaller number of nuts or empty nuts (Peiris et al. 2008)[10]. An increase in average annual temperature of 1.5°C would enable a further increase in the altitude at which palms bear. In areas where there is a large increase in rainfall, with a concurrent increase in cloud cover, nut production is likely to decline. Bourke (2013) points out that nut production is already low in coastal locations with very high levels of cloud cover, such as southwest Bougainville.

Rising temperatures and lower rainfall could reduce the effectiveness of the fungus, *Metarhizium anisopliae*, which is still used in the control of rhinoceros beetle[11]. As discussed in Section 5.1.6.1, an increase in rhinoceros beetle populations has been observed across the Pacific such that the effectiveness of *M. anisopliae*, as well as the other biocontrol agent, OrNV is being questioned. In Vanuatu, the problem of foliar decay (FDMT) could also increase under lower rainfall and warming temperatures due to the enhanced activity of the disease vector, *Myndus taffini* (Jackson pers. comm.). As little is known about Bogia coconut syndrome, it is impossible to predict how this disease will respond to the projected conditions.

Coconuts are unlikely to be significantly impacted by climate change (changes in mean annual temperature and precipitation) until beyond 2050 when, depending on the emissions scenario, rainfall could be a factor affecting production, particularly in those areas where rainfall and cloud cover are already relatively high.

5.4.1.2 Coffee

Increasing average annual temperature is expected to have a significant impact on the production of Arabica coffee, both globally and in the PICTs, even within a twenty year time frame, mainly because of the narrow genetic base of Arabica coffee (Davis et al. 2012).

Bourke (2013) notes that future increases in temperature and rainfall, even if small, will increase the risk that coffee leaf rust will become more severe in the main PNG coffee-producing areas. Given the difficulty of controlling CLR, greater incidence of the disease would reduce production in the main producing zone.

10 An analysis of monthly rainfall data from 1932 to 2003 in seven coconut-growing regions in Sri Lanka, and annual coconut production data from 1971 to 2004 showed that coconut production was inhibited during drought years. The data were used to develop a model which could predict annual coconut production, based on temperature and rainfall patterns in Sri Lanka's coconut-growing regions as well as greenhouse gas emission data. Studies are underway at the Sri Lanka Coconut Research Institute to determine the most sensitive stages of the coconut reproductive phase to high temperature and water stress, and to assess the impact on coconut yield in different areas, land suitability classes and varieties. Similar research would be of value for the Pacific region.

11 Rhinoceros beetle can also be controlled by baculovirus but some countries, for example, Guam, have found the fungus to be more effective, especially in the control of larvae and prelarvae in breeding sites. http://www.pestnet.org/SummariesofMessages/Crops/Plantationcrops/Coconutoilpalm/Insects/Oryctesrhinoceros/Outbreak,Guam.aspx

Increasing temperatures could mean greater prospects of coffee berry borer (CBB) incursion. Jaramillo et al. (2009), analysing data from Colombia, Kenya, Tanzania, and Ethiopia, estimate that for every 1°C rise in average temperature there would be an 8.5% increase in the pest. In a later paper, Jaramillo et al. (2011) predict that for every 1°C rise in average temperature, coffee will have to be grown about 150 m higher to avoid CBB damage. In East Africa, the CBB is already present at altitudes of 1800 m and reports from Tanzania indicate that the insect has spread 300 m higher in altitude during the last 10 years. PNG is one of the few remaining coffee growing areas where this damaging pest is not present, but it is threatening to cross the border from Indonesia into PNG.

A quality problem could arise with warmer average temperatures. Increased plant growth may lead to lower coffee fruit quality. High summer temperatures and drought are likely to cause physiological stresses, such as the reduction of photosynthetic efficiency (Haggar and Schepp 2012).

It could be expected that, increasingly, areas currently classified as optimum (> 1400 m) for the production of Arabica coffee, will become marginal, adversely affecting the livelihoods of large numbers of rural people. This is shown schematically for East African coffee production areas in Fig 5.1. A similar scenario could be expected for the PNG Highlands.

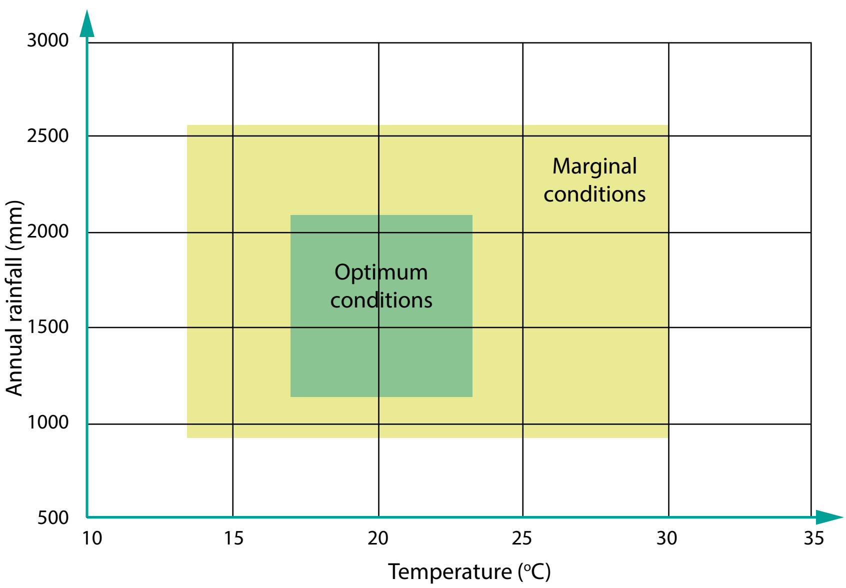


Figure 5.1 The bioclimate envelope for Arabica coffee (source: ED&F MAN/VOLCAF 2012).

Changes in the rainfall pattern will also affect production, because of the sensitivity of different stages of the growth and production cycle to rainfall patterns.

Coffee is likely to be affected by climate change, mainly due to the impact of increasing temperature and rainfall on CBB and CLR. The frequency and intensity of extremes of temperature and rainfall will determine impact prior to 2030; impact between 2030 and 2050 will similarly depend on these events but will also be affected by increases in general warming if tracking of high emissions continues. Quality will also be reduced by warming temperatures.

5.4.1.3 Cocoa

An increase in average temperature up to about 1.5°C is unlikely to adversely affect cocoa production in PNG and Solomon Islands. Such an increase would probably be favourable for cocoa-growing areas in Vanuatu, Fiji and Samoa, which are further south of the equator and are currently sub-optimal for cocoa in terms of temperature.

For many cocoa-growing areas in West Africa, The International Centre for Tropical Agriculture (CIAT) is projecting that the yearly and monthly minimum and maximum temperatures will increase by 2030 and will continue to increase progressively by 2050 (up to 2°C), assuming that the world continues tracking the very high emissions scenario, RCP8.5 (CIAT 2011). The projections show that the suitability for cocoa production within the current global centres of production will seriously decline by 2050. As the average temperature of the main Pacific cocoa-producing areas of East New Britain, Bougainville and Malaita is several degrees above that of the main West African and South American cocoa producing areas, it is likely that increasing temperatures will impact on cocoa production in the Pacific, and at an earlier time than the world's major cocoa-producing areas — which would be determined by the emissions scenario. In contrast, Vanuatu and Fiji can expect to be more favourably placed for cocoa production. In the longer term, should average temperatures increase by more than 2°C, areas in Tonga could become suitable for cocoa production.

Bourke (2013) notes that in PNG, even a modest increase in rainfall of 8% per year could reduce production to some degree because of an increased threat from black pod disease. A higher increase of 25% in annual rainfall would almost certainly increase the incidence of black pod disease, with a significantly negative impact on cocoa production. The same situation is likely to prevail in other cocoa-producing areas. The likely impact of changing climate on cocoa pod borer (Jackson pers. comm.), and vascular streak dieback (Davis pers. comm.) is unclear.

Cocoa severely affected by black pod Photo: Andrew McGregor

Until 2030 the impact of increasing temperature on cocoa production is likely to be minimal. Beyond 2030, and if the higher emission scenarios continue to be tracked, then cocoa-growing areas such as PNG and Solomon Islands are likely to be disadvantaged but other countries, where temperatures are currently below optimal levels, such as Vanuatu, could benefit. Increased precipitation will affect cocoa by increasing the prevalence of black pod disease.

5.4.1.4 Oil Palm

An increase in average temperature of up to 2°C is unlikely to have any significant impact on palm oil in the existing production areas, including those in the Pacific Islands. Bourke (2013) suggests that any large increases in rainfall may have some negative impact on palm oil yields and thus affect those growing oil palm in the already high rainfall areas of West New Britain, Oro and Milne Bay provinces. The expected increase in the intensity of cyclones is not seen as relevant since the palm oil production areas are located in latitudes not prone to tropical cyclones — although a major cyclone did affect Guadalcanal in 1986. Sea-level rise is not relevant to locations growing oil palm.

Very little information is available on the physiology of growth of *Ganoderma* spp., therefore, how *Ganoderma* disease will be affected by a warmer climate is unclear. Leaching of nutrients through increased precipitation could decrease resistance to fungal infection (Paterson et al. 2013).

Young palm killed by basal stem rot Photo: Richard Markham

The impact of climate change on oil palm before 2030 is likely to be minimal; any major impacts will be seen beyond 2030 and only if very high emissions continue. Importantly, the planting of oil palm will contribute to those emissions when forests are cleared; converting grassland or cane to oil palm; however, should result in a net carbon capture, such as in the Ramu Valley in PNG. The two major actors in palm oil production in PNG, New Britain Palm Oil Ltd and Hargy Oil Palms Ltd, now subscribe to the Roundtable on Sustainable Palm Oil conventions[12]. For growers to be certified, they must abide by eight principles which include responsible development of new plantings. This requires that all new plantings are in grasslands, not forest; there is no drainage of swamps; and runoff of chemicals into the sea or waterways is prohibited.

12 http://www.rspo.org/en/

5.4.1.5 Sugar

An increase of 1.5°–2°C in average temperature is not expected to have any direct adverse impact on sugar production in Fiji, as temperatures would still be within the optimum range. However, the likelihood of increased rainfall during the September to April period could adversely impact on sugar recovery[13] (tonnes cane (TC)/tonnes sugar (TS) ratio). As the TC/TS ratio has been consistently increasing over the last two decades, this will add to the industry's challenge to increase efficiency.

Fiji disease virus could worsen with lower rainfall and rising temperatures if this results in an increase in the population of the insect vector, *Perkinsiella* species (Jackson pers. comm.). A small increase in rainfall in the Ramu Valley, where industrial sugar cane is grown in PNG, is likely to increase cane productivity. However, rainfall at Gusap, where sugar is also grown, has shown a downward trend since 1982 (Kuniata pers. comm.).

5.4.2 Extreme climate events

As discussed in previous chapters, it is projected that cyclones are likely to be fewer in number but more intense. An increase in the frequency and intensity of very hot periods and very wet periods is also projected.

The potential impacts of more extreme climate events on export tree crops and sugar are discussed briefly below.

5.4.2.1 Coconuts

In locations subject to cyclones, increasing cyclone intensity is probably the climate factor likely to have the greatest impact on coconuts. The report on Fiji's Tropical Cyclone Tomas in 2010 provides an indication of the expected impact on coconuts from cyclones of increasing intensity, where it states that 'the gusts of 240 km/hr winds were sufficient to fell the normally cyclone-resistant Fiji tall coconut trees. The fact that quite a number of coconut trees were felled is testimony to the strength of Cyclone Tomas — it is also a reflection of the old age structure of Fiji coconut trees' (McGregor et al. 2010). The same effect on the Samoa tall coconut trees was seen with Cyclone Evan in December 2012 (Government of Samoa 2013).

13 Sugar recovery ratio used to be 7.5, which was very good by world standards, but is now >9.0.

Damage to coconuts following Cyclone Tomas Photo: Andrew McGregor

Extremes of temperature and periods of drought could lead to reduced yield. Research carried out in Sri Lanka has illustrated that reproductive development in coconut is more sensitive to high temperature stress and water stress than vegetative development (Peiris et al. 2008). Nut setting is the most important yield-determining factor in coconut and reduced nut setting due to heat stress and long dry spells is often experienced in coconut plantations in the dry–intermediate and dry zones, even those under irrigation. Poor pollen quality can result from continuous exposure to heat or water stress, which prevents the accumulation of starch and sucrose in the developing anthers (the main source of energy for pollen germination). Further, high temperatures, low relative humidity and a high vapour pressure deficit at the stage of pollination may result in pollen drying, consequently resulting in reduced nut set. The degree of sensitivity to high temperature can vary with the variety, depending on their tolerance to stress[14].

5.4.2.2 Coffee

Extremes in rainfall could be significant because of the moisture sensitivities of the growth and production cycles. High temperatures experienced as a result of extreme heat days may also cause an excessive fruit ripening and lower fruit quality. Flowers could abort if relatively high air temperatures occur during blossoming, especially if associated with a prolonged dry season. Continuous exposure to daily temperatures as high as 30°C could cause reduced growth and abnormalities such as yellowing of

14 http://climatenet.blogspot.co.uk/2012/07/potential-impacts-of-climate-change-on.html

leaves (Haggar and Schepp 2012). Most of the region's coffee is not grown in cyclone-prone areas so more intense cyclones projected for the region are unlikely to have an impact.

5.4.2.3 Cocoa

Most of the world's cocoa producing areas are not prone to cyclones, including PNG and usually Solomon Islands. This is not the case for the other PICT cocoa producing countries, such as Vanuatu, Samoa and Fiji. Provided the cyclone is not too severe, the 'pruning' of the cocoa and associated shade trees during a cyclone can be beneficial.

Further, cocoa trees can usually recover from cyclones in the longer term (unless completely blown over), by sending up a basal chupon[15]. However, an increased intensity of cyclones will certainly challenge the viability of cocoa production in those countries that are subject to cyclones. The Samoa post-disaster needs assessment for Cyclone Evan (December 2012) reported that 15% of cocoa trees were destroyed (Government of Samoa 2013). The trees that remained were also affected, with flowering delayed or completely stopped (Iosefa pers. comm.). Long periods of drought will cause cocoa buds to wither[16]. A study of a cacao/*Gliricidia* agroforestry system in Indonesia over a 13-month drought period showed a reduced yield of cocoa beans (Chapter 3). Cocoa is very climate-sensitive; therefore any prolonged periods of high temperature will affect production, especially if coinciding with limited water availability. High temperature events will be more problematic in those areas, where maximum temperatures are already high, such as East New Britain, Bougainville and Malaita.

5.4.2.4 Palm Oil

High temperatures experienced at frond emergence or bunch formation can negatively affect palm oil production (Corley 1977). Analysis of data in Malaysia did link high temperatures with reduced yield in 2007 in production areas in Peninsular Malaysia[17]. Excessive rainfall is detrimental as yield can be significantly affected. Flood-related problems in southern Malaysia decreased the production of crude palm oil by 26.3% in December 2006 (Rahman 2009). The expected increase in the intensity of cyclones is not seen as relevant since the palm oil production areas are currently located in latitudes not prone to tropical cyclones. However, the susceptibility to cyclones needs to be factored in when evaluating any proposals to plant oil palm in Fiji and Vanuatu.

15 Main or central stem.
16 http://www.bloomberg.com/news/2012-09-21/drought-in-ghana-s-cocoa-regions-curbs-farmers-outlook-for-crop.html
17 http://www.geo-informatics.org/publications/subana_2012%20ModellingClimateChange.pdf

5.4.2.5 Sugar

An increase in the severity of cyclones, particularly if associated with more flood events, would adversely impact on production, especially if this occurred during harvesting. High temperatures (>38°C) reduce the rate of photosynthesis and increase respiration, and also at higher temperatures reversion of sucrose into fructose and glucose may occur. However, no information is available regarding the length of time such temperatures would have to persist before any impact occurs. Extremes of temperature will also increase evapotranspiration[18]. Extreme rainfall leading to prolonged flooding has serious implications for sugar (Section 5.3.5).

5.4.3 Sea-level rise and salinity

As discussed in Chapter 3 (Section 3.5.4), the IPCC (2013) recently reported that the global mean sea level will continue to rise during the 21st century. There is considerable spatial variability across the Pacific but very high rates of sea-level rise are observed in the western tropical Pacific. The impact of sea-level rise on extreme sea-level events is of significance (Chapter 2).

5.4.3.1 Coconuts

For atoll locations, the greatest impact on coconut production will come from the rise in sea level, although copra is not a major contributor to exports from atoll countries. Already some palms growing near the sea are being destroyed by seawater encroachment; further rises in sea level will continue this trend and threaten the survival of coconuts in these locations. There will also be some loss of palms in low-lying coastal locations. Coconut palms were planted in coastal locations decades ago when returns on copra were much greater; many nuts are now not harvested due to low returns. Thus, these losses are unlikely to have a significant overall impact on coconut production and consumption.

5.4.3.2 Other export tree crops and sugar

Sea-level rise is not relevant to locations growing coffee, cocoa and oil palm. In Fiji some sugar cane is grown on reclaimed mangrove and other coastal lands, with productivity relying on the maintenance of drainage systems. Sea-level rise coinciding with extreme tides and heavy rainfall will significantly affect the crop in these locations (Lal 2010). However, these areas represent only a small proportion of the total cane land.

5.4.4 Elevated carbon dioxide

Experiments carried out on field crops have indicated that yield increases associated with elevated carbon dioxide could be in the order of 8 to 15% (Long et al. 2005),

18 http://www.sugarcanecrops.com/climate/

assuming other inputs, such as water and nitrogen, are not limiting (Erda et al. 2005). References in the literature addressing eCO_2 and tree crops such as oil palm, cocoa and coffee tend to refer to the contribution made to emissions through the clearing of land to expand production of these tree crops, rather than the capture of carbon by these crops or the impact of eCO_2 on their yield. While there may be a positive contribution to growth of cash crop species from eCO_2 concentrations, there is presently little information available to assess the actual benefits on productivity and also to determine what the impact might be on the quality and/or nutritional value of the crop. It is an area where more research is needed.

5.4.4.1 Sugar

Some models point to the positive impact of climate change on sugar cane production due to the impact of eCO_2. For example, in Brazil and Australia cane yields are predicted to increase by up to 13% as the result of increased temperature and CO_2 levels under 2070 climate change scenarios (da Silva et al. 2008). Similarly, Black et al. (2012) applied a process-based crop model to conditions in Ghana; the results suggested that doubling CO_2 (from pre-industrial times) mitigates the degree of water stress associated with a 4°C increase in temperature. In Brazil, Marin et al. (2013) considered the projections for rainfall, air temperature and CO_2 concentrations for four future climate scenarios. Using the DSSAT/CANEGRO model the simulations showed an increase in stalk fresh mass (24%) and water usage efficiency (34%). Water usage efficiency will improve partly because of greater root densities and also because the stomata will be open for less time compared with a 'normal' CO_2 atmosphere (Chapter 3). There are no reports in the literature that discuss the impact of eCO_2 on sugar content (Crimp pers. comm.).

5.4.5 Post-harvest

As discussed in Chapter 3 (Section 3.7) a warming climate is likely to increase the build-up of insects and fungi in stored produce. Wet and hot spells at harvest time would make stored produce more vulnerable to attack. Post-harvest storage pests for cocoa and coffee have not been discussed; however, it is not expected that a 1°–3°C increase in mean annual temperature would have a significant impact on the shelf life of cocoa and coffee. If storage involves air conditioning or refrigeration, then higher temperatures will mean increased costs.

Chapter 1 (Section 1.5.6) discussed the importance of adequate roads for marketing, highlighting the role that the Highlands Highway in PNG plays in supporting the growth of the coffee industry. Damage, particularly from more intense cyclones, caused to marketing infrastructure such as roads and jetties, will be a threat to the marketing viability of these commodities, but the overall impact of climate change on infrastructure is likely to be much less than the impact from inadequate investment in maintenance should this continue into the future. More frequent extreme weather events occurring under climate change will also damage other forms of infrastructure important for export commodities, such as storage and processing facilities. Significant investment in resources is always required to secure markets; failure to maintain continuity of supply would have a damaging effect on producers and livelihoods. The impact of climate change on infrastructure has been discussed in Chapter 3.

5.4.6 A summary of the projected vulnerability

The projected vulnerability of specific tree crops for medium- and long-term time frames is summarised in Table 5.1.

Table 5.1 A summary of vulnerability to climate change and climate extremes for Pacific Islands tree crop commodities and sugar.

Crop	Climate change/climate variability impact in recent decades	Projected climate impact to 2030[19]	Projected climate impact to 2050[20]
Coconuts	Main impact has been loss of palms growing close to the sea. Also damage from cyclones, mainly affecting senile palms. It is reported that existing palms in PNG highlands growing at what were altitudinal limits are now producing nuts	A 1°C increase in mean annual temperature is not expected to impact on coconut production. Ageing coconuts trees will become more vulnerable to cyclone damage with increasing cyclone intensity. Extremes of temperature and periods of drought could lead to reduced yield	Increasingly severe cyclones will have a major impact on coconut production. Possible impact from increasing rainfall in those locations where rainfall is already high. Unclear as to the impact on major pests and diseases. Extremes of temperature and periods of drought could lead to reduced yield
Coffee	Most apparent impact — coffee leaf rust (CLR) in PNG	An increasing mean annual temperature is likely to have a significant impact on production of Arabica coffee mainly through CLR and CBB. Quality also affected. Extreme heat events will be significant	Increases above 2°C could be expected to have a major negative impact. Most current coffee-growing areas in PNG will become sub-optimum for coffee production, with pests and diseases likely to become a major problem. Quality also affected
Cocoa	No discernible impact over recent decades	A 1°C increase in average temperature is not expected to have significant impact, although increased rainfall could have a negative impact through increasing incidence of black pod	Suitability of the major current cocoa-growing area in PNG and Solomon Islands is expected to decrease significantly beyond 2050. Vanuatu's cocoa areas are likely to be less affected
Oil palm	No direct climate change impact, likely that climate change has favoured oil palm relative to other tree crops such as cocoa	Unlikely to be any significant impact	Possibly some adverse impact from pests and diseases but unclear at this stage. Very high emission temperatures could affect production
Sugar	Negative impact from severe cyclones, floods and droughts, largely associated with ENSO cycles therefore unclear what the contribution of climate change has been	ENSO cycles likely to have the greatest impact on Fiji's sugar production. Increased rainfall between September–April adversely affects sugar content	Unlikely that a 2°C increase in average temperature will have any major impact, but more severe cyclones, floods and droughts would have very significant impact

19 Temperature rise of +0.5° to 1°C regardless of emissions scenario.
20 Temperature rise will vary from +0.5 to 1°C (RCP2.6) to +1° to 2°C (RCP8.5).

5.5 Resilience and adaptive capacity

Chapter 4 (Section 4.7) discussed in some detail how traditional Pacific Island food production systems provide a degree of resilience to climate change, and thus strengthening these systems can provide an important climate change adaptation strategy. The same applies to the production of export commodities. Throughout the PICTs, coconuts, coffee and cocoa are now overwhelmingly smallholder crops that have been integrated into traditional farming systems; cocoa in particular is commonly found as part of a traditional system. A 2009 FAO Study on the Vanuatu Organic Cocoa Growers Association (VOCGA) specifically describes the system with respect to cocoa:

A major advantage that cocoa offers smallholders is that it can be integrated into a food garden or grown under mature coconuts. Following the planting of yams, cocoa seedlings can be planted along with taro, bananas, and other food crops. In the same garden it serves as an excellent companion crop to kava, offering shade to the young kava plants. Following 2 to 3 years of food production, a mixed cocoa kava block is left, with stand-alone cocoa remaining after the kava is harvested. Like copra, cocoa also has the advantage of always having a market, albeit in the past at relatively low returns. Through VOCGA the returns from cocoa have been greatly increased while still remaining a good component of the traditional farming systems (McGregor et al. 2009).

The Fiji sugar industry has been smallholder-based for more than a century and was once regarded as one of the lowest cost sugar producers in the world (Landell Mills Commodities Studies 1982). Traditionally Fiji's cane farms maintained a high degree of food security and environmental sustainability. Farmers grew rice and pulses in rotation with cane and met most of the fruit and vegetable needs of the household[21]. It was mandatory for cane farmers on sloping land to plant vetiver grass (*Chrysopogon zizanioides*) as a soil conservation measure (Truonga and Gawanderb 1994). Such farming practices have to a large extent disappeared on Viti Levu cane farms, although they still remain reasonably common in parts of the Vanua Levu cane sector (Lincoln International 2003). Overall, cane farming became a monoculture, often extending to marginal sloping land with severe land degradation consequences (Ministry of Primary Industries [Fiji]/ADB 1985; Fozia 1996). There is therefore, considerable scope for households in the cane areas to re-establish a greater degree of food self-sufficiency and environmental sustainability. In a sense this involves going 'back to the future', albeit with more efficiency, through the adoption of improved varieties and practices.

An appropriate combination of crops for food, cash and soil conservation can provide a degree of food security and livelihood protection in the face of climate extremes, and enhance resilience to future climate change. Livelihood and labour saving benefits can accrue from growing crops together. As discussed in Chapter 4 (4.7.1.1), farmers in Uganda are able to obtain 50% more income from intercropping banana

21 Most cane farming households now purchase most of their food needs.

and coffee than from growing either crop alone. The Vanuatu Cocoa Land Use Profile illustrates how cocoa production for most smallholders is only viable when integrated with food and kava production (Vanuatu Land Use Planning Office 1999). Identifying the most appropriate crop combination and cropping systems needs to be a research priority.

5.6 Implications of climate change for the comparative advantage of export commodities

The effect of climate change on the comparative advantage of export commodities will depend on both local and global impacts. It is possible that climate change could adversely affect the domestic production of an export commodity in a particular PICT, yet that country's comparative advantage could be enhanced as the result of climate change affecting competing countries or competing products more severely. Thus it is conceivable that in some cases climate change will make farmers better off, at least in the medium term. These inter-relationships are discussed briefly below for selected commodities.

5.6.1 Tree crop commodities

The competitiveness and resilience of traditional tree crop commodities in western Melanesian countries has been demonstrated by the remarkable recovery of Solomon Islands copra and cocoa industries after the 2002 'crisis': the export of these crops virtually ceased but has now been restored to historically high levels. In Melanesia, there remains considerable scope for enhancing the contribution of these industries to broadly-based rural livelihoods by increasing productivity and improving quality.

5.6.1.1 Coconuts

It is not expected that climate change, through until at least 2050, will have a significant effect on coconut production. The main impact will be from the expected increased intensity of cyclones on the increasingly senile population of coconut palms, although there could be some offsetting benefits from less frequent cyclones. Further loss of palms adjacent to the sea can be expected. Copra production uses virtually no fossil fuel, with fertiliser rarely, if ever, applied. Thus with the important exception of increasing transportation costs, copra industries will not be affected by rising energy costs.

The major direct competition for copra and coconut oil comes from the Philippines. The Philippines dominates the world coconut economy, accounting for about 40% of world copra production and 60% of world exports of coconut oil (APCC 2011). It can be expected that the Philippines and the PICTs will be similarly impacted by climate change, with the possible exception of cyclone frequency in the Philippines.

Some studies depart from the view that across the globe cyclones will increase in intensity but decrease in frequency, and suggest that tropical cyclones are likely to become stronger and more frequent in the coming years, with a potentially significant increase in storm frequency and intensity in the Northwest Pacific Ocean Basin (Emanuel 2013)[22]. Typhoon Haiyan (November 2013) could be indicative of future cyclones for the Philippines[23]. Should typhoons of similar intensity to Haiyan become a more regular occurrence in the Philippines, the Pacific coconut industry could benefit. However, pests and diseases could also influence the impact of climate change between the two regions (e.g. Bogia coconut syndrome in the Pacific) where current lack of information prevents any projection of impact from climate change. Knowledge gaps concerning key pests and diseases must be addressed so that opportunities, if available, can be utilised by Pacific coconut growers.

In the production of oil and meal, coconuts have numerous close substitutes that will be variously affected by climate change. The price of oils reflects their demand and supply and competitive position amongst other oils and fats. As a result of this inter-relationship, the prices of vegetable oils tend to move together. The lauric oils (palm kernel[24] and coconut oil) are almost perfect substitutes. Over the period 2001 to 2012 there was a 0.99 correlation between the average monthly prices for the two products (Fig 5.2). World production of palm kernel oil in 2012 was 6.8 million tonnes compared with 3.7 million tonnes for coconut oil[25]. On balance, oil palm is probably better placed to cope with climate change than coconuts, which would further enhance palm oil's competitive position.

World palm kernel oil production is dominated by Indonesia and Malaysia, which together account for around 85% of world production. The privileged position of the traditional lauric oils in the market place is now under threat with the emergence of genetically modified rapeseed (canola) oil with high lauric acid content[26]. Rapeseed (*Brassica napus*), is a temperate/subtropical field crop, with world production dominated by the EU, China, Canada and India. Existing rapeseed crop areas can expect to face greater climate change challenges than the tropical tree crop sources – palm kernel and coconut oil (Qaderi et al. 2006; Harvey and Pilgrim 2010; Chattopadhyay et al. 2011). However, the large expansion in potential grain farming in areas that are currently cold-limited could mean that rapeseed production may benefit from climate change, especially in Canada and northern USA. But any expansion could be constrained by the controversy surrounding the use of neonicotinoids, which have been recently banned in the EU[27].

22 Emanual's results have not yet been supported by subsequent research from other groups. http://www.climatecentral.org/news/super-typhoon-haiyan-a-hint-of-whats-to-come-16724

23 The Wall Street Journal (November 21, 2013) reports 15 million coconut trees, or about one-tenth of the total, in Eastern Samar were destroyed by Typhoon Haiyan. It is suggested that industry in some regions could take up to a decade to recover.

24 Palm oil is extracted from the mesocarp of palm fruits, while palm kernel oil is extracted from the palm kernels. The latter is considerably more valuable but makes up a much smaller proportion of the production from an oil palm tree. The high lauric acid content of coconut and palm kernel oil affords particular advantages in food and industrial uses (www.mpiz-koeln.mpg.de/rohde).

25 http://www.indexmundi.com/agriculture

26 www.mpiz-koeln.mpg.de/rohde

27 http://www.eea.europa.eu/highlights/neonicotinoid-pesticides-are-a-huge

A further consideration is the cost of fossil fuel. Where global oil consumption continues to rise, the cost of fossil fuel derived inputs required to maintain production will increase. Rapeseed requires and draws large quantities of nitrogen from the soil. Zimmer (2010) estimates that rapeseed requires 100 kg of nitrogen per tonne of oil produced, compared with the estimated 25 kg of nitrogen used per tonne of palm oil produced. The cost of fertiliser therefore also needs to be considered when comparing these various oil production systems. In the United States, the cost of fertiliser is declining because of the low natural gas prices and increased supply resulting from an expanding shale gas industry[28]. However, natural gas prices can also be pegged to crude oil prices[29]. Determining whether the comparative advantage will swing back in favour of lauric oils produced from coconuts and palm kernel is therefore complex.

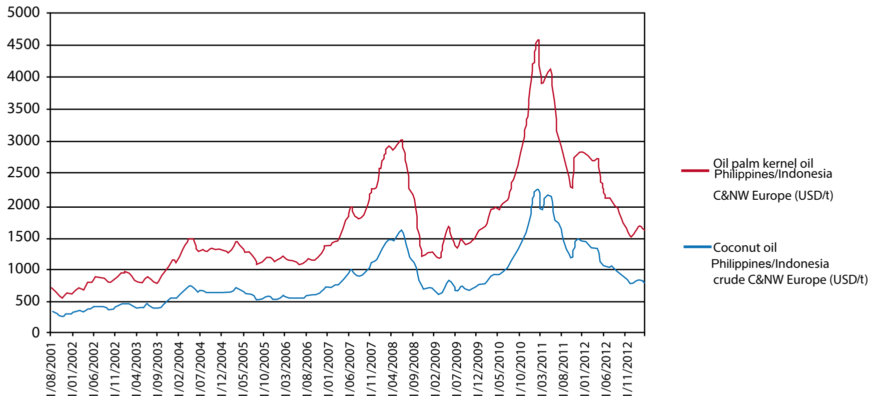


Figure 5.2 The monthly average price for coconut oil and oil palm kernel oil over the period 2001–2013 (source: Public Ledger May 2013).

5.6.1.2 Palm oil

Climate change is likely to have minimum impact on palm oil production in the Pacific Islands for the foreseeable future. In addition, increasing crude oil prices would generate more demand for biofuels, which would in turn increase the price of palm oil.

Palm oil (the oil extracted from the mesocarp of palm fruits), followed by soya bean and rapeseed oils, is the main source of oil for world's food and cosmetic industries[30]. The products are regarded as reasonably close substitutes and the prices tracked together along with the other oils in the 'veg oil complex' (coconut oil, palm oil, palm kernel oil, soybean oil, sunflower oil and rapeseed oil). The correlation between the prices of palm oil and soya beans over the period 1998 to 2013 was 0.91 (Figure 5.3), almost as close as the correlation between palm kernel oil and coconut oil. In recent years, a key factor driving prices within the entire 'veg oil complex' has been petroleum prices and the diversion of supplies for use as biodiesel. All vegetable oils are technically suitable as substitutes for diesel. In economic terms, it is soya bean,

28 http://www.theglobeandmail.com/report-on-business/breakthrough/why-cheap-natural-gas-is-a-boost-to-farmers/article14227180/
29 http://marketrealist.com/2013/02/brent-oil-moves-nitrogenous-fertilizer-prices/
30 In 2012 world production of palm oil was some 56 million tonnes, compared with 43 million tonnes for soya bean oil and 24 million tonnes for rapeseed oil (Oil World 2013).

palm oil, rapeseed and corn oil that are the most suited because they are available at the lowest price due to their higher productivity and lower production cost. Generally, palm oil is considered to have the lowest unit cost of production and is the most competitive (Zimmer 2010). The relatively high price of coconut oil means that it is seldom used as a biofuel. Remote island locations such as Bougainville are the exception, where coconut oil is competitive because of the high transport costs of imported diesel. However, any diversion of soya bean oil or palm oil production to biofuel still impacts on coconut oil prices, as less of these substitutes are then available to compete with coconut oil in its traditional edible oil uses. Palm oil and crude oil prices have tracked closely together over the last decade (Figure 5.4).

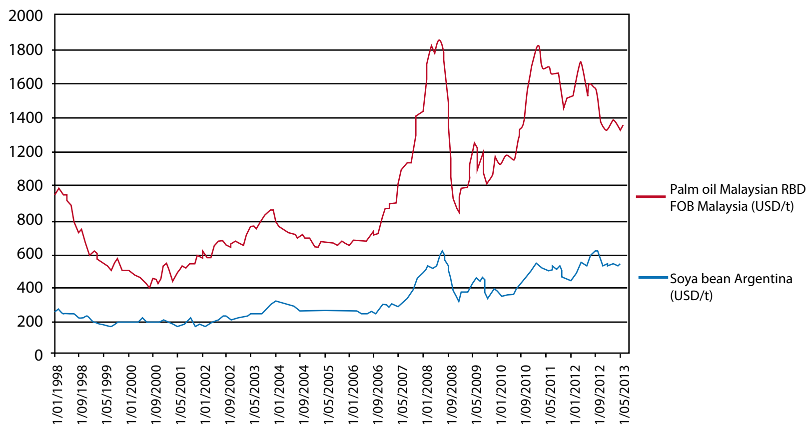


Figure 5.3 World palm oil and soya bean prices: 1998–2013 (source: Public Ledger June 2012).

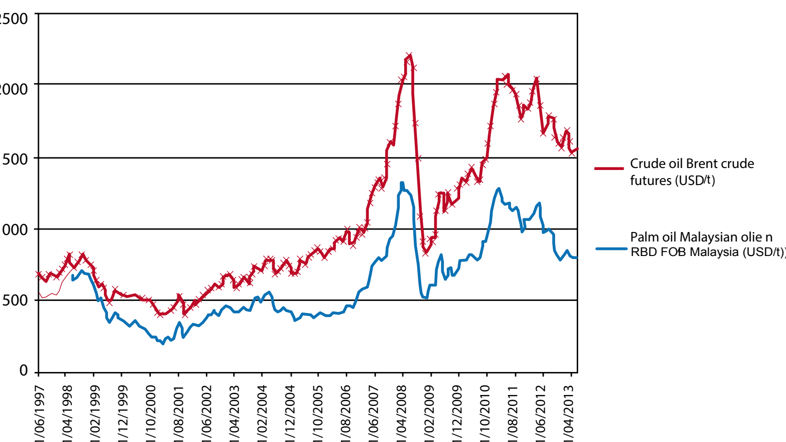


Figure 5.4 World palm oil and crude oil prices: 1997–2013 (source: Public Ledger June 2012).

Soya bean, palm oil's main competing substitute, as with rapeseed, is projected to be affected by climate change (Travasso et al. 2009; Ainsworth 2010; Hao et al. 2010). As noted above, rapeseed is a heavy user of nitrogen compared with oil palm — with the cost of nitrogenous fertiliser closely correlated to crude oil prices. Soya bean has the advantage of being a legume, with the bacteria present in the root nodules able to fix nitrogen from the atmosphere, normally supplying most or all of the nitrogen (N) needed by the plant. As noted in Chapter 3, legumes are better placed to take advantage of eCO_2 being able to transfer excess carbon to the root nodules; however, the level of CO_2 at which these benefits will accrue is not clear. The soya bean plant also has high demand for other nutrients from the soil[31]. As Travasso et al. (2009) note for Argentina 'the trend to soya bean monoculture is severely compromising soils quality by reducing soil organic matter and nutrients.'

A consequence of this situation is likely to be increasing pressure to convert forest and traditional cropping land in PNG and Solomon Islands to palm oil production, which will mean further loss of biodiversity, increased food insecurity and increased GHG emissions. Oil palm's greater resilience to climate change compared with competing edible oil and biofuel crops is likely to result in an overall increase in the area of arable land devoted to palm oil production; this could be expected to further feed climate change, depending on the previous use of the converted land.

5.6.1.3 Coffee

Arabica coffee has been identified as the commodity most likely to be severely impacted by climate change. Highland production areas in PNG are likely to be affected in the same way as the highland areas of East Africa and Central America. Significant increases in real prices of Arabica coffee can be expected. There may be some additional price premiums accruing to Pacific growers for the development of niche markets for single origin, certified organic and fair trade coffee, from which PNG has already received some benefit. In The Public Ledger, May 10 2013[32], Ric Rhinehart, Executive Director of the Speciality Coffee Association of America, notes that global coffee production is threatened on almost every front. In an address to the American Spice Trade Association he remarked:

Coffee has been threatened by climate change in an unusual way. It's not that temperatures are going up and making it increasingly difficult to plant this sensitive plant, but the weather patterns are changing dramatically. We're seeing a lot more extreme weather events …. Demand is growing at a rate of 2.5% a year to a point where there is virtually parity between supply and demand. Projections indicate that

31 The NSW Department of Agriculture recommendation for fertiliser inputs in Northern NSW for a soya bean crop yielding 2.5 tonnes/ha is:

- 17kg P/ha
- 123 kg K/ha
- 14.5 kg of sulphur/ha.

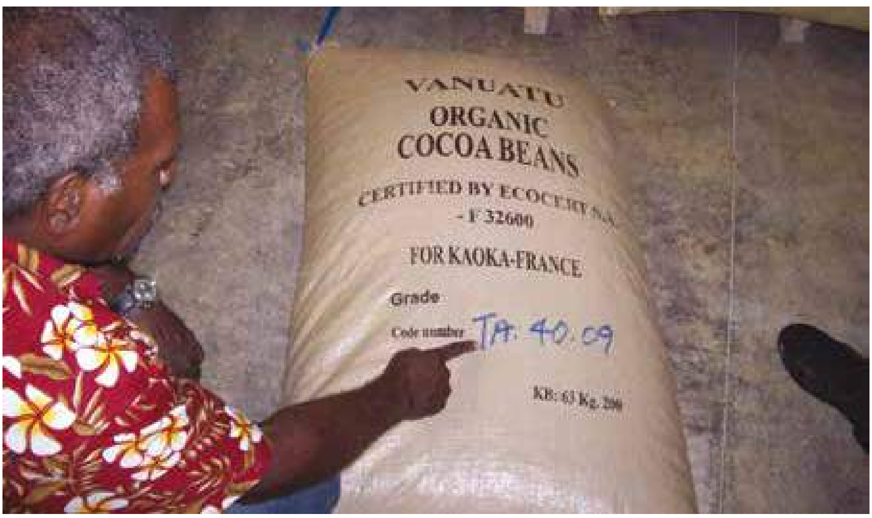
32 http://www.pbabrokerage.com/?author=3&paged=33

the world will need 170 million bags of coffee by 2025. We don't really see where the other 30 million bags of coffee are going to come from. The largest world producer, Brazil's output for this year was about 55 million bags, while the second biggest origin Vietnam, produces around 20 million bags and the other global origins 10 million bags or less. Based on the current scenario and raft of challenges, it seemed unlikely that an extra 30 million bags could be reached. Smallholder farmers account for about 70% of the world coffee supply and extreme weather is among a number of challenges they face.

However, this projected price increase probably will not be sufficient to offset the adverse impact on incomes resulting from a substantial decline in the production. Thus, while the competitive position of PNG's main agricultural export industry, compared with the other main Arabica coffee-producing areas, is probably not going to be adversely affected, there is the prospect of the overall livelihoods generated by this industry being substantially reduced.

5.6.1.4 Cocoa

According to the International Cocoa Organization (ICCO), the current annual value of the cocoa market is USD 8–10 billion[33]. To meet the increasing demand of countries such as India and China by 2020, it is projected that current production must increase by 25%. Fine-flavour and speciality chocolates, such as single origin, fair trade and organic chocolate, are particularly in demand, accounting for around 5% of today's market. Connoisseurs of chocolate are prepared to pay a high price for specific cocoa flavours resulting from a mix of variety, bean quality, geographical origin, and growing and processing conditions[34].



Vanuatu organic cocoa destined for French chocolate maker Photo: Andrew McGregor

33 http://www.icco.org/statistics/cocoa-prices/daily-prices.html
34 http://sustainability.thomsonreuters.com/2013/09/11/taste-whats-come-cocoa-collaboration/

Cocoa is expected to be affected less by climate change than Arabica coffee. PNG and Solomon Island cocoa-producing areas are unlikely to be more affected than the world's major cocoa-producing areas in West Africa, (expected to become relatively drier), and South America. More southern production areas in Vanuatu, Fiji and Samoa could be relatively better off, at least in the medium term.

The overall net impact of climate change on PICT cocoa livelihoods is unclear, and worth noting is that negative local production impacts from severe weather events, such as cyclones, could potentially offset positive world market price benefits, highlighting the importance of appropriate adaptation and marketing strategies.

5.6.1.5 Sugar

The comparative advantage of the Fiji sugar industry in recent decades has declined significantly in the face of falling cane yields and sugar recovery (Landell Mills Commodities Studies 1991; McGregor 2000; Lal 2008). This deterioration has been the result of a combination of economic, social and political factors. The sugar industry with its high overhead cost structure (four mills and transportation infrastructure) has seen average costs rise sharply with declining production (McGregor 2000)[35]. The Fiji industry is not expected to be made any better or worse off than the major sugar-producing areas of the world by climate change. Increasing crude oil prices can be expected to have favourable price implications for sugar in that it is a major feed stock for biofuel. These price benefits will probably be offset to some degree by the likely increases in fertiliser prices, the loss of the EU preferential market and other factors.

5.7 Uncertainty, gaps in knowledge and research priorities

Much of the uncertainty and gaps in the knowledge outlined for the staple food crops in Chapter 4 apply also to the export tree crops and sugar, as they will for the horticulture crops covered in Chapter 6.

5.7.1 Interactions between environmental factors and production

Better understanding of the interaction between environmental factors, such as temperature, rainfall and cloud cover, soil fertility and production patterns is needed for most tropical tree crops. The importance of this knowledge was well illustrated when predictions for a decrease in coffee yield the year after the 1997/98 drought in PNG were proven wrong, when increases in yields were obtained. An analysis of production and meteorological data, similar to that previously mentioned for coconut in Sri Lanka, would be useful for all PICT export commodities. An improved understanding of physiology would also assist in determining whether

35 For the decade ending 1990 the average annual sugar production was 412,000 tonnes, compared with 245,000 tonnes for the decade ending 2011 (Fiji Bureau of Statistics).

impacts are the result of climate variability, such as in ENSO events, or the slow onset of climate change, or some other factors. However, adequate capacity and resources necessary to carry out research remain a challenge. To undertake the type of work described by the Sri Lanka Coconut Research Institute would require a dedicated unit with close links to commodity industries and national research capacity.

The urgent need to focus applied research and extension on soil health/soil fertility that was highlighted in Chapter 4 is equally applicable to export commodities. The experience of the Fiji sugar industry, which in recent decades has neglected soil health, illustrates the importance of this work (Morrison et al. 2005). Demonstrating measures that sustainably increase sugar cane yields, such as the application of lime, should now be the highest priority of the Sugar Research Institute of Fiji (Lal 1999).

5.7.2 Linking with research institutes outside the Pacific

All export commodities discussed above are of global importance, with PICTs (even PNG) being minor suppliers. Thus, major research is being conducted in other parts of the world. Much of this research is not transferable because of the importance of local environmental conditions. However, where research findings are transferable it is important to create linkages with research institutes outside of the Pacific to access that knowledge and/or technology. For example, molecular tools for studying responses of coffee to both drought and temperature have been developed. Brazilian research groups have mapped the Arabica coffee genome and sequenced 200,000 expressed sequenced tags (ESTs), providing a very useful database upon which to base studies on coffee physiology and breeding — these data will assist in the production of cultivars with superior performance under adverse environmental conditions (DaMatta et al. 2006).

Unfortunately tree crop commodities are outside the mandate of the Consultative Group (CG) on International Agricultural Research (CGIAR) system, which makes linkages with international research more complex. The CG centres were largely established to focus on food security. At the time most tree crop production was in the hands of the international private sector, and there seemed little scope for the generation of 'global public goods' in this area. Tree crop research has largely been sponsored by metropolitan colonial governments, in particular France. CIRAD[36] (an amalgamation of different French tropical agricultural research institutes — IRHO (oil crops), IRCC (coffee, cocoa) IRCA (rubber), etc.) remains a leader in tree crop research and germplasm development, particularly in Africa.

Outside of PNG it is unrealistic to expect small commodity export industries and research officers in ministries of agriculture to keep abreast of the increasing volume of research relevant to adaptation to climate change. The SPC Land Resources Division is the appropriate body to access this ever-expanding body of knowledge, establishing formal links with CIRAD and PNG tree crop research institutes, and

36 Centre de coopération internationale en recherche agronomique pour le développement.

ensuring that relevant information reaches the Pacific commodity industries. Links with the World Agroforestry Centre[37], which operates five regional programmes through regional network offices in Africa, Asia and Latin America, would also be desirable.

5.7.3 Centralised versus decentralised research

Centralised research stations have been responsible for research on tree crops in the Pacific for more than a half a century[38]. Outside of PNG these research stations have been operated by ministries of agriculture, or other public sector institutions. At the time of independence, and for some time beyond, these research stations were well funded. This is no longer the case and in an increasingly resource-scarce environment they are severely underfunded. The overall impact of these centralised research stations, outside of PNG, has been minimal. In 2000, Labouisse and Roupsard described coconut research in Vanuatu:

Vanuatu's coconut research programme focuses on coconut breeding and genetic improvement through: the management of an important field genebank and hybrid trials; implementation of a regional project and its participation in COGENT activities; developing a physiological method of predicting the productivity of coconut palms; and optimization of coconut-based farming systems. Four scientists, including two senior scientists from CIRAD, and five research assistants are currently working on this programme.

Despite the substantial resources devoted to this research no discernible impact on the coconut industry is evident. Vanuatu, at the time of Independence in 1980, had some 80,000 ha under coconuts with around 48,000 tonnes of copra produced annually (Vanuatu Land Use Planning Office 1999). Today there only 62,000 ha under coconut, with copra production oscillating around 35,000 tonnes. The concerted programme to introduce high yielding hybrids to farmers failed, as it has throughout the PICTs. A Strategic Review of the Coconut Industry and Commodities Marketing in Vanuatu undertaken for the Ministry of the Prime Minister in 2007 noted:

Overall the performance of these hybrids has been disappointing. For most smallholders, yield achieved from hybrids was below expectation, the trees had a relatively low economic life with productivity starting to decline within 10 to 15 years of replanting. The hybrid nuts had a higher moisture level which also led to lower oil recovery on the part of millers (Hopa et al. 2008, p. 13).

Similarly for cocoa, there has been 50 years of research into improving cocoa yields through variety selection. Yet yields throughout the region, outside of PNG, continue to fall. In Vanuatu's main cocoa-producing area on the island of Malekula, farmers

37 http://www.worldagroforestry.org/

38 Such research stations include: Cocoa and Coconut institute (CCI) or the Coffee Research Institute (CRI) in PNG; the Vanuatu Agricultural Research Technical Centre (VARTC) (formally the IRHO (Institute des Huiles et Oléagineux) for coconuts and IRCC (Institute de Recherché du Café et Cacao) for cocoa; the Mua Research Station in Fiji for coconuts; and the Atele Research Station in Samoa for cocoa.

are now selecting their own seed despite the substantial resources devoted to cocoa selection over the years at the VARTC Research Station located at Saraoutou in southeast Santo. As a result, the industry is now experiencing significant inbreeding yield depression (Bastide et al. 2006; Lebot pers. comm.). Faced with the demands and uncertainties of climate change the research needs of the export commodity sector are now greater than ever. Yet the capability of the centralised research stations to meet this demand is severely depleted.

For certain objectives, such as breeding for resistance to a serious disease (e.g. *Ganoderma* in oil palm) centralised research is required before local evaluation can be undertaken. Furthermore, centralised research stations can have an important role in facilitating the introduction of improved germplasm for subsequent evaluation by farmers. This is particularly relevant for PNG where there are large tree crop industries with significant resources at their disposal, for example, the PNG Cocoa and Coconut Research Institute Ltd (CCRIL) breeding programme at Tavilo. CCRIL have imported international materials ('the Reading collection') as a source of resistance and diversity; crosses have been made with locally adapted materials and the progenies distributed as seed — so there is plenty of diversity and a range of improved traits in farmers' fields. CCRIL researchers are now going back and making single-tree selections of the best-performing materials on farmers' fields. The best of these (after confirmation of their performance at Tavilo) are being distributed as clones and tested for local adaptation.


Latest CCIL selections (l);CCIL grafting to distribute new cvs (r) Photos: Richard Markham

A similar approach was described in Chapter 4 for root crop breeding in Vanuatu. Germplasm was imported by VARTC, often through the SPC Centre for Pacific Crops and Trees (CePaCT), and planted for preliminary selection before distribution to farmers for their own on-farm evaluation and selection.

A different approach to that followed in the past for tree crop research is required if the needs of farmers are to be met and to minimise climate change impacts. This approach should ensure an appropriate balance between the work undertaken at centralised research stations and participatory research undertaken in farmers' fields. Any new research strategy needs to recognise that Solomon Islands, Vanuatu, Fiji and Tonga are 'archipelagic' countries, meaning that climatic and environmental conditions vary considerably over short distances. In Vanuatu, for example, climate ranges from hot tropical in the north to almost subtropical conditions in the south. Average seasonal temperatures range between 21° and 27°C. Southeast trade winds create a more forested side to the windward of most islands and lighter vegetation to their leeward side. At low altitudes, the windward sides of the islands have a typical equatorial climate, with rainfall between 2500 and 4000 mm, while leeward slopes generally have rainfall less than 2000 mm. As a result of this climatic variability, selected cultivars of different crops developed at the Tagabe Research on Efate (17 45° S) performed poorly when taken north to Santo (15 25°S) (Lebot pers. comm.). Similarly, the performance of high-yielding cocoa developed at the VARTC at Saraoutou in southeast Santo has been disappointing when planted in the main cocoa growing area on the Island of Malekula, less than 100 km south.

5.7.4 Identified research and intervention priorities for climate change adaptation

Some of the identified priorities for export commodities include:

5.7.4.1 Decentralised seed orchards

Decentralised seed orchards are particularly necessary in archipelago situations for crops where there are large genotype x environment (GxE) interactions. Such orchards enable genetic improvement via recurrent selection of local elite material rather than producing hybrids which would have to be distributed geographically. To avoid inbreeding yield depression, 'new' diversity would be made available, when appropriate, as in the breeding programme at CCRIL. The improvement could be relatively fast, if the focus is on a few traits. Selected improved plants could then be incorporated into other populations to introduce 'new blood'. For example, for coconuts, selection objectives could include improved albumen yield, while for cocoa and coffee improved aromatic compounds might be desirable (for increasingly important niche markets, that might increase farm-gate prices and so offset any loss in production attributable to the effects of climate change).

5.7.4.2 Implementing effective programmes to encourage coconut replanting

The income earned from coconuts is critical for the livelihoods of a large number of the poorest people across the region. Mature coconut trees (five years to around 50 years) are expected to be reasonably tolerant to climate change. However, older trees become increasingly vulnerable to cyclones, which are expected to increase in intensity in the future. The vast majority of coconut plantings in the PICTs are more than 50 years old, with many considerably older. Thus, the most effective climate change strategy for coconuts is replanting. Substantial replanting would enable farmers to take advantage of biofuel opportunities. Biofuel is expected to become an increasingly attractive value-added product in the future in the face of the rising price of petroleum products.

Past programmes to encourage replanting have been ineffective. The lack of interest of farmers in re-planting can be attributed to a number of factors. As previously discussed, hybrids developed in the past were not suited to local conditions — their failure to perform better than the traditional 'talls' was exacerbated by their requirement for additional inputs (fertiliser). Another factor, and probably more of a deterrent for replanting, is the arduous labour requirements of producing copra. Most coconut products, including biofuel, cannot be efficiently produced without first making copra. Thus, there is an urgent need to develop less arduous processing techniques for copra. A first step should be to learn from the Philippines and other major copra producing areas, highlighting again the need for more external linkages, in particular, south–south collaboration. In addition, the issue of creating a reasonable economic value for senile palms should be considered, thereby providing an incentive for farmers to clear and replant.

Senile coconut trees, Vanuatu Photo: Andrew McGregor

Any replanting programme must consider the benefits that would accrue, such as ecosystem services (shade/microclimate and protection from coastal erosion), local markets for profitable products, such as coconut water and virgin coconut oil (VCO), which would depend on access to processing facilities and be influenced by the cost of transport. The varieties selected for replanting should be targeted to specific uses. For instance, dwarf varieties may be particularly appropriate if the main market is for drinking coconuts. Clearing of senile palms also provides farmers with the opportunity to move from a coconut monocrop towards a more diversified system.

5.7.4.3 Decentralised agroforestry systems research and demonstration plots

The plantation era is now over in the Pacific Islands and monoculture production systems must be replaced by small-scale agroforestry. Land for food production in close proximity to many Melanesian villages has become scarce, and the cost and low productivity of labour in relation to the value of tree crop commodities also affects agriculture development and change. Smallholder farmers sell copra, cocoa beans or coffee cherries to buy rice, bread and biscuits to feed their families, but this practice will become less viable as the relative price of imported grain increases in the face of climate change and raises the cost of these imported goods. Thus, it is necessary for smallholder farmers to incorporate food crops with tree crops in order to feed their families.

Agroforestry systems have traditionally been used as a buffer against stresses from both abiotic (from the surrounding environment, including factors such as temperature, water and wind) and biotic (from living organisms) sources.

Cocoa agroforestry, Savaii, Samoa Photo: Andrew McGregor

Research carried out in various parts of the world has provided some information on how these systems affect soil moisture, total soil organic carbon, nitrogen mineralisation and soil microbial activity (de Souza 2012). However, as highlighted in Chapter 4, far more information is required on the role of agroforestry systems in buffering against climate variability, and how the different components can be utilised and fine-tuned to make the systems more flexible and more economically sound for farmers to work with. The conversion of land from existing systems, such as land planted to coconuts, to agroforestry presents a significant challenge and deserves research. In addition the value of tree crops in mitigating the effects of climate change also needs to be quantified.

5.7.4.4 A better understanding of the climate-related pest and disease problems

Some of the major climate change threats to these tree crops are likely to emanate from pests and diseases and their flow-on effects on crop yield and quality. For coconut a better understanding of the Bogia coconut syndrome (BCS) is urgently needed, in particular the vector and other host plants. For example, is the banana wilt disease recently identified in PNG caused by the same phytoplasma as the one responsible for BCS? The collection held at the PNG Stewart Research Centre near Madang could be screened for resistance to BCS. The identification of the disease in close proximity to this important collection highlights the vulnerability of field collections of long-lived palms and the importance of perfecting effective and viable cryopreservation protocols to safely conserve important diversity. A cryopreservation protocol has been successfully applied to zygotic embryos of four different coconut genotypes, but additional work is required to refine the cryopreservation procedure[39].

Other priorities for pest and disease research include greater clarity on the impact of an increasingly warmer climate on: *Ganoderma* and *Fusarium* in oil palms; coffee berry borer; coffee leaf rust; and cocoa pod borer.

In the light of the limited knowledge on pests and diseases and how they will respond to climate change, improved monitoring of these pests and diseases and identifying and evaluating more preventative approaches and management options for their control is essential.

5.7.4.5 The development of alternative livelihood strategies for coffee producers in locations most susceptible to climate change

Many of the current coffee growing areas in PNG will become sub-optimal for coffee production in the medium term (to approximately 2050), with the likelihood that pests and diseases will be a major problem. For some coffee growers, production problems will be offset by increased global prices and niche/value-added marketing. However, the growers benefiting from these markets will tend to be in the areas less affected by climate change. Thus, it can be expected that as many as a million households in the PNG Highlands will need to develop alternative livelihoods within a decade or so.

39 http://www.ncbi.nih.gov/pubmed/22020411

To avoid major social and economic disruption, research and planning for alternative livelihoods for coffee producers needs to commence now.

Drying coffee in PNG Highlands Photo: Fairtrade, New Zealand

5.7.4.6 Applying long-standing soil health knowledge to Fiji's sugar cane farms

Fiji used to be a leader in environmentally sustainable smallholder sugar cane production (Lowndes 1956), through pioneering innovations such as the use of vetiver grass for soil conservation (Greenfield 1989) and incorporating lime to restore soil pH. More recently a great deal of practical knowledge has been acquired on the rehabilitation of degraded soils on the Fiji island of Taveuni through the ACIAR Soil Health Project[40] and the work of the farmer organisation Tei Tei Taveuni[41]. Large benefits would now accrue to Fiji if this knowledge could be adopted by today's cane farmers. The Sugar Research Institute of Fiji would have to play a lead role in establishing demonstration plots, but for effective outreach, farmer organisation(s) equivalent to Teitei Taveuni should be established in the Fiji cane belt.

5.7.4.7 Identifying best practice from single origin marketing, certified organic production and fair trade

Niche marketing is seen as an important climate change adaptation strategy to increase market prices and so offset the adverse impact of climate change on yield. Research is required in such areas as: determining optimum processing methods; selecting and enhancing aromatic compounds desired by the market; and identifying best practice from single origin marketing, certified organic production and fair trade.

40 http://aciar.gov.au/project/smcn/2009/003
41 http://teiteitaveuni.com/

5.8 Policy implications and recommendations

5.8.1 Developing a new research and extension paradigm

As has been previously discussed, outside of PNG, climate and environmental conditions can vary within very small distances, highlighting the importance of developing locally adapted germplasm and technologies with the strong support and involvement of farmers. The traditional model of a few centralised research stations to undertake tree crop research is no longer a solution for many climate/environment related research priorities.

What the research priorities should be, is relatively clear. The questions are how best to understand the problems and gaps in knowledge that exist, and importantly, how to address these problems. With the scarcity of resources available for research, the significant GxE interactions and the biosecurity constraints (often challenging and costly) in moving germplasm around the region, the move towards more decentralised research becomes increasingly attractive as a more sensible and realistic alternative for the future.

Despite the enormity of the challenge there have recently been some small but encouraging developments in effective decentralised applied research, though not all applied to export commodities. These include:

- the successful adoption by East New Britain cocoa farmers of a Farmer Field School-based approach to Integrated Pest and Disease Management (IPDM) (Konam et al. 2008). Through IPDM's participatory process farmers have seen the value of improved sanitation and have been able to select superior germplasm for planting material, resulting in substantial yield increases;
- a successful pilot project to introduce new genetic diversity and evaluate on-farm conservation in Vanuatu's traditional cropping systems (McGregor et al. 2011). This pilot programme involved close collaboration between VARTC and a long-established farmer organisation, the Vanuatu Farm Support Association (FSA). FSA, with its low overhead cost structure and farmer-based network, has been able to implement this programme effectively at surprisingly low cost. This approach has been discussed in Chapter 4;
- the work of the farmer organisation 'Tei Tei Taveuni' in testing and developing measures to reverse declining soil fertility on the Fiji island of Taveuni;
- the formal establishment of the Pacific Island Farmer Organisation Network (PIFON). PIFON is in a position to facilitate farmer-to-farmer exchanges relating to lessons learnt in climate change adaptation.

The multiple challenges discussed in this chapter with regard to export commodities, in particular tree crops, highlight the need for a platform which will allow for the discussion of existing research priorities and ensure that ongoing needs are identified. Tree crops involve a diverse group of stakeholders largely because of the importance of the private sector market players — traders, processors, and certification groups. Identifying a consultation mechanism that will assist in making early progress and setting the stage for future research prioritisation is crucial.

The suggested approach is to first hold an over-arching agricultural tree crop research conference[42], which would be followed by a series of meetings for the individual tree crop sectors. The main priority of the conference would be to agree on research model(s) to meet both short-term (to 2030) and medium-term (to 2050) needs. The conference participants would comprise representatives from relevant sectors and all stakeholders (policy makers, farmers, researchers, extensionists, practitioners), key regional and international organisations, relevant donor agencies, and industry partners. The conference is a specific recommendation for this chapter; however, it is equally relevant to determine research approaches and priorities for agriculture in general. Resources and capacity are limited. Therefore, identifying what is needed to minimise impact and maximise opportunities from climate change in the agriculture sector is essential.

This first step to achieve multi-stakeholder planning will set the stage for a more integrated approach to identifying research priorities, which will in turn nurture production approaches that take on board the challenges of climate change and at the same time allow maximum benefits to be gained from the opportunities that arise. Once in place, institutional mechanisms must continue to be supportive of an integrated approach; financial mechanisms would need to allow for funding initiatives with multiple, inter-related objectives, and monitoring and evaluation systems to account for a variety of impacts at the landscape scale.

42 It is recommended that SPC convene the conference, probably in collaboration with other entities such as ACIAR and/or CIRAD. This book, Vulnerability of Pacific Island agriculture and forestry to climate change, would be one of the key resources to guide the deliberation of the conference. Other keynote theme papers will need to be commissioned.

5.9 Summary: The likely response of export commodities to climate change

Crop	Climate change/climate variability impact in recent decades	The impact of climate change over the next two to three decades (2030–2050)	The impact of climate change beyond 2050
Coconuts	Main impact has been loss of palms growing close to the sea and cyclones breaking senile palms.	No major effect is expected until at least 2050. The main impact will be from the expected increased intensity of cyclones on the increasingly senile population of coconut palms. **Overall production and economic impact assessment: Low**	The likelihood of increasingly severe cyclones could have a severe impact on coconut production. Rainfall could reduce production especially in areas where rainfall and cloud cover are already relatively high. The impact of major pests and diseases is unclear; effectiveness of biocontrol agents for rhinoceros beetle could be reduced. **Overall production and economic assessment impact: Low to Moderate**
Coffee	Most apparent impact coffee leaf rust in PNG	Arabica coffee has been identified as the PICTs commodity most likely to be significantly negatively impacted by climate change. This brings with it the prospect of the livelihoods earned by a large number PNG's rural households being adversely impacted. **Overall production and economic impact assessment: Moderate**	Increases above 2°C could be expected to have a major negative impact. Most current coffee-growing areas in PNG will become sub-optimum for coffee production, with pests and diseases likely to become a major problem. As a result the livelihoods of large number PNG's rural households and the PNG economy will be severely impacted. **Overall production and economic impact assessment: High**
Cocoa	No discernible impact over recent decades	PNG and Solomon Island cocoa-producing areas unlikely to be more affected than world's major cocoa-producing areas in West Africa and South America. Cocoa growing areas, such as Vanuatu, Fiji and Samoa could benefit from increasing temperatures. **Overall production and economic impact assessment: Small production; Insignificant economic**	The suitability of the major current cocoa-growing area in PNG and Solomon Islands is expected to decrease significantly beyond 2050. Vanuatu's cocoa areas are likely to be less affected. Could be a threat from black pod disease from increasing rainfall. How other pests and diseases, such as CPB will be affected is unclear. **Overall production and economic impact assessment: Moderate to High production; Moderate economic**

Oil Palm	No direct climate change impact	Pacific Island palm oil producers likely to be minimally impacted. In addition, palm oil producers can also expect to benefit from increasing crude oil prices which will increase the demand for biofuels. **Overall production and economic impact assessment: Insignificant production; positive moderate economic.**	Some possible adverse impacts from pests and diseases but this is unclear at this stage. Very high emission temperatures could affect production **Overall production assessment: Small; positive moderate economic**
Sugar	Severe impact of cyclones, floods and droughts associated with ENSO cycles – although unclear what the contribution of climate change has been.	ENSO cycles will continue to have a significant impact on Fiji's sugar production, with increased interaction with climate change expected. Climate change likely to be a minor factor contributing to the decline of the industry compared with other factors. **Overall production and economic impact assessment: Small production; Insignificant economic**	Unlikely that a 2°C increase in average temperature will have any major impact, but more severe cyclones, floods and droughts would have a significant impact. **Overall production and economic impact assessment: Moderate production; Small economic**

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Photo: Kalara McGregor

Chapter 6

Vulnerability of high-value horticultural crops to climate change

Kyle Stice and Andrew McGregor

Contents

6.1 Background

Traditional Pacific Island horticultural farming systems include a range of staples, fruit, vegetables and spice products. For example, Weightman (1989) describes a contemporary ni-Vanuatu horticultural food garden below.

The gardens are planted to a variety of crops, often inter-planted as single plants, though sometimes planted with patches of one crop, such as sweet potato, taro, yam or manioc. The soft yams are planted first and take pride of place where the garden offers the best conditions for their cultivation. Other crops follow: sugarcane, island cabbage, naviso, pineapple, pawpaw, water melon, tomato, Chinese cabbage, sweet potato, manioc, bananas, taro and kava. A single garden will generally contain many varieties of yam or taro and several other crops (p. 51).

The traditional horticulture-based farming systems have largely been covered in Chapter 4, which focused on the staple food crops of the PICTs. The focus of this chapter will be on commercially important (high-value) horticultural crops, which have been divided into three broad categories: fruit and vegetable crops (papaya, mango, citrus, pineapple, watermelon and tomato), stimulant crops (kava and betel nut) and spices (vanilla and ginger).

6.1.1 Fruits and vegetables

In some PICTs highly suitable agro-ecological conditions can be found for the production of a range of fruit and vegetable crops, for example, the highlands of PNG for sub-tropical fruit, vegetables and floriculture products and western Viti Levu, Fiji, for tropical fruits. The export of horticultural products and sales to urban areas has often been identified as the agricultural activity with the best growth prospects (McGregor and Macartney 1985; ADB 1996, 2004; AusAID 2006).

New Zealand, Australia and the west coast of the United States have large and increasing Pacific Island and Asian populations that offer a significant market for a range of horticultural products, but actual export performance has been disappointing, with horticultural exports still only a small fraction of bulk commodity exports. However, there are indications that this situation is starting to change. In Fiji, for example, smallholder horticulture is now the fastest-growing sector in an otherwise stagnant economy, despite some major climate events. The future comparative advantage of this sector is likely to be significantly influenced by climate change.

Fiji has a significant papaya export industry and considerable scope for its expansion has been identified. New Caledonia, Samoa and Vanuatu are now exporting small volumes of Tahitian limes to New Zealand during the New Zealand off season. In all PICTs, domestic fruit and vegetables contribute significantly to food and nutritional security.

6.1.2 Spices

Spices are often promoted to diversify agricultural exports and rural income in PICTs. There have been some notable successes — vanilla in PNG, Tonga and Vanuatu (McGregor 2004; Bianchessi 2012) and ginger in Fiji (McGregor 1989). These spice crops are seen to be highly sensitive to the micro-climate of the location in which they are grown.

6.1.3 Stimulants

Two major stimulant crops, kava grown in Vanuatu, Fiji, FSM, Tonga and Samoa, and betel nut grown in PNG, Palau, FSM, and Solomon Islands, contribute significantly to rural livelihoods. In PNG, betel nut consumption distributes income from the coffee-growing areas in the highlands, mining enclaves and urban areas to growers in the lowlands and at intermediate altitudes. The economic impact of this income distribution is often under-estimated. Bourke and Harwood (2009) estimated that the sales of betel nut and betel pepper generated the equivalent of around USD 10 million in annual incomes for rural villagers over the period 1990–1995. This represented 10% of the income generated from agriculture production by village farmers. Since then the income earned from betel nut sales has increased significantly because of price rises and increased sales to highlanders. The estimated value of betel nut exports in 2005 from FSM to Guam and the RMI was USD 0.4 million. FSM also exports kava to Hawai'i and Guam, mainly frozen, but also freeze-dried. For Vanuatu, kava provides the main mechanism for distributing income from the urban centres to the outer islands. In Fiji, kava has, for many years, enabled income to be generated in the cane growing and urban areas and distributed to the outer islands and the interior of the main islands.

Wholesale betel nut market, PNG

Photo: Timothy Sharp

6.2 Optimum bioclimatic conditions for selected high-value horticultural crops

6.2.1 Fruits and vegetables

6.2.1.1 Papaya

Photo: Kyle Stice

Solo Sunrise papaya performs exeptionally well in the Western Division of Fiji

Papaya (*Carica papaya*) is an important cash and food crop across PICTs. Fiji has a significant papaya export industry, with exports in 2011 totalling 805 tonnes and mainly going to the Australian market. Considerable scope for expansion of exports has been identified (FACT 2009).

The Cook Islands used to be a significant exporter of papaya to New Zealand; however, increasing costs (production and marketing/export), pressure on farm land from housing development by local families, and tourism have brought exports to a halt. Papaya is now sold domestically to the lucrative tourist and non-tourist markets.

The three major bioclimatic factors for commercial production of the 'Solo' type[1] papaya are temperature, moisture (rainfall and soil drainage), and wind. Sunlight is also important; insufficient sunlight results in low yields, fruits with inadequate sugar and encourages plant diseases. The hermaphrodite papaya plant preferred for commercial orchards is more sensitive to the growing environment than the female papaya plant.

In the absence of irrigation, fruit production is optimal in areas with a minimum monthly rainfall of about 100 mm, minimum relative humidity of 66% (Nakasone and Paull 1998) and with a temperature range of 21°–33°C (Villegas 1997; Nakasone and Paull 1998; OECD 2003). Temperatures below 12°–14° C strongly retard fruit maturation and adversely affect fruit production (Nakasone and Paull 1998).

1 Solo' type papaya refers to varieties that produce smaller fruit - fruit that can be consumed by one person. Hawaiian 'Solo' type papaya cultivars can be either red- or yellow - fleshed and include varieties such as 'Sunrise', 'Sunset', 'Kapoho' and 'Waimanalo'. 'Solo' type papayas are generally gynodioceous, producing either female or hermaphrodite plants.

Temperatures below 16°C cause carpeloidy, which results in 'cat-face' deformity of fruit when floral stamens develop abnormally into fleshy, carpel-like structures. Even at low elevations, fruits formed during the cooler winter months can express carpeloidy. Cool growing conditions also result in a reduced sugar content and delay fruit maturity. Papaya is extremely sensitive to frost, which can kill the plant.

Adequate air movement is important in reducing the incidence of fungal diseases such as fruit rot caused by *Phytophthora palmivora* and anthracnose caused by *Colletotrichum gloeosporioides*; the severity of these diseases increases with high humidity around the plants (Nelson 2008; Rawal 2010).

Tolerance of papaya to extreme climatic events

Photo: Kyle Stice

Papaya is very susceptible to standing water; even 6–8 hours of exposure to puddle water will kill a papaya tree

High temperatures (32°–35°C) may induce 'female sterility', in which normally hermaphroditic papaya plants produce male flowers, resulting in poor fruit set and production (Nishina et al. 2000).

Papaya requires good soil drainage and is very susceptible to waterlogging. Papaya plants can be killed when subjected to super-saturated soil for even a few hours. Papaya is susceptible to fungal root diseases usually caused by *Phytophthora* spp., where soil drainage is restricted, or in periods of very heavy rainfall (Nishina et al. 2000).

Papaya plants exposed to constant wind develop deformed, crinkled leaves. Excessive wind stress results in reduced growth, fruit set, fruit quality (strong winds also cause damage to fruits from leaves rubbing onto mature fruit) and productivity. Wind-blown dust can cause sap bleeding that harms fruit appearance. In coastal regions, salt spray carried by wind can desiccate leaves and kill papaya plants. Winds in excess of 60 km/hr can uproot papaya trees, especially if accompanied by heavy rain (Nishina et al. 2000).

Extended periods of drought will cause flower drop in papaya plants, resulting in a gap in fruiting (Nakasone and Paull 1998). For example, in Cook Islands, long drought periods have caused gaps in production and affected supply to the market over the last 5–10 years. The timing of life-cycle events like flowering and crop maturity have only recently been an area of research in relation to the potential impacts of climate change.

6.2.1.2 Mango

Mango (*Mangifera indica*) is cultivated throughout the tropical and sub-tropical world for commercial fruit production; it is a popular garden tree and shade tree. In PICTs, most mangos were introduced from other parts of the world but some indigenous varieties are still consumed in high rainfall locations in PNG. Mangos now play an important role in income generation and nutrition for many island communities.

Air temperature and rainfall are two of the most important factors determining the suitability of an area's climate for mango production. The seasonal cycles of shoot, root, floral and fruit development are influenced by these climatic conditions and the variety. The cycle of the mango tree is either advanced or retarded with rise and fall of temperature and the onset of wet and dry seasons (Rajan 2012).

The optimum temperature range for mango production is 24º–27 °C (Bally 2006), with flowering bud induction promoted by a period of cool weather (Nunez-Elisia and Davenport 1994). The maximum temperature of the warmest month may be a limiting factor for mango cultivation and will vary between varieties. Cool temperatures below 17°C produce abnormal and non-viable pollen grains in mango.

As the mango originated in a monsoonal tropical environment it is well suited to many parts of the PICTs, particularly the leeward sides of islands with a distinct dry season. Hot, wet climates promote vegetative growth, with little or no fruit production. The mean annual rainfall range is 400–3600 mm, with a dry period that lasts from 1–2 months (Bally 2006). Low rainfall during fruit development and maturity is critical to achieving disease-free fruit.

Mango is a host for a number of fruit flies, depending on the country, which can result in production and quarantine problems. These include *Bactrocera frauenfeldi* (mango fly) which is found in PNG, Solomon Islands, Palau, FSM, RMI and Kiribati [2].

Tolerance of mango to extreme climatic events

Unpredictable rains during pre-flowering and flowering periods may cause poor fruit and low pollinator activities. Anthracnose (*Colletotrichum gloeosporioides*) can be a serious problem in mango cultivation in humid, high rainfall environments (Cook 1975; Lim and Khoo 1985; Ploetz 2003). In certain areas of southern Thailand and India, excessive vegetative growth and drop of flowers are associated with heavy and prolonged rainfall; however, some resistance can be found in a number of southeast Asian cultivars. Very low rainfall (less than 40 mm) in the wettest month of the year may be a limiting factor in commercial production.

High temperatures during panicle development in mango speed up growth and reduce the number of days when hermaphrodite flowers are available for effective pollination, which may lead to unsatisfactory production. Rising temperatures cause

2 www.spc.int/pacifly/species_profiles/B_frauenfeldi.htm

desiccation of pollen and poor pollinator activity resulting in low fruit set and, ultimately, a poor crop (Bhriguvanshi 2010).

Mangos are relatively wind resistant and are sometimes used in windbreaks. However, cyclonic winds can be especially damaging to them, causing breakage of major branches or uprooting of the whole tree. Although preventing damage from cyclonic winds is difficult, good post-storm management can hasten recovery and minimise secondary effects. Fallen trees should be straightened immediately following the storm, while the soil is soft, to prevent re-damaging roots. Damaged branches should be removed to prevent disease infections and to promote new growth (Bally 2006).

Mango is moderately tolerant of drought for up to eight months (less than 40 mm rainfall/month) in certain situations (Bally 2006).

6.2.1.3 Citrus

Citrus grows in tropical and sub-tropical conditions, ranging between 40° north and south of the equator, but citrus quality is generally regarded as superior in subtropical and Mediterranean climates. Oranges and mandarins produce the best quality fruit in subtropical locations (between 35° and 15° north and south of the equator), where most flowering occurs in spring as temperatures increase following the dormant winter period (Jackson 1999).

Oranges and mandarins produced in tropical locations are usually of poorer quality and are therefore consumed locally. The ever-bearing nature of trees in a tropical environment is not conducive to superior fruit quality (Rosenzweig et al. 1996) with fruit size and shape, rind colour and internal quality compromised by the growing conditions (Jackson 1999). Oranges only develop their distinctive rind colour when temperatures fall below 7°C for an extended period (Klein et al. 1985). However, some citrus such as limes, grapefruit and pomelo can thrive in hot wet tropical conditions and for these citrus types, the rind colour is acceptable.

Altitude can compensate for latitude, and high quality oranges and mandarins can be grown at mid-elevation equatorial regions provided other agronomic factors (such as the absence of frost) permit. For example, in the highlands of PNG oranges can be produced at up to 1800 m above sea level, but the best quality oranges and mandarins in PNG are produced at 800–1400 m altitude.

Citrus have been a part of PICT village self-sufficiency for centuries. Limes (*Citrus aurantifolia*) were introduced by European sailor/explorers around 1700 AD. Other citrus types introduced over the last century or so now make a major contribution to the self-sufficiency of village households. These include orange (*Citrus sinensis*), mandarin (*Citrus reticulata*), grapefruit (*Citrus paradisi*), lemon (*Citrus limon*) and pomelo (*Citrus grandis*). At the time of the 1999 Vanuatu Land Use Project food garden survey, citrus was the dominant seasonal fruit available, with around 90% of households consuming some citrus fruit during the previous week, with most eating citrus at least three or four times a week. Very little other fruit consumption was indicated by the survey.

Citrus trees were first introduced in PNG in the 1870s (Bourke and Harwood 2009). Table 6.1 shows the months when a plentiful supply of different citrus varieties is available.

Table 6.1 Months in which there is a plentiful supply of citrus available in PNG (source: Camarotto and Bourke 1994).

Common name	Scientific name	PNG Highlands (months available)	PNG Lowlands (months available)
Grapefruit	*Citrus paradisi*	March–August	
Kumquat	*Fortunella japonica*		February–December
Lemon	*Citrus limon*	May–October	
Lime	*Citrus aurantifolia*		January–December
Mandarin	*Citrus reticulata*	May–August	
Orange	*Citrus sinensis*	April–August	
Pomelo	*Citrus maxima*		January–December

In Samoa, the Ministry of Agriculture introduced a wide range of citrus varieties as part of a UNDP Project in the 1990s; as a result over 5000 grafted seedlings were distributed to growers. More recently, the Australian Centre for International Agriculture Research (ACIAR) supported a similar project in Tonga. Despite these efforts limited commercial citrus production is found in the region. PNG imports 200 to 300 tonnes of citrus annually even though there is significant local production, particularly in some highland locations. All other PICTs are significant net importers of citrus, particularly oranges.

Three countries (New Caledonia, Samoa and Vanuatu) now export Tahitian limes (*Citrus latifolia*) to New Zealand in the off season (August–December)[3]. This particular lime thrives in tropical condition and, unlike the West Indian lime (*Citrus aurantifolia*), does not suffer from the damaging *Citrus tristeza virus* (CTV). Tahitian limes are a non-host to fruit flies in those countries free of citrus canker. Fiji, in the 1980s, tried unsuccessfully to establish an orange juice processing industry at Batiri on Vanua Levu to supply the then protected New Zealand market.

3 In 2010 the combined exports of these three island countries was 27 tonnes, compared with total New Zealand imports of 185 tonnes (Statistics New Zealand).

Tolerance of citrus to extreme climatic events

In tropical climates flowering is usually initiated after a stress event, commonly water deficiency, which can occur at any time of the year and more than once a year. Thus extreme events can seriously disrupt flowering and fruiting patterns and the long-term health of the tree. Cyclonic winds can also cause considerable damage to citrus, but less compared with fruit trees such as rambutan and avocado. Tree fall data collected after severe Tropical Cyclone Ofa in 1991 for Samoa indicate that citrus trees were the least damaged of all fruit trees (Table 6.2). Citrus tend to have a relatively strong root system and a wood grain resistant to the twisting and shear forces caused by a cyclone.

Table 6.2 Estimated tree fall caused by Cyclone Ofa in Samoa. (source Clarke 1992).

Crop	Estimated tree fall (per cent)
Mature banana	100
Coconut depending on location	5
Breadfruit	50 to 90
Pawpaw	30 to 80
Citrus	10 to 50
Mango	30 to 80
Advocado	30 to 80
Mature cocoa	10 to 50

Citrus does not tolerate waterlogging; with temperatures over 24°C, fibrous root death from lack of oxygen can occur within 7–14 days. In contrast, citrus can generally tolerate drought (e.g. 3–4 months of minimal rainfall), that is, less than 40 mm for consecutive months (Manner et al. 2006). Citrus grafted or budded on shallow rooted rootstocks such as trifoliate are more prone to drought, but tree management, soil type, evaporation rates and location will all affect how long such trees can tolerate drought conditions without wilting. Rough lemon and scarlet mandarin stocks, both deep rooted rootstocks, are highly tolerant of drought conditions.

Tolerance to cold is variable between citrus varieties, but in general citrus is damaged when temperatures fall a few degrees below freezing for a short period.

6.2.1.4 Pineapples

Pineapple (*Ananas comosus*) was introduced to the South Pacific around 1777 by Captain James Cook who planted pineapples on the Society Islands. However, it was not until 1885 that the first sizeable plantation of five acres (2 ha) was established in Oahu, Hawai'i (Purseglove 1972). Pineapple is the third most important tropical fruit in world production after banana and citrus. In PICTs, the pineapple is heavily traded in municipal markets and is one of the most common fruits consumed in PICT households.

Photo: Kyle Stice

Pineapples are a very important domestically traded horticulture crop in almost all Pacific Islands

Most PICTs generally have very favourable pineapple growing conditions. A temperature range of 18°–32°C is optimum for pineapple cultivation (Bartholomew et al. 2003). Plant growth decreases rapidly at mean temperatures below 15°C or above 32°C (Neild and Boshell 1976). Altitude has an important effect on the flavour of the fruit. In Hawai'i, the 'Smooth Cayenne' is cultivated from sea level up to 600 m. At higher elevations the fruit is too acid. In PNG, pineapples are grown at up to 1800 m, with the best-flavoured fruit produced at 400–1200 m (Bourke 2010).

Although pineapple plants will grow almost anywhere in the tropics, they are most productive in dry environments (Black 1962; Purseglove 1972; Py et al. 1987). Ideally, annual rainfall should be about 1140 mm, evenly distributed between spring and autumn. However, pineapple will produce fruit under yearly precipitation rates ranging from 650–3800 mm, depending on cultivar, location and degree of atmospheric humidity.

In PICTs, natural flowering is a major problem and only occurs with mature plants during the months of May and June. To avoid this seasonality, 'forcing' (i.e. artificial induction with chemicals) is practised in some commercial farms (Botella et al. 2000).

Tolerance of pineapple to extreme climatic events

Pineapple is relatively tolerant of drought but susceptible to waterlogging and prolonged wet weather: under these conditions, top rot and root rot caused by the soil fungi *Phytophthora cinnamomi* and *P. nicotianae* var. *parasitica* can be an issue[4]. Good soil drainage is therefore essential to avoid these problems.

High (>35°C) and low (<10°C) temperatures affect fruit development and retard growth (Purseglove 1972; Py et al. 1987). Because of their low-growing nature, pineapples are highly resilient to extreme winds.

6.2.1.5 Tomato

Tomato (*Solanum lycopersicum*) is widely grown across many PICTs and is an important crop for income generation and nutrition. For example, a food garden survey conducted in Vanuatu found that virtually every garden contained tomatoes

4 http://www.kau.edu/prsvkm/Docs/DiseasesofPineapple.pdf

(Vanuatu Land Use Planning Office 1999). The survey reported that 'almost half the respondents indicated "fulup" (a glut) consumption. These tomatoes were mostly consumed as refreshment "snacks" in the garden – although some were consumed with meals. In contrast, tomato is a minor crop in PNG, where it is only grown by around 2% of the rural population (Bourke and Harwood 2009).

Tomatoes grow well over a wide range of temperatures (18º–30°C), with different varieties varying in their sensitivity to temperature. A temperature range of 20º–25°C is considered optimum for the growth of tomato. At higher altitudes, when daytime temperatures are warm but night temperature drops below 12°C, many varieties will not set fruit. In summer, when day temperature is above 35°C and night temperature is above 25°C, flowers may produce oddly-shaped (rough) fruit or flowers can fall prior to fruit set. Moderate increases in mean daily temperature, for example, from 28º–32°C (day temperature) and from 22º–26 °C (night temperature) have been shown to cause a significant decrease in the number of fruit set. Under marginal conditions fruit may set without adequate pollination but the internal fruit segments will contain few seeds and the tomato will be flat-sided and puffy. Irregular pollination can also cause the fruit disorder known as cat face (Rudich et al. 1977; Peet et al. 1997; Sato et al. 2006; Deuter et al. 2012).

Fruit colour is also temperature-dependent. Lycopene and beta-carotene are carotenoids that determine colour and are not synthesised above 29°C. As well, lycopene is not synthesised below 10°C, precluding normal colour development in ripening fruit (Falcone 1994). These compounds are not just important for visual appeal but are also nutritionally beneficial. Dietary carotenoids are linked to health benefits such as decreasing the risk of certain cancers, eye disease, cardiovascular disease and diabetes.

The main constraint to production in the summer months is bacterial wilt (*Pseudomonas solanacearum*), which is dependent on soil water temperature as well as air temperature. The variety 'Heatmaster' (semi-determinate) type, cultivated commercially in Cook Islands, is resistant to bacterial wilt and nematodes. However, when temperatures reach 33°C resistance starts to break down. The impact of this disease can be minimised during the summer/warmer months by cultivating the crop on sandy-type soils (Wigmore pers. comm.).

Tomato is generally susceptible to a number of diseases and disorders including damping off (*Pythium aphanidermatum*), early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), leaf mould (*Cladosporium fulverum*) and blossom end rot (a disorder associated with calcium/water imbalance). These diseases result in yield and quality losses and can proliferate under high humidity and insufficient drainage (Hessayon 1985). Tomato fruit borer or fruitworm (*Helicoverpa armigera*)[5] and fruit fly (e.g. *Bactrocera facialis*) are also significant pests in some countries.

5 http://www.nzffa.org.nz/farm-forestry-model/the-essentials/forest-health-pests-and-diseases/Pests/Heliothis-armigera

Screening of tomato genotypes in Pakistan found that some genotypes gave better resistance than others (Usman et al. 2013).

Tolerance of tomato to extreme climatic events

Heavy rain events have a significant impact on the yield and quality of tomato plantings. Heavy rain not only encourages disease but also results in flower loss (Weerakkody and Peiris 1997). Grafting tomato scions onto selected rootstocks of eggplant and tomato can minimize problems caused by flooding and soil-borne diseases. Sometimes the use of grafted tomato plants can be the difference between harvesting a good crop and harvesting no crop at all (Black et al. 2003). The farm benefits of tomato grafting can be achieved only if soil-borne disease or flooding constrains tomato production, as grafted seedlings are more costly and have no other yield benefit over non-grafted seedlings, as shown by several studies conducted by AVRDC in Taiwan and Vietnam. However where these constraints exist, in both locations, the average yield from grafted tomato plants was substantially higher than that of non-grafted plants (Genova et al. 2013) This practice of grafting is being trialled in Solomon Islands and in the floods of 2014, grafted plants survived whereas all non-grafted plants were lost (Tikai pers.comm) .

As discussed, tomatoes are generally sensitive to increases in mean daily temperature, which results in a substantial decrease in the number of fruit set, although there are significant differences between varieties.

Tomatoes are also sensitive to strong winds, which impair pollination and fruiting; in addition dry winds result in flower loss. The crop is sensitive to both drought and salinity: even at moderate levels plants will suffer and become unproductive.

6.2.1.6 Watermelon

Watermelon (*Citrullus vulgaris*) is grown in many locations around the Pacific, as a cash crop and also a novelty fruit for home consumption. Watermelon attracts many relatively large commercial farmers because of the crop's short growth cycle and the potential income that can be earned. Tonga in the past exported watermelon to New Zealand and is now in the process of re-developing this export industry. There is a wide range of watermelon varieties grown in the Pacific, with the majority of seeds sourced from Asia.

Watermelon is native to dry areas in tropical and subtropical Africa, south of the equator. The crop prefers a hot, dry climate with mean daily temperatures of 22°–30°C. Maximum and minimum temperatures for growth are about 35°C and 18°C, respectively. Fruits grown under hot, dry conditions have a high sugar content of 11% in comparison to 8% under cool, humid conditions[6].

6 http://www.fao.org/nr/water/cropinfo_watermelon.html

Watermelon, like many of the other vine crops including squash, pumpkins, cucumbers, and gourds, are bee-pollinated. Bees are very weather-sensitive, will only work on bright sunny days and are easily affected by insecticide sprays. If bees fail to pollinate these flowers, the fruit will start to develop but shrivel and fall off. If bees pollinate the flowers only sparingly, the fruit may develop but will be misshapen or poorly filled (Kansas State Research and Extension Note 2013).

Photo: Kyle Stice

A wide range of watermelon varieties are available throughout the Pacific, sourced mainly from southeast Asia and China

Watermelon is susceptible to a number of pests and diseases. Gummy stem blight (*Didymella bryoniae*) is a fungal disease affecting the leaves and the stem, which eventually leads to poor fruit development. It can spread very quickly with heavy and continuous rain, destroying entire crops[7]. Melon fly (*Bactrocera cucurbitae*), found in PNG and Solomon Islands[8], can attack flowers as well as fruit, and additionally will attack stem and root tissue, causing significant damage to all cucurbit crops wherever it occurs. Infection with *Cucumber mosaic virus* (CMV), transmitted by aphids, can also result in significant economic damage. *Watermelon mosaic virus* is also a debilitating disease of watermelon (Thomas 1980: Davis and Tsatsia 2009)

Tolerance of watermelon to extreme climatic events

As outlined above, watermelon is very susceptible to a number of fungal diseases and insects, which can destroy an entire crop, especially under wet, humid conditions. Therefore in PICTs, watermelon is grown in the dry season (winter).

Watermelon is relatively tolerant of high temperatures but needs adequate irrigation in order to combat heat stress and produce a marketable crop. Watermelon has poor tolerance of drought, but significant variation in drought tolerance has been found in the USDA watermelon germplasm collection. Twenty-five accessions have been

7 http://www.pacificdisaster.net/pdnadmin/data/original/MAL_SLB_Didymella_ExtDFsheet7.pdf
8 http://www.cabi.org/isc/datasheet/17683

identified as potential sources of tolerance to drought, of which the most drought-tolerant originated from Africa. These accessions could be used for rootstock breeding or for developing drought-tolerant watermelon cultivars (Zhang et al. 2011).

Prolonged periods of strong winds, especially during active vegetative growth, will affect vine and fruit development. Strong winds will affect bee activity, resulting in poor pollination. The influence of climate change on pollinators is discussed in Chapters 3 and 7.

The crop is moderately sensitive to salinity, with yield decrease from salinity being similar to that for cucumber.

6.2.2 Spices

6.2.2.1 Vanilla

Vanilla is the region's most important spice export crop, with significant industries existing in PNG, Tonga and Vanuatu. Small industries are found in a number of other countries including Fiji, Niue, New Caledonia, Tahiti and Solomon Islands.

Vanilla is an epiphytic orchid which obtains most of its nutrients from the air and from debris and mosses collected in the trees upon which it grows. The crop thrives in hot, moist, insular climates up to 600 m altitude. The optimal temperature is 21°–32° C, with an average around 27°C. Rainfall should be between 1700–2500 mm and evenly distributed. However, two drier months are required (with precipitation considerably lower than evaporation) to check vegetative growth and induce flowering (Bianchessi 2012). A distinctly cooler period, with temperatures towards 20°C, will also help induce flowering. The stress requirements to induce flowering in *Vanilla planifolia* are greater than for *V. tahitensis*. Thus *V. tahitensis* tends to be suited to a wider geographic area. The crop's ecological requirements significantly limit the locations in which vanilla can be successfully grown or, in particular, flower. In PNG, during the vanilla boom, extensive planting was undertaken well beyond these limits and most plantings subsequently failed (McGregor 2004).

Tropical islands can, however, provide suitable ecological conditions — thus it is no coincidence that island locations, in particular, Madagascar, dominate world vanilla production. Locations in the PICTs that offer ideal climate conditions for vanilla production include:

- Maprik/Dreikikir/Wosera area of East Sepik Province in PNG. East Sepik was the main production area during the vanilla boom; it succeeded because it has an extended dry period
- the leeward side of Va'vau in Tonga
- small islands of northern Vanuatu such as Ambae and Malo

- Western Guadalcanal in Solomon Islands
- eastern Vanua Levu in the rain shadow of Taveuni.

Vanilla is generally free of pests and diseases; however, poor growing conditions can lead to plants being affected by various rots, the most serious of which is root rot or Fusarium wilt. Vanilla potyvirus, *Odontoglossum ringspot virus* and *Cymbidium mosaic virus* are serious viral diseases, which can lead to significant crop losses[9].

Tolerance of vanilla to extreme climatic events

Vanilla is highly susceptible to extreme climatic events as are most plant species introduced clonally into the Pacific with a very narrow genetic base. This shallow-rooted vine will die when faced with a prolonged drought, as was evident during the 1997/98 drought in Fiji, when almost the entire Vanua Levu vanilla crop was lost. A severe cyclone will also destroy vanilla plants, which will take three years to recover. In recent years cyclones have had a major impact on production in Madagascar, the world's biggest vanilla producer, significantly impacting world prices (McGregor 2004).

6.2.2.2 Ginger

Ginger is the rhizome from an herbaceous perennial plant cultivated commercially as an annual. It belongs to the family *Zingiberaceae* and the sub-family *Zingiberoideae*. This sub-family includes other important spice crops, such as turmeric (*Curcuma domestica*) and cardamom (*Elaettaira cardamom*). The crop is propagated vegetatively from its rhizome, with large amounts of 'seed' required to produce a commercial crop.

Ginger is grown in many tropical and subtropical locations, although Fiji is the only PICT with a commercial ginger industry. In the past Samoa, Tonga and Vanuatu, after observing the apparent success of the Fiji ginger industry, tried unsuccessfully to establish commercial ginger export industries. In the case of Tonga the necessary agronomic conditions are not met — in particular high rainfall requirements. In the case of Samoa, as with Vanuatu, insufficient attention was given to markets and marketing requirements. Fiji has been exporting ginger since the 1950s to New Zealand and North America. In 1986, ginger was Fiji's second biggest agricultural export after sugar, with nearly 2500 tonnes of fresh ginger exported (McGregor 1996).

Growers have shown a preference for growing immature ginger, which is less affected by fungal diseases and gives a higher return to labour. Therefore, most ginger grown today is harvested immaturely and used in the processing of crystallised ginger. Kaiming Agro Processing Ltd (KAPL) is one of Fiji's leading agricultural exporters, and has built up a successful export industry of ginger products, such as ginger confectionery. In 2006, in its first year of operation, the company earned US$315,000, which increased to US$2 million by 2013, with KAPL now exporting to Australia, New Zealand and the US[10].

9 http://www.agriculture.gov.fj/images/docs/publications/crop-farmers-guide.pdf
10 http://www.new-ag.info/en/focus/focusItem.php?a=3044

Most PICTs grow small quantities of ginger and turmeric for subsistence and local market sales. For example, the Vanuatu Land Use Planning Project Ginger Profile 1999 notes 'Ginger has a very minor subsistence role – although it is commonly found in food gardens, and is used to flavour stews'. Ginger is highly nutritious and makes a valuable contribution to household food security.

Preparing ginger for export, Fiji Photo: Richard Markham

Ginger is an annual crop that is planted in spring and then harvested, depending on maturity, from late winter to early summer. Thus, the seasonal availability of fresh ginger depends on the latitude at which it is grown. Fiji, as a southern hemisphere producer, must complete planting by the end of October; harvesting of mature ginger occurs from July to November. Immature ginger for processing is harvested between February and March. PICTs closer to the equator would have greater flexibility in terms of planting time.

Ginger thrives in a high temperature and rainfall environment, but it demands free-draining soils. Without irrigation, an average annual rainfall of around 3000 mm is required. In Fiji's ginger-growing areas good drainage has largely been achieved by planting on steep slopes; however, this has been at considerable cost in terms of land degradation (Buresova and McGregor 1990). Ginger is easy to grow in PNG, with an altitudinal range of 0–1950 m and rainfall of 1500 to over 6000 mm/year, depending on the location (Bourke 2010).

Ginger, when grown as a commercial crop, is highly susceptible to disease. Bacterial wilt (caused by *Pseudomonas solanacearum*) almost destroyed the Hawai'i ginger industry in the early 1990s. A programme of soil fumigation and strict sanitation brought the disease under control. Australia's ginger growers at Buderim have also faced bacterial disease problems. *Pythium* soft rot is responsible for serious damage to ginger crops both in Fiji and Australia, and disease epidemics are triggered by wet weather events when soils remain saturated for lengthy periods during summer and early autumn. Molecular and morphological studies have identified *Pythium myriotylum* as a causal species found on ginger in both countries; however *P. vexans* and *P. graminocola* have also been isolated from diseased rhizomes in Fiji and *P. zingiberis* has been identified as the main cause of losses in Australia. The presence of nematodes, *Radopholus similis* (burrowing nematode) in Fiji, also exacerbates disease development. In 2004, farm-gate losses due to soil-borne pathogens were estimated at FJD 530,000 for Fiji.

Control strategies for *Pythium* include managing waterlogging and limiting surface water movement by deepening the furrows between beds and increasing the number of cross-row drainage channels. The use of suitable rotation crops and lengthening the period between susceptible ginger crops may also limit the build-up of pathogen loads in the soil. However, development of more disease-suppressive soils is also a viable strategy and an ACIAR-funded project has demonstrated that ginger-growing soils can be managed in such a way as to create microbial communities capable of suppressing *Pythium* soft rot in ginger. Soils amended with poultry manure and sawdust, as well as cropped soils subjected to minimal disturbance, were the most suppressive to the disease and the best for harvestable rhizome yield. Timely applications of poultry manure can be very effective in controlling soil infestations of burrowing nematode. For control of both burrowing nematode and *Pythium* soft rot clean planting material is essential, as is the need for adequate crop rotation and removal of volunteers and weeds that may be acting as hosts for pathogen (Smith et al. 2012) Although the value of using clean planting material, grown under drier conditions away from the main production areas, has been demonstrated at a pilot scale, Fijian ginger producers still do not have access to such material on a commercial scale and the routine use of clean planting material has not yet been established (Smith pers. comm.).

Tolerance of ginger to extreme climatic events

Ginger introduced clonally into the Pacific has a very narrow genetic base, which makes it susceptible to extreme climate events. However, ginger tends to be less directly impacted by cyclones, being a short-term crop that is harvested before the cyclone season (July to November for mature ginger). The indirect impact of cyclones, however, can be considerable due to soil erosion if ginger is grown on steep slopes without the necessary contouring. Ginger has no tolerance to drought or waterlogging and is highly susceptible to bacterial or fungal diseases that can be induced or exacerbated by extreme climate events.

6.2.3 Stimulants

The stimulants, kava (in Vanuatu, Fiji, FSM, Samoa and Tonga) and betel nut (in Palau, FSM, PNG and Solomon Islands) are major cash crops in these islands.

6.2.3.1 Kava

Kava (*Piper methysticum*) is best suited to humid tropical low-elevations locations (up to 1000 m) with high rainfall. Therefore, the region offers ideal conditions for the crop, whose origins can be traced to Melanesia. Rainfall needs to be evenly distributed throughout the year, with a mean annual rainfall range of 1900–4600 mm, depending on temperature, elevation and soil type (Nelson 2011). A mean annual temperature of 20°–25°C is optimum for kava, with a mean maximum temperature limit in the hottest month of 35°C and a mean minimum temperature limit in the coolest month of 15°C (Nelson 2011).

Tolerance of kava to extreme climatic events

Kava is incapable of reproducing itself sexually (Lebot et al. 1991) and as such the species has a very narrow genetic base. About 100 cultivars with different morphotypes can be found in the region, but morphological and chemical variation is controlled by very few genes (Lebot et al. 1999). These cultivars have been selected locally over hundreds of years in different island environments. The species is thus genetically vulnerable and the agro-ecosystems in which it is cultivated are being modified faster than clones can adapt to environmental and other changes (Nunn 1990).

Although basically environmentally friendly, cultivation techniques have been elaborated, and cultivation is presently constrained by the rapid spread of 'kava dieback' (Osborn 2001). Kava dieback is the most important cause of yield reduction in Fiji, with estimated crop losses averaging around 40%. The primary cause is *Cucumber mosaic virus* (CMV); however, the relationship between kava and CMV is not a simple one. Kava dieback is a very variable problem that appears to result from a complex of interactions of kava with environmental, agronomic or other stresses, with CMV at its centre (Davis et al. 2005).

Kava and taro intercropping, Vanuatu Photo: RM Bourke

The kava production areas of Fiji and Vanuatu are highly vulnerable to cyclones. Once a kava plant reaches 12 to 18 months of age, it is very susceptible to wind damage. If the tops break and the roots are shaken, the plant will die. The effectiveness of cutting tops prior to a cyclone, as is done for cassava, is debatable. A damaged two-year old crop is unlikely to survive. The roots of older plants can be salvaged if they are pulled and dried immediately. However, this is the most labour-intensive stage of kava production and immediately after a cyclone demands on labour are at their highest. Thus, losses to kava from cyclones can be significant, particularly in larger plantings where the crop is grown without tree cover. These plantations, lacking the natural windbreaks of small traditional forest gardens, make kava a high-risk crop, especially as it takes three years to reach maturity and several more years to reach optimum production.

The report by Clarke (1992) of Cyclone Ofa, which struck Samoa in 1992, discusses the damage caused:

As expected, kava was badly affected by Cyclone Ofa. Uprooting caused 25 to 75 percent of plants to die, depending on whether the area was protected from or exposed to the winds. The age of the trees undoubtedly contributed to whether the plants survived, yet some apparently destroyed mature plants reportedly produced new young stalks to replace some damaged by the cyclone (p. 69).

Kava, particularly when young, is susceptible to drought. A kava plant of less than one year can tolerate one month of less than 40 mm rainfall. Once stressed, plants are more susceptible to kava dieback. Kava does not tolerate waterlogging despite the need for high rainfall to support its large leaf area and superficial root system.

Betel nut palms, PNG Photo: Timothy Sharp

6.2.3.2 Betel nut

In PNG, betel ('buai') is consumed as a mixture of betel nut (i.e. the seeds of *Areca* palms) and the inflorescences (or sometimes leaves) of two *Piper* species: *Piper betle* in the lowlands (and most of Asia) and *P. gibbilimbum* in the highlands.

Betel nut (*Areca catechu*) is best suited to humid, tropical low-elevated locations (up to 1100 m) that are high in rainfall. Betel nut, unlike kava, has a wide geographic distribution, and is cultivated in much of south Asia, Melanesia, Micronesia and East Africa. A second species, *Areca macrocalyx,* supplies some betel nuts in the highlands of PNG but is much less widespread and less well known.

The climate conditions best suited to betel nut palm are very similar to those for kava. Rainfall should be evenly distributed throughout the year, with a mean annual rainfall range of 2000–4000 mm, depending on temperature, elevation and soil type (Staples and Bevacqua 2006). The optimum temperature for good growth is 15°–38°C. The climate requirements for the two *Piper* species do not appear to have been scientifically studied.

Coconut leaf beetle (*Brontispa longissim*a) will attack betel nut palm, especially young palms, and severe attacks will affect productivity[11].

Tolerance of betel nut to extreme climatic events

Betel nut has low drought tolerance, although as a palm tree its tolerance is greater than that of kava. It also has a low tolerance to waterlogging. Betel nut is unable to withstand extremes of temperature and wide diurnal variation (Staples and Bevacqua 2006). The *Areca* palm, however, is highly vulnerable to cyclones — although most production areas in PICTs (PNG, Solomon Islands and FSM) are generally not affected by cyclones.

6.3 Observed climate impact on horticultural crops over the last 30 years

6.3.1 Fruit and vegetables

6.3.1.1 Papaya

Overall, papaya production has been severely affected by cyclones, flood and drought events associated with ENSO events over the last 30 years. The bumper crop expected in 2012 was literally wiped out after floods destroyed about 90% of plants in the Sigatoka Valley, Fiji, the main papaya-producing area in the country. A large volume of seedlings (about 41,000) were distributed to farmers to bolster production in the aftermath of the floods, but these were then affected when Cyclone Evan struck later in the year[12].

6.3.1.2 Mango

Climate variability has brought widespread changes in flowering and fruiting patterns of mango, which can mostly be attributed to ENSO. In some locations, these climate fluctuations have adversely affected fruit production, while in others they have improved fruit production. In some parts of the world, rising temperatures are enabling mango to be grown in areas previously too cold for production. For instance, mango cultivation is now possible in the valley areas of Himachal Pradesh and Uttarakhand in India due to an increase in temperature during the coldest months (Rajan 2012).

11 http://www.fao.org/forestry/13374-0bba732bf9dfa85a4f0cd036b5a26f6d0.pdf
12 http://www.fijitimes.com/story.aspx?id=247860

There are some indications that mango production, in recent years, has been reduced in the Port Moresby area of PNG. This could be the result of increasing rainfall and/or extension of the wet season, or less flower induction as a result of warm, dry seasons (Kambuou pers. comm). Reports from Cook Islands indicate that fruits are maturing much earlier in some locations/islands over the past 30 years (Wigmore pers. comm.).

6.3.1.3 Citrus

During the past 10 years, changes in the fruiting/harvest of citrus in Cook Islands have been observed. Citrus (oranges) of the variety 'Rarotonga Seedless' would normally have two harvests per year with the first harvest starting during the latter part of March and lasting about six weeks. However, for the past 10 years four harvests have been possible in some years, but the total yield from these four harvests only amounts to approximately 50–75% of the harvest from the preceding 10-year period (Wigmore pers.comm.).

6.3.1.4 Pineapple

There has been no clearly discernible impact of climate change on Pacific Island pineapple production in recent decades.

6.3.1.5 Tomato

Over the past five years increased flooding and tropical cyclones in countries such as Fiji and Samoa have affected tomato production, but there is no evidence that clearly shows any impact of climate change on tomato production. A study carried out in South Africa (Tshiala and Olwoch 2010) examining the correlation of climate change factors such as temperature with tomato production, concluded that the increasing temperature from 1971 to 2006 corresponds to an increased yield. However, the impact from other factors, such as the application of fertilisers and the use of irrigation systems, must also be considered.

6.3.1.6 Watermelon

There has been no clearly discernible impact of climate change on watermelon production in the Pacific over recent decades.

6.3.2 Spices

6.3.2.1 Vanilla

Climatic events associated with ENSO have affected the region's vanilla production in recent decades. Variability in climate, coupled with price fluctuations, has led to wide swings in the amount of vanilla produced in the Pacific Islands.

6.3.2.2 Ginger

There has been no discernible impact of climate change in recent decades on ginger production in Fiji and other PICTs. The Fiji ginger industry has faced considerable pest (nematodes) and disease (fungal and bacterial) challenges over the last 30 years but it is unclear what role climate played in increasing the severity of these pests and diseases.

6.3.3 Stimulants

There has been no clearly discernible impact of climate change on kava and betel nut production over recent decades. However, kava monocropping in Vanuatu has recently shown signs of high vulnerability to droughts and cyclones, exacerbated by the increasing size of the cultivated plots. Kava needs windbreaks and therefore production based on large fields (0.2 to 0.5 ha) is risky.

6.4 Projected vulnerability of horticulture crops to climate change and climate extremes

6.4.1 Exposure sensitivity and potential impacts

The projected vulnerability for the crops discussed in this chapter is considered within the temperature and rainfall conditions described in Chapter 2. As with other chapters, the focus is on impacts up to 2050.

6.4.1.1 Fruit and vegetables

Papaya

The projections for papaya production in Fiji will be similar for other papaya-producing PICTs such as Samoa, Tonga and Cook Islands. An increase in mean temperature of 0.5°–1°C (projected for 2030, regardless of emission scenario) could increase the occurrence of 'female sterility', in which normally hermaphroditic papaya plants produce male flowers, resulting in poor fruit set and production. However, this increase in temperature during the winter months might also result in better ripening during these normally 'slow' months of the year.

As discussed in Chapter 2, larger rainfall extremes are projected even in regions where average rainfall is projected to decrease. Any increase in rainfall will exacerbate the severity of fungal diseases such as *Phytophthora* and anthracnose which are already causing production problems.

Fiji's papaya-growing areas are very prone to cyclones with the associated winds having a devastating impact on papaya trees, particularly when accompanied by heavy rainfall. The projected increase in intensity of cyclones will significantly impact on papaya production. Damage to crops and vegetation tends to increase exponentially with wind speed. For example, the South Pacific Disaster Reduction Programme (SPDRP) report on Disasters and Agriculture in the Pacific Islands indicated that 180 km/hr winds are four times more damaging than 90 km/hr winds (McGregor and McGregor 1999). However, for a given wind speed other factors are at play that will determine the actual damage caused. These include the duration of the cyclone (particularly the strongest gusts), amount of rainfall, extent of the flooding that accompanies the cyclone, and prevailing weather after the cyclone. For example, the Fiji papaya industry was more severely impacted by the floods of January and August 2009 than by Category IV Cyclone Evan that struck western Viti Levu in December 2012 (McGregor pers. comm.). It is not uncommon for a late season cyclone to be followed by a prolonged dry period or even a drought, which can prove even more damaging than the immediate impact of the cyclone itself to horticultural crops such as Fiji's papaya that often do not have access to irrigation. Systematic research on these interactions is needed. However, in the absence of research that separates the impact of the various variables at play, on balance more intense cyclones, even if they are less frequent, will have significantly unfavourable production implications for PICTs' horticultural crops. Road conditions in papaya production areas of Fiji are already a major contributing factor to post-harvest losses, and the likely negative impacts of extreme weather events on road conditions could make this situation worse.

Overall, it is highly likely that the Fiji papaya industry will be adversely impacted by climate change in the short to medium term (2030–2050).

Vulnerability of the papaya industry

In order to project the vulnerability of the papaya industry in Fiji, some analysis of how countries currently thought of as competitors for the same market will be affected by climate change is necessary. Domestic production of papaya in north Queensland provides the main competition for Fiji with regard to the Australian market. More than 95% of papaya production in north Queensland is located around Innisfail and Mareeba (Atherton Tablelands). The bioclimatic conditions in Innisfail are quite similar to that of Fiji's Eastern Division, with an average temperature range of 19º–29ºC and an annual average rainfall of 3570 mm. In Mareeba the average temperature range is 16.5º–29 ºC with an average annual rainfall of 915 mm, where papaya is grown with irrigation. Both dioecious[13] and 'Solo' type papaya are grown commercially in Australia; however, due to low temperatures in winter months, dioecious varieties generally perform better (Drew et al. 1998; Chay-Prove et al. 2000).

An increase in temperature of at least 1°C in the main northern Queensland growing areas may help to improve papaya production of 'Solo' type papaya varieties by reducing the incidence of physiological disorders such as carpeloidy and 'winter spot'. An increase in the minimum mean temperature may also help to improve the

13 *Dioecious* papaya varieties have male and female flowers on different plants which mean that both male and female plants are needed for fruit production.

incidence of reduced sugar content and delay in fruit maturity currently faced during the winter months. These advantages may particularly benefit those Queensland growers who have moved to the Atherton Tablelands to reduce the risk of cyclones.

It is projected that the northern Queensland industry will also see an increase in average rainfall and the number of heavy rain days (20–50 mm), due to its proximity to the Intertropical Convergence Zone (ITCZ). This is likely to have a significant impact on the severity of some diseases such as *Phytophthora* and anthracnose, which are already causing production problems in this region.

According to a 2008 CSIRO report[14], the prospects for the north Queensland horticulture industry in the light of current climate change projections were good as decreased frost risk could allow for an expansion of the industry. The report did highlight that heat stress/flooding/erosion and cyclones can all have devastating impacts and therefore, risk assessments will need to be undertaken. Further, intake scheduling and marketing responses will need to be adjusted to take into account changes in cropping cycles because of increasing temperatures.

However, in comparing the impact of projected climate conditions on both the Australian and Fiji papaya industry, it is likely that the competitive position of the Australian papaya industry will be enhanced relative to Fiji and other potential PICTs' producers.

Mango

Mango, being a perennial fruit crop, will respond differently to increases in temperature than annual crops (Litz 2009). A perennial crop such as mango may survive desiccating conditions, which could be highly beneficial for yield in succeeding growth seasons.

An increase of 0.5°–1°C by 2030 will have little or no impact on mango production in the region. However, an increase in mean annual temperature of at least 1.5°C (projected for 2050 under RCP8.5) may adversely impact the flowering of mango trees, because floral induction occurs in response to cool temperatures. Flower panicles originate from terminal or sub-terminal buds on the most recent vegetative flush (Wilkie et al. 2008). The most likely impacts of climate change on mango production relate to the unpredictable rains and temperature fluctuations occurring during winter months when trees are flowering, which would adversely affect fruit set. Similarly, frequent pre-wet season rains will encourage anthracnose, which affects fruit quality and therefore market value.

The impact of climate change on the incidence and severity of *Bactrocera frauenfeldi* (mango fly) is unclear. Higher rainfall is expected to cause an increase in the pest, but excessive rainfall could also decrease populations (Jackson pers. comm.)

14 An overview of climate change adaptation in Australian primary industries — impacts, options and priorities.

Citrus

Citrus trees of the various species and cultivars are widely adapted, and will survive and grow (although sometimes with difficulty) in nearly any climate that does not kill them (Jackson 1999), but a warming temperature and a wetter environment can be expected to increase the incidence of pests and diseases. More intense cyclone events could accentuate the spread of diseases. Table 6.3 shows the means of spread and optimum climatic conditions for the infection of common citrus foliar diseases.

Table 6.3 Means of spread and optimum climatic conditions for the infection of common citrus foliar diseases. (source: Timmer 1999 p. 107).

Disease	Means of spread	Optimum temperature for spread (deg C.)	Optimum wetting period
Greasy spot	Wind	24–27	Several nights
Post bloom fruit drop	Water splash	25–28	10–12 hours
Melanose	Water splash	25–29	10–12 hours
Citrus scab	Water splash	21–29	5–6 hours
Citrus canker	Wind blown rain	25–28	4–6 hours
Black spot	Wind	21–32	1–2 days
Alternaria brown spot	Wind	21–27	12–14 hours

On the positive side, an increase in the mean annual temperature by 1.5°C by 2050 (under the very high emissions scenario) could be expected to expand the frost-free area of production in the PNG highlands and therefore increase the number of locations supportive of citrus production, possibly creating commercial opportunities.

Pineapple

No apparent adverse impact from an increase in mean annual temperature is likely for pineapple production. Any increase in severe rain events could negatively impact pineapple because of its susceptibility to waterlogging. An increase in cyclone intensity will have a relatively limited impact on pineapple production.

Diseases like pineapple wilt disease, a serious disease of pineapples vectored by *Dysmicoccus brevipes*, are likely to increase with a reduction in rainfall (Jackson pers. comm.).

Tomato

Considering the sensitivity of tomato to increases in temperature, projected increases are likely to affect the reproductive capacity of tomato plants, with the potential to reduce yields of cultivars currently used in production. As temperatures continue to rise, the adverse effects on tomato yields will demand more heat-tolerant cultivars so that growers can maintain production. Without these more heat-tolerant cultivars, the production season in all regions will contract even further to the cooler months.

An overall increase in rainfall levels and an increase in severe rain events will certainly impact disease incidence in rain-fed tomato plantings during the wet periods, further shrinking the growing season. Both early and late blight will worsen with increasing rainfall; late blight will be particularly of significance in the PNG highlands (Jackson pers. comm.).

Watermelon

An increase in mean annual temperatures is unlikely to adversely affect watermelon production. An overall increase in rainfall levels and an increase in severe rain events will certainly impact disease incidence in watermelon plantings. In particular, the incidence of gummy stem blight is likely to increase, and may become the limiting factor determining the growing season for this crop. Lower rainfall will favour CMV because of its influence on aphid vectors. If climate change negatively affects the bee species responsible for pollinating watermelon, then this will obviously affect fruiting and production output (the impact of climate change on Pacific bee species is discussed in Chapter 7).

6.4.1.2 Spices

Vanilla

An increase in average minimum temperature could have an adverse impact on the induction of flowering in vanilla. Similarly, an overall wetter environment, if it means a shorter and wetter dry season, will negatively affect flowering. More intense cyclones would certainly have a significantly adverse impact on vanilla production outside of PNG. However, an important consideration will be whether such extreme events will be worse in Madagascar, which accounts for over 50% of world vanilla production[15]. If cyclones continue to be more extreme in Madagascar, as they have been in recent decades, Pacific Island producers could benefit from substantially higher vanilla prices.

Ginger

It is unlikely that an overall increase of 1.5°C in mean temperature (projected for 2050 under RCP8.5) would have any direct impact on ginger production. An overall increase in rainfall could increase the areas where ginger could be commercially grown. For example, in Fiji new areas in western Viti Levu and Vanua Levu could be planted; these are free of damaging nematodes and do not require planting on steep slopes.

More intense cyclones would not directly impact ginger production, but would exacerbate already severe soil conservation problems in Fiji's main production areas.

15 This Indian Ocean island is located in a region prone to extreme tropical cyclones. The early 1980s and 2000s were periods of severe cyclonic activity in Madagascar's vanilla-growing northeastern region. In April 2000, Cyclone Hudah destroyed about 35% of the standing crop and 15% of stocks. Cyclone Gafilo followed in February 2004, with almost as much damaging effect. Superimposed on these natural events was a civil war that enveloped the country from 2001 to 2002. As a consequence, world vanilla supply declined sharply, resulting in an unprecedented escalation of vanilla prices (McGregor 2004, p. 13).

The effect of an increasing average temperature, an overall wetter environment and more intense cyclones on the incidence of ginger pests and diseases is not known.

6.4.1.3 Stimulants

A 1.5°C increase in mean annual temperature (projected for 2050 under RCP8.5) is unlikely to have an adverse impact on kava and betel nut production. In fact, an increasing temperature would enable the crops to be grown at a higher elevation in the PNG highlands, where demand is the greatest. Any overall increase in rainfall levels is unlikely to be damaging to either kava or betel nut production; if rainfall increased in currently drier areas, then the impact could be positive. The impact of the projected climate conditions on kava dieback is not clear, except that an increase in environmental stress could mean the plant is more susceptible to the disease.

Any increase in the intensity of cyclones will increase the risk and reduce the viability of growing kava, a major cash crop for Vanuatu and Fiji and an important cash crop in Tonga and Samoa.

6.4.1.4 A summary of the observed and projected impact of climate change and variability

Table 6.4 A summary of the observed and projected impact of climate change and variability on selected Pacific Island horticulture and spice crops.

Crop	Climate change/climate variability impact in recent decades	Projected short-term (approx. 2030) climate impact[16]	Projected medium-term (approx. 2050) climate impact[17]
Fruits and Vegetables			
Papaya	Overall, papaya production has been severely affected by cyclones flood and drought events.	Severity of some diseases such as *Phytophthora* and anthracnose likely to increase because climate will be wetter. Increases in temperature could affect fruit set. Although cyclone frequency is expected to decrease, papaya production will be negatively impacted by increasing intensity of cyclones.	Impacts of increased temperature, rainfall and intensity of cyclones are likely to be significant. The competitive position of the Australian papaya industry relative to Fiji and other potential Pacific Island producers is expected to improve.
Mango	Climate variability adversely affected fruit production in some locations but improved fruit production in others. Rising temperatures are making some locations, previously too cold for mango production, more suitable.	Fruit sets will continue to be adversely affected by unpredictable rains and temperature fluctuations during winter months. Reduction of fruit quality would result from frequent rains. Increasing problems with anthracnose are possible	Mango production will be negatively impacted by increasing intensity of cyclones. Unpredictable rains could also have a significant impact. Possible increasing mango fly problems. High temperatures could affect flowering.

16 Temperature rise of +0.5° to 1°C regardless of emission scenario.
17 Temperature rise will vary from +0.5 to 1°C (RCP2.6) to +1° to 2°C (RCP8.5).

Crop	Climate change/climate variability impact in recent decades	Projected short-term (approx. 2030) climate impact[16]	Projected medium-term (approx. 2050) climate impact[17]
Citrus	There has been no clearly discernible impact of climate change.	Minimal impact on pests and diseases of citrus as a result of a warmer and generally wetter environment.	Increasing temperature and wetter environment can be expected to increase the incidence of pests and diseases. More intense cyclone events could accentuate the spread of diseases. An increase in temperature could expand the areas for production in PNG highlands.
Pineapple	No clearly discernible impact	Expected to be minimal	No apparent adverse impact from increasing temperature. Severe rain events and subsequent waterlogging would impact production. A reduction in rainfall could increase pineapple wilt disease.
Tomato	No reported impact	Increase in rainfall and severe rain events will adversely impact disease incidence, further shrinking the growing season. Extreme heat, depending on timing, could affect fruit production and yield.	A 1.5°C increase in mean annual temperature is likely to reduce yields of existing cultivars. Adverse effects of high temperature will demand more heat-tolerant cultivars. Early and late blight will worsen with increasing rainfall
Watermelon	No clearly discernible impact	Increase in rainfall during winter months will impact disease incidence, especially gummy stem blight.	Increase in average annual temperatures unlikely to affect watermelon production. Increases in disease, for example, gummy stem blight.
Spices			
Vanilla	Variability in climate, coupled with price fluctuations, has led to wide swings in the amount of vanilla produced.	Unlikely to cause any significant impact in the existing production areas.	An increase in average minimum temperature and overall wetter environment could have an adverse impact on the induction of flowering. More intense cyclones would certainly adversely impact vanilla production outside of PNG.
Ginger	The Fiji ginger industry has faced considerable problems with pests (nematodes) and diseases (fungal and bacterial), but influence of climate unknown.	Overall increase in rainfall could increase the areas for production. More intense cyclones would not directly impact ginger production, but would increase already severe soil conservation problems in Fiji's main production areas.	Unclear how an increasing average temperature, an overall wetter environment and more intense cyclones will affect the incidence of ginger pests and diseases.
Stimulants			
Kava	Other than cyclones no discernible impact	More intensive cyclones likely to have significant impact, particularly when not planted in agroforestry food gardens.	Significant increases in rainfall could cause problems with waterlogging. How climate projections will affect kava dieback is not known. More intense cyclones expected to have a major impact.
Betel Nut	No clearly discernible impact	Unlikely to cause any significant impact on betel nut in existing production areas	An increase in rainfall levels in currently dry areas could favour production.

6.5 Adaptive capacity

In most PICTs and generally around the world, the ability of a farmer or an industry to plan for and respond to climate extremes is critical for success. Farmers in the Pacific have had to deal with climate extremes including cyclones, floods, tidal surges and droughts for centuries, and indeed many traditional farming systems are, as a result, relatively resilient. However, as the attraction of new horticultural crops and potential markets provide the incentive to move away from traditional farming systems, growers and industries must ensure they have adequately considered and, where possible, mitigated the potential impacts of extreme climate events and natural disasters. The sections below provide examples of disaster risk management and climate change adaptation for the papaya industry and vegetable crops. The examples given are from Fiji, reflecting the experience gained through project implementation; however, the approaches/strategies described could be used in other countries where similar, high-value horticultural crops are being produced.

6.5.1 Fiji papaya supply chain approach to climate change mitigation

The intensity and frequency of both cyclones and flooding in recent years have caused the Fiji papaya industry to develop strategies for mitigating the risk of natural disasters. A longer-term variety improvement programme is also in place so that Fiji can be self-sufficient in papaya seed and to allow for ongoing genetic selection based on performance under Fiji's agro-ecological conditions. These strategies are discussed briefly below.

6.5.1.1 Fiji papaya variety improvement programme

The Fiji papaya industry grows a variety called Solo Sunrise which is an inbred gynodioceous line developed by the University of Hawai'i. The seed line is self-pollinating and stable when the flowers are bagged to protect from wild cross pollinations; however, cross-pollination is a recurrent problem for farmers who do not keep true-to-type seeds. As a result seed must be continually imported, which increases the risk of introducing seed-borne diseases and means that the industry is reliant on the supply of seed from overseas.

Solo Sunrise has exceptional fruit qualities and performs well under Fiji's conditions. Despite the quality of Solo Sunrise, the industry has developed a certified seed producer's scheme with two primary objectives: to become self-sufficient in papaya seed supply; and to put in place an ongoing variety improvement programme that continually selects for the best-performing material at the farm level. The scheme currently involves 10 farm enterprises and the Fiji Ministry of Primary Industries Research Division. As environmental conditions continue to evolve, the seed production system will continually select for the best-performing plants under these conditions and these lines will be perpetuated.

6.5.1.2 Natural disaster mitigation strategies for the Fiji papaya industry

The industry is focused on developing practical adaptation strategies that smallholder farmers can implement in order to minimise the risk of their enterprise being completely destroyed by a natural disaster. These strategies, a reactive response to the lessons learnt from three major flood events and two cyclones that have occurred between 2009 and 2012, are:

- spreading out the geographic distribution of papaya plantings;
- using the recent floods as a benchmark for the flood line and planting only in areas above this line;
- spreading planting throughout the year — one planting immediately after the cyclone season (April) and one planting in August — so that trees are too small to be affected by strong winds in the event of a cyclone;
- developing farm budgets to calculate the effect of at least one major natural disaster in the three-year cropping cycle on the profitability of papaya;
- the use of high planting mounds for improved drainage;
- the adoption of production techniques that encourage the preservation of soil structure and decrease erosion; such techniques include the use of horses and bullocks during land preparation and incorporation of additional organic matter; and
- research into ratooning pre-cyclone, defoliation pre-cyclone and control of sunburn post-cyclone.

6.5.2 Natural disaster mitigation strategies for horticultural nursery enterprises in Fiji

The devastating floods that occurred in January 2009, and the subsequent rehabilitation activities, highlighted the vulnerability of Fijian farmers to weather events of such severity. The post-flood support provided by AusAID and the Ministry of Primary Industries for supplying seed to affected farmers was a critical step in helping farmers to rehabilitate their farms and to generate income relatively quickly. However, there was a significant time lag in the distribution of vegetable seedlings, which was basically caused by:

- the limited number of commercial nurseries producing high quality vegetable seedlings; and
- the damage caused to these nurseries and their seedlings by the disaster.

To address these constraints, the 'Small and Micro Nursery Enterprise Development Project for Sustainable Seedling Supply' was developed with two primary objectives, namely:

- to increase the number and capacity of local seedling nurseries to assist with crop recovery and rehabilitation following natural disasters; and
- to promote the use of seedlings for crop diversification by Fiji farmers.

Through this project, the following disaster mitigation strategy was developed and implemented for nursery enterprises supplying Fiji's fruit and vegetable industry.

6.5.2.1 'Disaster resilient' nursery design and construction methods

Employing 'build back better' principles, the project worked with experienced nurserymen to develop construction methods better equipped to deal with strong winds and flooding (associated with natural disasters). Key design approaches were:

- design for disassembly: nursery structures were designed to allow for easier disassembly in the event of an approaching severe storm event; and
- structural design to minimise wind loading: nurseries were designed to undergo 'controlled collapse' in extreme wind events to allow easy and low-cost reconstruction; the structural forms of the nurseries were designed to minimise wind loading in extreme events.

6.5.1.2 Use of disaster mitigation containers to protect seedlings in a disaster

A pilot concept introduced by the project involved the distribution of six custom 20-foot (6.096 m) shipping containers to selected nursery enterprises around the country. The disaster mitigation containers were fitted with special steel racks that allowed the nurseryman to stack seedlings inside the container prior to a natural disaster. The theory was that the seedlings stored inside the disaster mitigation container could withstand the effects of a cyclone or flooding and could be quickly distributed to reduce recovery time post-natural disasters. The six nurseries that received the pilot disaster mitigation containers were chosen based on the criteria that they were strategically placed in target fruit and vegetable production areas, and were active in producing and supplying fruit and vegetable seedlings.

There are a number of other factors besides construction and infrastructure that commercial nurseries must take into consideration in an attempt to minimise the risk of cyclone damage. These factors include:

- site location;
- tracking of weather systems to allow preparation for extreme events;
- contingency plans for protecting plants; and
- financial planning for 'rainy days'.

The arrival of Cyclone Evan in December 2012 provided an opportunity to put these strategies to the test and the findings were very encouraging.

Performance of 'disaster resilient' nursery design and construction methods

Immediately prior to Cyclone Evan, five of the supported nurseries in the heavily impacted Sigatoka-Rakiraki corridor and the one nursery in Taveuni were disassembled and all seedlings were relocated inside the nursery owners' houses or in disaster mitigation containers. Following the cyclone, the nurseries were quickly reconstructed at little or no cost in materials and saved seedlings were returned to the nursery structures.

Performance of disaster mitigation containers during Cyclone Evan

Four of the six distributed containers were utilised in Cyclone Evan. The use of these disaster mitigation containers led to 48,700 seedlings being saved. These saved seedlings were sold to farmers or used on the nurserymen's own farms.

Photos: Kyle Stice

a. Bula Agro Nursery owner, Sant Kumar, stands in front of his disassembled nursery after Cyclone Evan. This Nadi nursery was reconstructed within two days after the cyclone.

b. Sigatoka nursery owner, Yeshwant Kumar, points to his disassembled nursery which has already been refilled with the 4100 fruit trees that were saved from Cyclone Evan.

c. Papaya seedlings rest safely inside this nursery owner's house after the nursery was disassembled in anticipation of Cyclone Evan.

d. British American Tobacco nursery in Nadi suffered significant damage to the plastic covering and steel frames as a result of Cyclone Evan. Clearly, 'disaster resilient' nursery design practices need to be incorporated into any agribusiness operating in cyclone-prone countries such as Fiji.

6.5.3 Trialling and introduction of disease tolerant varieties of currently grown crops

The World Vegetable Centre (AVRDC) has been working in Solomon Islands and Fiji to trial new disease-tolerant open-pollinated tomato lines and especially the bacterial wilt-resistant open-pollinated lines. The introduction of these disease-tolerant lines allows farmers to battle current disease pressure and prepare for an increase in disease pressure. These new varieties from AVRDC are also open-pollinated which allows farmers and seed producers to select for good characteristics based on site-specific conditions and reduces reliance on imported seed, which is often not suited for local conditions.

Photos: Kyle Stice

a. A Fiji Ministry of Agriculture Research staff member evaluates new AVRDC tomato lines in the Sigatoka Valley.

b. AVRDC plant breeder discusses the new open-pollinated tomato lines with the owner of Fiji's largest farm supply company, Hop Tiy.

6.6 Future comparative advantage of Pacific Island horticulture crops and spices

6.6.1 Fruit and vegetable exports

The Pacific 2020 Report (AusAID 2006) identified New Zealand, Australia and the west coast of the United States as having large and increasing Pacific Island, and more particularly, Asian populations that offer a significant market for a range of horticultural products, including root crops. Fiji and the Polynesian countries were seen to be in a position to take advantage of these opportunities. Smallholder horticulture is now, after years of disappointment, the fastest growing part of Fiji's agricultural sector. A fivefold increase in total exports was seen as feasible without saturating the market. However, in the last three to four years the Fiji horticulture export industry has suffered some major climate-induced setbacks. For example, fresh fruit exports from Fiji (quarantine-treated papaya, eggplant, mango and breadfruit) were making significant strides until they were impacted in 2012 by two major flood events and a cyclone (Figure 6.1).

The ability of the PICTs to maintain horticultural exports in the face of climate change depends on the ability to put in place disaster risk management strategies and adopt adaptation measures of the type described in this chapter for Fiji papaya, vegetable seedlings, and in Chapter 4 for taro and other root crops. The impact of climate change on other countries that compete in the export market with countries in the Pacific will also influence how well the horticultural industry can be sustained. This consideration has already been discussed with regards to papaya in north Queensland, which has been badly affected by some major cyclonic events in recent years.

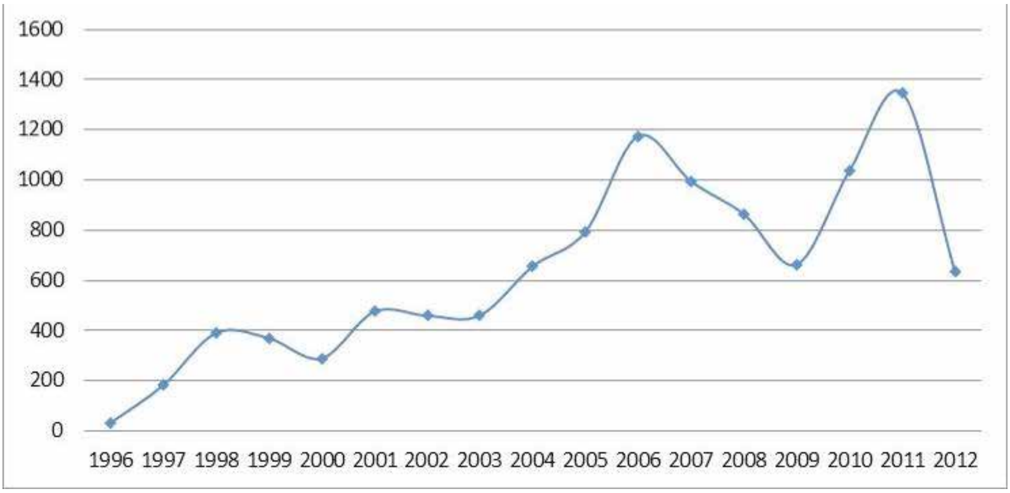

Figure 6.1 Fiji exports of high temperature forced air (HTFA) quarantine treated produce (papaya, eggplant, mango and breadfruit (tonnes) (source: Nature's Way Cooperative (Fiji Ltd).

Tropical highland locations can offer ideal growing conditions for temperate and subtropical fruit, vegetable and floriculture products. Such climatic conditions can be found, for instance, in the tropic plateaux of Ecuador, Colombia, Kenya and Ethiopia. Parts of PNG's eastern and western highland provinces also fit into this category. Climate change could favour horticulture and floriculture production in the PNG highlands compared with the lower altitude production areas in Australia. Whether any future production advantages would be sufficient to offset the current major disadvantages relating to poor infrastructure, such as inadequate road access, remains to be seen. Future extreme rainfall events will further threaten the already inadequate road infrastructure of the PNG highlands.

6.6.2 Spices

Transportation and phytosanitary issues (important determinants of success in horticultural exports), are far less important for the export of spice products such as vanilla. For such products, success has been based on three key factors:

- suitable agronomic conditions to produce products with identified markets;
- private sector marketing capability; and
- ability to resolve market access issues, particularly those relating to food safety certification.

The experience with vanilla in PNG shows that Melanesian countries can be highly successful in exporting spice products. In 1998 there were no official exports of vanilla from PNG, whereas five years later, 101 tonnes were officially exported, with an estimated value of USD 35 million. In 2003, vanilla represented 11% of PNG's agricultural exports for the year, and 10% of world vanilla production. At its peak, there were 50,000 people involved in the PNG vanilla industry and PNG was a major player in the world vanilla market, an unprecedented situation for any PICTs.

Even the relatively large PNG coffee and cocoa industries produce only some 1% of global production (McGregor 2004). The most obvious reason for the PNG vanilla phenomenon was the high prices offered from 2003 to mid-2004. The PNG grower price increased 1300% over a two-year period ending in December 2003. Similar price increases were on offer to vanilla farmers worldwide, but nowhere else did the response match that of the semi-subsistence village farmers of the East Sepik. Agro-ecological conditions in parts of this province proved ideal for vanilla production. Vanilla's high unit value and non-perishability when cured makes it particularly attractive to remote locations with poor or non-existent road access. Prices have since subsided to their pre-2003 level and despite decreases in the number of vanilla growers, a significant core of farmers growing better quality vanilla remains in place.

The relatively small global market for vanilla is characterised by extreme price fluctuations made up of high price peaks and prolonged troughs of relatively low prices. While other spice commodities such as cardamom, cinnamon and black pepper display similar fluctuating price patterns, none match the extreme price variability of vanilla. The vanilla market price pattern is characteristic of the classic 'cobweb' price-formation model[18], with prices being particularly sensitive to events in a single country — Madagascar. The recent vanilla price episode has been particularly extreme (Figure 6.2). The catalyst for the boom in world vanilla prices in 2003–2004 was the combination of climatic events in Madagascar (cyclones in 2000 and 2004) and, to a lesser extent, Indonesia (a drought in 2000), the countries that dominate world vanilla supply[19].

18 This price pattern is the result of:

- highly inelastic demand, at least within reasonable price ranges;
- large random shifts in supply (or demand) that trigger disproportionate changes in price; and
- a large price increase which triggers an excessive supply response, which depresses prices for an extended period until another substantial random supply shift triggers another sharp price increase. The greater the initial price increase, the larger the supply over-reaction and the longer and more depressed the subsequent price trough is likely to be.

19 In 2002 Madagascar accounted for 65% of world supply and Indonesia 20% of world supply (McGregor 2003, p. 11).

PNG's vanilla growing areas are not subject to cyclones, which gives it an advantage over Madagascar. How the projections for cyclones will affect vanilla production in the smaller islands, such as Tonga and Vanuatu, compared with the large Indian Ocean island of Madagascar, is not clear.

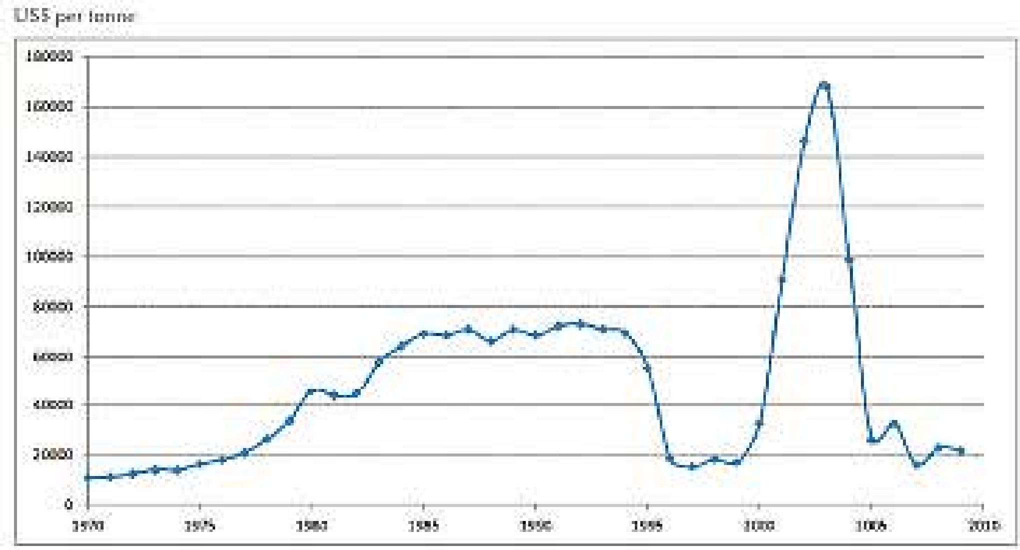

Figure 6.2 World vanilla prices (USD/tonne FOB Madagascar). (source: FAOSTAT).

6.7 Uncertainty, gaps in knowledge and future research

For most of the horticultural crops and spices discussed there is very little known about the possible implications of elevated carbon dioxide concentrations, eCO_2. As discussed in Chapter 3, studies on the benefits of eCO_2 for crop production indicate that at concentrations of 550 ppm yield increases in the order of 8–15% could be obtained. However, that assumes all other inputs, such as water and nitrogen, are not limiting. Elevated CO_2 could lead to decreases in the availability of important minerals such as calcium and magnesium. Similarly, there is little known about the possible pest and disease interactions that could be associated with climate change in the region. It is important that researchers in the region begin to address these information gaps and collaborate closely with other international research organisations in doing so.

6.7.1 Fruit and vegetables

6.7.1.1 Papaya

Very little formal research has been done on pre- and post-cyclone responses for papaya. Farmers will be in a better position to mitigate natural disasters such as cyclones if they have a better understanding of how practices such as defoliation, ratooning and sunburn control affect the papaya plant.

There is scope to explore more heat-tolerant, market-acceptable papaya varieties. Research is required to determine the package of practices needed to manage fungal diseases, assuming that the projected climatic conditions will favour an increase in disease incidence.

6.7.1.2 Mango

Currently mango production is based on very low inputs, which often result in high levels of flower anthracnose and poor cropping. There is scope to improve the way farmers approach mango production in order to manage an increasingly hot climate with potentially negative impacts on production. Opportunities also exist to introduce new mango varieties and develop local varieties that are best suited to the agro-ecological conditions of a particular area.

6.7.1.3 Pineapple

As pineapple production in the Pacific continues to expand on sloping land, good soil conservation practices should be promoted to prevent soil erosion in the face of more extreme rain events.

6.7.1.4 Tomato

High temperature-tolerant commercial varieties are needed to ensure that plants will set fruit under high temperature conditions (>35°C). Considerable genetic variability exists in high-temperature tolerance; this needs to be investigated either through local breeding programmes or by ensuring access to varieties available from elsewhere, for example, AVRDC.

Increased knowledge of protected cropping systems for tomatoes is required, which will allow farmers to mitigate the increasingly wet winter conditions and extend the production season far beyond what is currently possible with rain-fed production.

6.7.1.5 Watermelon

The effects of climate change are predicted to impact the typical cool, dry growing season for watermelon in the PICTs. In this respect there is a need to investigate new cropping systems that will allow farmers to be more effective at growing watermelon under humid and wet conditions.

6.7.1.6 Citrus

Only limited research has been conducted on citrus in PICTs, therefore any research into this species should focus on: evaluation of introduced and established cultivars; fertiliser requirements; optimum rootstock and budwood combinations; and pest and disease control. Information relating to these specific areas would contribute to enhancing the resilience of citrus production.

6.7.2 Spices

The main risks to vanilla production — physical damage from cyclones, drought, and *Fusarium* rots — can all potentially be reduced by modifying the growing environment; however, little formal research appears to have been done in this area. For instance, in PICTs, various woody species are used as supports for vanilla, including *Gliricidia sepium*, *Erythrina* spp. and *Jatropha curcas*. Given their different growth forms, these species are presumably damaged in different ways and to varying extents by high wind speeds; moreover, the extent of damage may be further modified by any larger trees planted to provide shade or wind-breaks. As with other agroforestry systems, research focusing on managing and better defining these variables and exploring options to optimise species combination and configuration, will improve the resilience of production in the face of climate variability and extreme weather events.

For ginger, the most important production threats are posed by soil-borne pathogens (especially *Pythium* spp.) and nematodes — with the former exacerbated by waterlogging and both being associated with degraded soils, of low organic matter content. Strategies to reduce these risks are well known, such as transferring production to better-drained, gently sloping sites, the use of clean planting material and rotation with other non-host crops. Encouraging the adoption of such practices therefore falls mainly into the realm of agricultural development policy and extension. However, additional research to better understand soil ecology, considering various options for crop rotation and management of soil organic matter, will assist in suppressing soil-borne pathogens and increasing the resilience of ginger production systems. As for other vegetatively propagated crops in PICTs, the current genetic base is narrow, so the introduction and testing of additional varieties could be helpful in managing risks; however, exacting market demands would need to be borne in mind and might limit the scope of this approach.

6.7.3 Stimulants

Further research should be conducted on the apparent sterility of kava and attempts to restore functional sexuality are urgently needed, so that new varieties can be produced through sexual recombination. Mutation breeding would be a fast-track approach but the cost is likely to be high and the outcome uncertain. Kava dieback remains a significant challenge for growers, and it is uncertain how the projected climate conditions will impact on one of the main contributing factors to that disease, CMV. In addition, CMV is just one factor responsible for that disease. It would be useful to know what other factors are involved, the impact of climate change on these factors and the optimum techniques for maintaining clean planting material.

Lack of research into betel nut diseases poses a threat to the livelihoods of large numbers of people dependent on the crop for their livelihoods now and in the future. Specifically, research is urgently required on the causes of and solutions for the "betel nut disorder" that was first identified in the Markham Valley in 1996 and that led to collapse of production in that area[20].

6.8 Management implications and recommendations

It is expected that climate change, particularly climate extremes and extreme weather events, will impact on horticultural crops by amplifying the pressure of existing threats. Current approaches to climate change adaptation are often criticised for a tendency to ignore current threats and focus on less defined climate change issues per se. By enabling farmers to adapt to weather threats and climate extremes in the short and medium term, future generations of farmers will be better placed to adapt to climate change.

The approach recommended in this chapter has been to improve capacity to manage existing threats and at the same time identify knowledge gaps and assess future threats.

Specific recommendations have been outlined for the crops described in this chapter in the previous section. This next section examines the major changes that will be required to put the commercial horticulture industry on a sound footing for the next 30/40 years, highlighting the need for a major paradigm shift in how commercial horticulture is practiced and the importance of a supportive economic and policy environment.

6.8.1 Protected cultivation and nursery systems

Extreme heat and rain events are often limiting factors for the production of many horticultural crops during the 'off season'. Climate change projections indicate that these conditions will increase in the years to come. Globally, many tropical production areas are benefitting from the use of protected cultivation[21] and nursery systems to manage these conditions and produce high quality horticultural crops all year round. There are a range of protected cultivation and nursery system options available depending on the crop and available capital.

Protected cropping can be used to extend 'off-season' planting of vegetables and protect 'winter planting' of tomatoes against unfavourable weather events. Growers could use irrigation and/or protected cultivation and relay planting of crops to practice year-round cropping. Increased use of pumps and drip irrigation would allow the production of tomatoes and other crops to be moved away from vulnerable river banks (where crops are rain-fed or hand-watered) to drier, less easily eroded plains, for example, on the north side of Vitu Levu and Vanua Levu.

20 http://www.pestnet.org/Betelnutdecline,MarkhamValley,PNG.aspx
21 http://avrdc.org/?page_id=304

Vulnerable riverside horticulture, Fiji. Photo: Richard Markham

Research and introduction of appropriate techniques, combined with better business planning, can mitigate increased risk of losses due to unfavourable conditions. To support such potentially major changes in commercial production would imply changes in the economic and policy environment. A practical example of adaptive nursery systems has been discussed in Section 6.5.2.

Protective structures in the Sigatoka Valley, Fiji. Photo: Richard Markham

Testing low-cost drip irrigation kits, Solomon Islands. Photo: Richard Markham

6.8.2 Natural disaster mitigation strategies

Formal research on natural disaster mitigation strategies for horticultural crops is technically difficult, precisely because of the unpredictability of extreme events. However, even without formal research, there is a need for researchers and farmers to give additional attention to developing practical adaptation strategies that smallholder farmers can implement in order to minimise the risk of being completely destroyed by a natural disaster. Section 6.5.2. discusses examples related to research into pre- and post-cyclone responses for papaya, but much more research is required so that farmers know how practices such as defoliation, ratooning and sunburn control will help mitigate natural disasters.

With the increased likelihood of heavy rainfall, production should move away from the alluvial plains to gently sloping lands, as used in the Atherton Tablelands in Australia. Such a move requires more research and attention to soil fertility and erosion management. Conversely, to mitigate drought, the incorporation of green manure and crops into production systems to improve soil moisture should be evaluated, as well as examining the feasibility of using irrigation systems.

6.8.3 Climatically suited varieties

Growing the most climatically suited crop variety is an important starting point for any farming enterprise. Although breeding programmes around the world are continually focusing on producing climate-resilient varieties, access to these varieties in the Pacific has historically been poor. Targeted resilience is not the only approach; as discussed in Chapter 4, increasing diversity of varieties grown is a 'no regrets' strategy for reducing risk on several fronts. Increasing diversity and at the same time generating climate-resilient varieties could be achieved if more effort was put into local selection initiatives, which would exploit the variability and adaptability of existing varieties. Such an approach would have to be supported by a local seed industry, which would multiply and deploy locally identified variants.

Photo: Richard Markham

Testing better adapted vegetable varieties in the Solomon Islands.

Strengthening strategic alliances to test a range of materials coming out of other breeding programmes dealing with environments and climates similar to those of the PICTs would also be of benefit.

6.8.4 Pest and disease management

In the light of the uncertainty surrounding pests and diseases and how climate change will affect their incidence, behaviour and dissemination, efforts have to focus on identifying both what the key pest and disease threats are, and also on strengthening monitoring and preventative measures. Participatory approaches, such as farmer field schools, can provide knowledge in various areas, such as insect life cycles and insect damage, which will help farmers to monitor outbreaks in the future. Such approaches will also encourage better understanding and use of cultural management practices.

Plant health clinics provide a system that enables surveillance and monitoring of new pest and disease incursions, which normally would not be intercepted unless a national pest survey was carried out. They also address an important issue faced by national extension systems: staffing constraints result in very low farmer to extension officer ratios. Plant health clinics represent a bottom-up approach to improving national plant health services. They offer at least a partial solution to the challenge of lack of resources in formal extension services. Plant health clinics are being trialled in Solomon Islands under the ACIAR-funded Integrated Crop Management project (ICM).

6.8.5 Management approach and mindset

In summary, continued production of high-value horticultural crops within an environment of climate variability and long-term climate change will require an increased awareness from farmers about the changing variables and continual innovation. Without more sustainable and innovative practices, yields of many of the crops currently grown commercially are likely to be impacted by climate change. Year-round production using tools such as climatically suited varieties, irrigation, protected cultivation, cover cropping and relay-planting of crops will work towards making production systems more resilient. Losses due to unfavourable conditions will be inevitable, but will vary from year to year, and if such an approach is supported by ongoing research and the introduction of appropriate techniques, combined with better business planning, these risks can be mitigated. Such a change in thinking would require a supportive economic and policy environment.

6.9 Summary: The likely response of high-value horticultural crops to climate change

Crop	Climate change/ climate variability impact in recent decades	The impact of climate change over the next two to three decades (2030–2050)	The impact of climate change beyond 2050
Fruits and Vegetables			
Papaya	Overall, papaya production has been severely affected by cyclones, flood and drought events.	Severity of some diseases such as *Phytophthora* and anthracnose likely to increase because of a wetter climate. Increase of 1°C could affect fruit set. Although cyclone frequency is expected to decrease, papaya production will be negatively impacted by likely increasing intensity of cyclones. **Overall production and economic impact assessment: low to moderate**	Impacts of increased temperature, increased high rainfall events and intensity of cyclones likely to be significant. It is expected that the competitive position of the Australian papaya industry relative to Fiji and other potential Pacific Island producers will improve. **Overall production and economic impact assessment: moderate to high**
Mango	Climate variability adversely affected fruit production in some locations but improved fruit production in others. Rising temperatures are making some locations, previously too cold for mango production, more suitable.	Fruit set will continue to be adversely affected by unpredictable rains and temperature fluctuations during winter months. Reduction of fruit quality would result from frequent pre-wet season rains. Increasing problems with anthracnose possible. **Overall production and economic impact assessment: low to moderate**	High temperatures could affect flowering. Mango production will be negatively impacted by increasing intensity of cyclones. Unpredictable rains could also have a significant impact. Possible increasing mango fly and anthracnose problems. **Overall production and economic impact assessment: moderate**
Citrus	There has been no clearly discernible impact.	Minimal impact on pests and diseases of citrus as a result of a warmer and generally wetter environment. **Overall production and economic impact assessment: insignificant to low**	Increasing temperature and wetter environment can be expected to increase the incidence of pests and diseases. The likelihood of more intense cyclone events could accentuate the spread of diseases. An increase in temperature could expand the areas for citrus production in PNG highlands **Overall production and economic impact assessment: low**

Crop	Climate change/ climate variability impact in recent decades	The impact of climate change over the next two to three decades (2030–2050)	The impact of climate change beyond 2050
Pineapple	No clearly discernible impact	Expected to be minimal **Overall production and economic impact assessment: insignificant**	No apparent adverse impact from increasing temperature. Severe rain events and subsequent waterlogging would impact production. An increase in drought events could increase pineapple wilt disease **Overall production and economic assessment impact: low to moderate**
Tomato	No reported impact	Increase in rainfall and severe rain events will adversely impact disease incidence, further shrinking the growing season. Extreme heat, depending on timing could affect fruit production and yield. **Overall production and economic impact assessment: moderate**	A greater increase in mean annual temperature is likely to reduce yields of existing cultivars Adverse effects of high temperature will demand more heat-tolerant cultivars. Early and late blight will worsen with increasing high rainfall events. **Overall production and economic impact assessment: moderate to high**
Watermelon	No clearly discernible impact	Increase in rainfall during winter months will impact disease incidence, especially gummy stem blight. **Overall production and economic assessment impact: low to moderate**	Increase in average annual temperatures unlikely to affect watermelon production. Increases in disease, for example, gummy stem blight are likely to occur and affect production **Overall production and economic impact assessment: low to moderate**
Spices			
Vanilla	Climate extremes, coupled with price fluctuations, have led to wide swings in the amount of vanilla produced.	Unlikely any significant impact in the existing production areas. **Overall production and economic impact assessment: insignificant**	An increase in average minimum temperature and overall wetter environment could have an adverse impact on the induction of flowering. More intense cyclones would certainly adversely impact vanilla production outside of PNG. **Overall production and economic impact assessment: low to moderate**

Crop	Climate change/ climate variability impact in recent decades	The impact of climate change over the next two to three decades (2030–2050)	The impact of climate change beyond 2050
Ginger	The Fiji ginger industry has faced considerable pests (nematodes) and diseases (fungal and bacterial), but influence of climate unknown.	Overall increase in rainfall could increase the areas for production. More intense cyclones would not directly impact ginger production, but would increase already severe soil conservation problems in Fiji's main production areas. **Overall production and economic impact assessment: insignificant to low**	Unclear how an increasing average temperature, an overall wetter environment and more intense cyclones will affect the incidence of ginger pests and diseases. **Overall production impact assessment: low to moderate**
Stimulants			
Kava	Other than cyclones no discernible impact	More intensive cyclones likely to have significant impact, particularly for plantings not in agroforestry food gardens **Overall production impact assessment: low**	More intense cyclones expected to have a major impact. Significant increases in rainfall could cause problems with water-logging. How climate projections will affect kava dieback is not known. **Overall production impact assessment: moderate**
Betel nut	No clearly discernible impact	Unlikely any significant impact on betel nut in existing production areas. **Overall production impact assessment: insignificant**	An increase in rainfall levels in currently dry areas could favour production. **Overall production impact assessment: low**

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Photo: Andrew McGregor

Chapter 7

Vulnerability of livestock to climate change

Shaun Lisson, Mary Taylor, Nichol Nonga, Ken Cokanasiga and Peter Manueli

Contents

7.1 Introduction

In the Pacific, livestock plays a critical multi-purpose role in smallholder agriculture, most importantly as a source of protein and as a celebratory food in cultural, social and religious activities. At the national level, livestock production is a significant source of employment and food security and contributes positively to foreign exchange earnings (SPC 2009). This chapter describes the current status of livestock production in the Pacific, the potential impacts of future climate change, research/knowledge gaps relating to climate change impacts, and management and institutional adaptation recommendations.

7.1.1 Importance of livestock globally

Livestock production accounts for about 40% of global agricultural gross domestic production, contributes 15% of total food energy and 25% of dietary protein intake, and provides essential micronutrients not easily sourced from plant based foods (FAO 2006, 2009). It is a significant global employer (approximately 1.5 billion people) and source of livelihood (approximately 1 billion people). While livestock production in developed countries is stagnating, the demand in developing countries is increasing sharply in response to growing population and income, increasing urbanisation and changes in food preferences (Delgado et al. 1999). Furthermore, globalisation is boosting trade in animal products and inputs. In response to these trends global meat production is forecast to more than double from 229 million tonnes in 1999/01 to 465 million tonnes in 2050. Over the same period milk production is expected to grow from 580 to 1043 million tonnes (FAO 2006).

In most developing countries livestock represent the key asset for rural people, providing multiple economic, social and risk management functions including: 1) traction for field operations such as tillage; 2) a readily saleable store of capital to meet major household needs; 3) a means of accumulating wealth and status; 4) a business enterprise to generate income; 5) a source of organic fertiliser and, 6) as a source of biogas/fuel (Lisson et al. 2010). While smallholder production systems continue to dominate in developing countries, there are some emerging intensification and geographical trends. Production is shifting away from rural and towards urban areas to get closer to consumers and sources of imported feedstuffs. The production of monogastrics (e.g. pigs, poultry) that are better suited to intensive/efficient production is increasing while the production of ruminants (typically suited to more extensive systems) is slowing. These trends are expected to have a number of flow-on effects including the marginalising of smallholders and pastoralists, greater competition for scarce land, water and other natural resources (especially in urban and peri-urban areas), and the potential intensification of pollution arising from animal waste (FAO 2009).

7.1.2 How livestock affect climate change

While the focus of this chapter is on how climate change affects livestock, it should be noted that animal production is a significant contributor to global anthropogenic greenhouse gas (GHG) emissions. Estimates of the contribution from various sources (IPCC, FAO, EPA and others) vary from 7% to 18% depending on the accounting approach used and the scope of emissions covered (FAO 2013). For example, recent estimates from FAO based on the Global Livestock Environmental Assessment Model (GLEAM) have livestock emissions at 7.1 gigatonnes CO_2-equivalent per annum, which represents about 14.5% of human-induced GHG emissions. The majority of these emissions arise from beef (41%) and cattle milk (20%) production with lesser contributions from pig meat (9%) and poultry meat and eggs (8%). Feed production and processing (45%) and ruminant-derived enteric fermentation (39%) are the two main sources of emissions. Manure storage and processing account for a further 10% with the remainder (6%) from animal product processing and transportation. On a regional basis, Latin America and the Caribbean have the highest level of emissions (almost 1.3 gigatonnes CO_2-eq), compared with Oceania (including the PICTs) which has emissions of ~0.15 gigatonnes CO_2-eq (FAO 2013).

7.2 Importance of livestock in the Pacific

In the PICTs, livestock are raised in most households and play an important role as indicators of wealth and social status; as an exchange medium and celebratory food in cultural, social and religious activities; as a source of household protein; and, as a form of investment. At the country level, semi-commercial and commercial livestock production plays an important economic role through the provision of employment and food security and contributes positively to foreign exchange earnings (SPC 2011).

Pigs are reared almost exclusively for traditional and cultural events and rarely slaughtered for home consumption (FAO 2004b). As the numbers of ruminant livestock, such as buffalo, cattle, sheep and goats, have increased since their introduction in the 1800s for meat and milk production, they have been gradually assimilated into traditional cultural practices. In some countries, such as Fiji and Vanuatu, they now rival pigs in importance. Other uses of livestock include the provision of feathers (from poultry) for handicrafts and as a source of manure for fertilising crops. Livestock also play an important role in weed control in plantations.

Production of livestock products is expected to increase in the near future in response to growing demand driven by changing dietary habits and increases in human population, urbanisation and disposable incomes (SPC 2009). Strategies will be required to address the major constraints to livestock production in order to meet this expanding demand, address future food security demands and contribute to the economic growth of the region. Addressing these constraints also provides an opportunity to increase the income of rural households.

7.2.1 Livestock constraints

The main constraints to livestock production were identified at a regional workshop in 2006 (SPC 2006, unpublished report) and are still regarded as applicable to current production (Nichol Nonga pers. comm.). The constraints can be grouped into eight areas and are listed below.

Policy and legislation

- Outdated animal health and production legislation and policies, including inadequate regulation/legislation relating to livestock waste management and the positioning of livestock facilities relative to waterways and residential areas
- Low policy priority of livestock issues and lack of resourcing of livestock programmes
- Failure of many governments to recognise the threat to public health from livestock diseases in their region
- Livestock farming not seen as an attractive business/career, especially for young people.

Infrastructure

- Limited national and regional diagnostic capacity to support livestock production (e.g. feed analysis and diseases diagnosis)
- Lack of suitable processing facilities (i.e. abattoir/slaughter facilities)
- Lack of adequate market facilities to buy and sell stock.

Human resource development

- Shortage of qualified veterinarians and the difficulty in retaining qualified regional veterinarians
- Limited opportunities for training veterinarians and livestock specialists
- Shortage of adequately trained livestock extension officers
- Lack of a regional system of cooperation in the provision of veterinary advice and services.

Feed/nutrition

- High cost of locally produced compounded or balanced feeds makes them less competitive with imported products
- Access to adequate supplies of good quality local feed
- Inadequate research and extension on the production and management of feedstuffs
- Inadequate storage and processing capability for locally available feed resources.

Genetic resources

- Limited availability of existing and improved genetic material for breeding and production

- Limited understanding of the diversity of animal genetic resources
- Limited efforts to conserve indigenous, adapted and locally bred livestock species in the face of climate change and other potential threats.

Production systems

- At the global level, livestock production systems are under increasing pressure from the demands of rapid population and economic growth, increased demand for food and food products, and increased conflicts over scarce resources such as land, water and feed. Climate change will add to the vulnerability of the livestock production systems. While these pressures are yet to be felt in many PICTs, these global trends are likely to influence future production in the region
- Household financial, educational, extension and accessibility constraints limit the ability of farmers to adopt appropriate husbandry and other technologies to enhance existing production systems
- The need to identify, support and promote useful traditional production systems, especially in areas where access to modern inputs is restricted. This support is essential to conserving the indigenous breeds prevalent in these systems.

Waste management

- Animal waste is becoming a human health hazard and has the potential to pollute water and land resources and contribute greenhouse gas emissions to the atmosphere
- Limited education about the risks of animal waste and the extension of proven techniques to minimise and control animal waste.

Data and information

- Limited accessibility and availability of research results on the key aspects of livestock health and production in the region. This not only restricts adoption by farmers but also hampers the development of informed government policy relating to the livestock sector. This is of particular relevance to climate change because of the importance of data in implementing evidence-based adaptation strategies.

7.3 Pacific livestock and their production systems

7.3.1 Pacific species

The livestock species found in the PICTs are cattle (beef and dairy), goats, sheep, buffalo, pigs, horses and donkeys, poultry (chickens and ducks), rabbits and honey bees. These species can be broadly categorised into ruminants and monogastrics. Ruminants, such as cattle, goats, sheep and buffalo have a multi-compartment stomach and acquire nutrients from plant-based food by a combination of microbial fermentation in the first stage of the stomach (rumen) and subsequent regurgitation/

chewing of the fermented ingesta, or cud, to aid breakdown and digestion. In contrast, monogastric animals such as pigs and poultry have a simple single-chambered stomach and do not chew cud. Table 7.1 shows the total populations of the common species found in PICTs (SPC 2009). While the species distribution varies with location, pigs and chickens are the dominant species across most countries. Cattle are important in the larger countries and territories such as Fiji, New Caledonia, PNG and Vanuatu, primarily as a source of beef and to a lesser extent, as draft animals (e.g. Fiji). There is also a small but significant regional dairy industry in Fiji (FAO 1998). Goats account for a substantial proportion of total livestock numbers in Fiji and French Polynesia. While not occurring in large numbers, horses and donkeys play an important role in carrying heavy loads, transport and as draft animals in field operations such as tillage, especially in Fiji (SPC 2006).

While their numbers are small, sheep are gaining in popularity now that heat intolerance and parasite problems associated with early breeds have been addressed (Manueli 1997). The three main sheep-producing regions are Fiji (14,000 head in 2013), New Caledonia and PNG. Smaller numbers (approximately 800 head each in 2014) are produced in Samoa and Tonga (Peter Manueli pers. comm.). Honey bees provide an alternative source of income and a range of useful products that can either be used directly within the household or sold for income.

Table 7.1 Livestock population in PICTs — 2007 (source: SPC 2009).

PICTs	Chickens (000)	Pigs	Cattle	Goats	Ducks (000)	Beehives
American Samoa	68	64,208	300	n/a	n/a	20
Cook Islands	24	15,900	300	3600	n/a	n/a
Federated States of Micronesia	18	23,000	125	50	1	n/a
Fiji Islands	1656	92,251	156,074	251,765	70	3000
Guam	5	635	112	124	5	265
Kiribati	36	39,851	0	0	3	n/a
Marshall Islands	15	15,000	0	0	6	n/a
Nauru	2	880	0	0	n/a	n/a
Niue	10	1527	30	0		800
Northern Mariana Islands	11	1483	1395	276	n/a	n/a
New Caledonia	400	25,447	111,308	8130		1971
Palau	14	2500	15	25	1	n/a
Papua New Guinea	3,900	1,700,000	92,000	2500	14	n/a
Pitcairn	N/A	N/A	N/A	N/A	N/A	80
French Polynesia	293	33,644	8037	27,286	2	1642
Samoa	497	257,658	48,751	20	1	10,000
Solomon Islands	400	97,000	3,000	300	n/a	n/a
Tokelau	2	1050	0	0	n/a	n/a
Tonga	178	113,580	10,354	2741	1	900
Tuvalu	14	10,202	0	0	3	n/a
Vanuatu	368	88,694	211,152	8792	n/a	n/a
Wallis and Futuna	63	30,100	60	7000	n/a	551
Total	7973	2,614,510	643,013	312,609	108	19,149

7.3.1.1 Cattle, goats, sheep, buffalo

Cattle

Cattle are raised in almost all the countries and territories where there is spare land for pastures, except for the low-lying coral atoll countries. Historically, beef cattle were initially introduced to control grass growth in coconut plantations; however, there is now an increase in the number of specialist beef breeds and farms in the region (FAO 2007). The main cattle breeds (beef and dairy) used are purebred or crossbred Brahmans, Braford, Droughtmasters, Santa Gertrudis, Shorthorn, Angus, Friesian, Murray Grey, Hereford, Charolais Limousin, Jersey, Javanese Zebu and many other locally developed and adapted breeds such as the Samoan bovine (Povi Samoa), Solomon Island Red and others (FAO 2007). Most of the European breeds were brought in by early traders and settlers to provide meat and milk to feed themselves and their workers (FAO 2004b). Cattle are raised primarily for domestic consumption with the exception of Vanuatu, which has been exporting beef to many countries in the region as well as to Japan and Korea.

Among cattle breeds in general, Zebu (*Bos indicus*) breeds tend to tolerate heat and drought, and deal better with low-quality forage than do taurine (*Bos taurus*) breeds, while the latter have better feed conversion ratios when fed on high-quality feed (Albuquerque et al. 2006). The majority of cattle are fed almost exclusively on pasture, either improved or native, with some use of bush or forest areas in times of drought (including tree legumes). Supplementary feeding is mainly done on dairy farms but rarely in beef operations.

Smallholder beef cattle in PNG Photo: Andrew Tukana and Aurelie Brioudes

Goats and sheep

Goats were introduced into the Pacific almost at the same time as cattle and are primarily raised for meat production. They are small, hardy, minimal-care animals that can survive in harsh environments, browsing on a wide range of shrub, tree and broadleaf species as well as pasture. Their hardiness has also resulted in goats becoming feral in many countries with detrimental effects in terms of depletion of grazing lands, land degradation and the transmission of diseases and parasites into native habitats. The main goat breeds found in PICTs are Anglo-Nubians, Saanen, Fiji goat, Angora and other locally adapted goat breeds.

Sheep were introduced into the islands as an alternative source of meat for the population and to provide a smaller ruminant that can be more easily managed and handled by farmers. The woolly nature of early British sheep breeds introduced into the Pacific meant they were unsuited to the hot climate and as a result, they did not breed well. They were also highly susceptible to parasite infestation. In response to this, the 'Fiji Fantastic' breed was developed with traits better suited to the local conditions. This is a hair-type breed, derived from crosses between the tropically adapted Barbados Blackbelly with Corriedale, Poll Dorset and Wiltshire ewes, that sheds its coats under warm environments and high rainfall conditions, and has some resistance to parasites (Manueli 1997). This breed is now successfully produced in Fiji and in small numbers in Samoa and Tonga and is seen as an alternative climate change-resilient and environmentally sustainable species.

Fiji Fantastic in Samoa Photo: Nichol Nonga

Buffalo

Southeast Asian Swamp buffalo were introduced into the Pacific in the late 1800s, primarily for the provision of draft and later were evaluated for beef production. The current status of buffalo production is unclear.

7.3.1.2 Pigs, poultry (chickens, ducks), rabbits and honey bees

Pigs

There are three types of pig breeds in the region, namely local (i.e. indigenous), improved (a cross between exotic and local breeds) and exotic breeds characterised by high performance productivity. The most common exotic breeds are Large White, Land Race, Duroc, Hampshire, Saddleback, Tamworth and Berkshire. A study into the animal genetic resources of the southwest Pacific identified two major genetic lineages, one from Solomon Islands and Vanuatu and the other from Fiji, Niue, Samoa and Tonga (Jianlin 2012).

Local or improved pig breeds tend to be preferred in the traditional or subsistence production systems because of their hardiness and availability. In these systems, the herd sizes are variable and range from one to five sows. Animals are normally fed on kitchen wastes, coconuts and fibrous feeds such as grasses and banana trunks and basically whatever they can forage for. The pigs may be confined in communal pigpens or allowed to range freely (FAO 2003). Pigs play an important multi-functional role in the subsistence system including being used as an exchange medium and celebratory food in cultural, social and traditional activities, and as a measure of wealth and prestige.

Photos: Nichol Nonga(l), Farm Support Association (FSA) Vanuatu (r)

(a) Free-ranging pigs in Tonga; (b) Vanuatu Farmer Support Association village pigs project

Poultry

Poultry (chickens and ducks) are the most common form of livestock produced throughout PICTs and are raised in each of the three major production systems (subsistence, semi-commercial and commercial). Their eggs and meat are an important source of protein for the expanding population. Chickens were introduced into the Pacific hundreds of years ago, most likely from India, southeast and southern Asia (Jianlin 2012). Two main genetic lineages are recognised; one centred on Fiji, Samoa and Tonga and the other across Niue, Solomon Islands and Vanuatu. The local or indigenous chickens that are typically used in the subsistence, free-range systems have proved to be resilient to the historical impacts of climate change and could be useful for future crossbreeding with commercial breeds for adaptation to climate change.

Commercial broiler (meat) and egg laying operations are common in almost all PICTs and are high input, intensive operations based on the provision of balanced diets, water, housing and optimum husbandry. The majority of birds used in commercial layer and broiler operations are imported from Australia and New Zealand as day-old chicks or fertile eggs. Some countries such as Fiji maintain parent flocks and produce their own replacement stock. The most common breeds used in commercial operations are introduced and include Leghorns, Rhode Island Reds, Black Australorps, Brown Shaver, White Shaver and Cobb.

Photos: (a) Andrew Tukana and Aurelie Brioudes, (b) FSA, Vanuatu, (c) FSA, Vanuatu

Figure 4 (a) Broiler chicken production on slatted floor (b) Ducks, Vanuatu Farmer Support Association (FSA) village project (c) Chickens, Vanuatu FSA Village project

Rabbits

Rabbits have been introduced into some countries of the Pacific region as a cheap, alternative source of protein. In PNG for example, rabbits are being encouraged in remote areas where there is protein deficiency in the local diet (FAO 2004a). The meat is either consumed within the village or traded for other items. Their small size makes them suitable for production by smallholder farmers with restricted land area, although production is typically done in semi-commercial and commercial systems involving controlled environments and purchased inputs. Rabbits are seen by some as an alternative livestock that could be raised in all the countries of the Pacific regardless of whether or not land is available. It should be noted, however, that rabbits are a proven invasive pest that, if left unchecked, can cause large-scale economic and environmental damage in many countries. In Australia, grazing and burrowing by rabbits has caused serious erosion problems, reduced the recruitment and survival of native plants, and modified entire landscapes (NSWDEC 2005).

Honey bees

An Italian variety of the European honey bee (*Apis mellifera*) was introduced into the PICTs around the 1960–1970s to provide honey for consumption, wax for candles and other useful products. The bees also provide an alternative source of income for farmers in rural areas and an environmental service by pollinating flowers and crops. With the improvement of sea and air transportation, the threat of the introduction of bee pests and diseases is a constant concern; e.g. such diseases as European Foulbrood (*Melissococcus pluton*), American foulbrood (*Paenibacillus larvae*), and pests including the Asian bee (*Apis cerena*) and the Varroa mite, which are present in some countries of the region. Recent movements of the Asian honey bee (*Apis cerana*) introduced the Varroa destructor mite into Solomon Islands, leading to decimation of the managed *Apis mellifera* population (Groom pers. comm.).

The native bees of the southwest Pacific are comprised largely of two families, the *Halictidae* and *Megachilidae*, with some lesser representation of the *Apidae*. The most abundant family, the *Halictinae*, is almost entirely represented by a subgenus, *Homalictus*, of which there are four species. These native bees play a critical role in the pollination of native angiosperms throughout the Pacific (Groom pers. comm.).

Native bees (a) *Megachile laticeps* (b) *Homalictus fijiensis* Photos: Scott Groom

7.3.2 Importance of diversity

Maintaining and conserving biodiversity in livestock is an important climate change adaptation strategy, especially given the uncertainty regarding the impacts on livestock. Biodiversity helps to protect ecosystems against decline in overall functioning because a greater variety of species increases the probability that at least some will continue to provide functions (Ensor 2009; Pilling and Hoffmann 2011). The principal stewards of livestock diversity are the smallholder farmers who typically maintain breeds over long time-frames because of their beneficial traits such as growth rate, reproduction, resistance to certain pests or diseases and performance under limited feed and water conditions.

The biggest threat from the impacts of climate change on livestock diversity is that the speed of climate change may outstrip the ability of animal genetics to adapt or of farmers to adapt their husbandry methods (Pilling and Hoffmann 2011). This may give rise to the need for breed or species substitution, as has already occurred in parts of Africa (Gouro et al. 2008) and in some cases may lead to the extinction of breeds that cannot be maintained in their home environment. The FAO State of the World Animal Genetic Resources Report (2007), reports that of the 7616 breeds included, 20% are classified as at risk; in the last six years, 60 breeds have been lost (almost one breed per month); data are unavailable for 36% of the breeds; and the genetic diversity of animals has declined rapidly.

The maintenance and introduction of animal species diversity is an important climate change adaptation option available to farmers, especially in times of drought. The different feeding capacities and habits of different types of animals are essential in enabling the livestock sector as a whole to use a wide range of feed resources. For example, goats browse more (shrubs and trees) than do sheep and cattle, and are better able to detoxify the tannins found in the leaves of trees and shrubs (Silanikove 1986). By virtue of their mobile upper limbs, prehensile tongues/mobile lips and ability to rear up on their hind legs, goats are able to pluck leaves from thorny shrubs and select the most nutritious parts of the plant (Huston 1978). By making use of forage that cannot be used by other animals, there is a degree of complementarity when grazing and browsing animals are kept together (Pilling and Hoffman 2011).

7.3.3 Livestock pests and diseases

The isolated nature of the Pacific Island region, where the total land area accounts for just 2% of the total ocean area (30 million km^2), has helped to keep the region free of major exotic animal pests and diseases, including zoonotic diseases. Current animal health problems are limited to gastrointestinal parasites, poor nutrition, foot rot, clostridial diseases and coccidiosis. Leptospirosis, bovine brucellosis and bovine tuberculosis (in cattle), Marek's disease and fowl pox (in chickens) and American foulbrood (in bees) are present in some countries (SPC/FAO 2013).

The following transboundary animal diseases have been identified as priority threats in PICTs: Newcastle disease, highly pathogenic avian influenza (HPAI), tuberculosis, bluetongue, foot and mouth disease, classical swine fever, rabies, brucellosis, Q-fever, leptospirosis, bee diseases, and aquatic animal diseases. The list includes both exotic diseases that need to be prevented from entering PICTs and other endemic diseases that need to be better managed by member countries (SPC/FAO 2013).

Changes in environmental conditions due to factors such as climate change, coupled with increasing trade, improved transportation, and tourism, can lead to exotic pests and diseases, and disease vectors, being introduced and established within PICTs. It is therefore important that capacities and systems within the animal health services be developed to be able to detect any incursions of these exotic pests and diseases, and to make effective responses to address them. It is also important that veterinary services and capacities are developed and sustained if this favourable disease situation is to be maintained. Diagnostic capacity varies greatly across PICTs with only Guam, Fiji, PNG and New Caledonia having accredited animal health diagnostic laboratories.

7.3.4 Livestock production systems

There are three main types of production systems used by livestock farmers, namely: 1) traditional/extensive/subsistence; 2) semi-commercial or smallholder; and 3) commercial production systems. The choice of system is a function of the resources the farmer has available for production (i.e. labour, housing, land area, management skill and feed) and the local customs, regulations or laws that govern the ways in which livestock can be reared (SPC 2011).

7.3.4.1 Subsistence/traditional/extensive production system

The subsistence/traditional/extensive system is a low input system in which animals are given limited feed, limited care and minimum (if any) housing. Animals are typically grazed in small areas of grassland or other vegetation along roadsides, under coconut or fruit trees. This type of system is used extensively for ruminant animals and pigs, especially in the larger Melanesian and some Polynesian countries where more land is available. While accurate figures on the number of livestock reared in this way are not available, it is estimated that more than 60% of livestock populations are raised in this way (FAO 1998). In these systems, traditional knowledge around farming practices is very important and is usually passed on from generation to generation, with improvements and adaptations taking place according to changes in local conditions. The livestock play a multi-functional role in the household, including home consumption; use in cultural, social and traditional activities; as a readily saleable store of capital to meet major household needs; as a symbol of wealth; to utilise/dispose of household kitchen waste; and in some countries (e.g. Vanuatu), as a source of ornamental pig tusks. There are five traditional sub-systems used by farmers, namely free-range, tethering, dirt floor, slat floor and palisade.

Free-range

In this system the animals are allowed to freely roam and scavenge for feed all around the villages and settlements with little or no provision of housing or extra feed. The advantage of this system is that animals are free to find shade and cool water (if available) during hot days and escape during disasters such as cyclones and floods. However, in times of drought they are vulnerable unless provided with supplementary feed and water. Such systems can be damaging to food crops and can be a source of considerable conflict in village communities.

Goats grazing in a coconut plantation Photo: Andrew McGregor

Tethering

In the tethered system, the animal is anchored with a rope that restricts roaming to a small area. The animals are either retained in the one location and provided with cut and carry feed or periodically moved to new pasture/forage. The system is employed for a range of livestock including pigs, cattle, goats, sheep and even chickens. Unless able to be evacuated to safer ground, animals kept in this way are vulnerable during times of flood, cyclone and other extreme events.

Dirt floor

Pigs reared in this system are confined in earth yards, enclosed by fences made of timber, bamboo or rocks, often with crude shelters. As with all the systems involving confinement of the animal, the pigs are reliant on the farmer for the provision of food and water as well as relocation to safe ground during extreme events. Animal waste will accumulate in this system, resulting in odour problems and a potential animal and human health hazard.

Slat floor

In this system the pigs are reared in raised wooden pens with slatted floors that allow dung and urine to pass through or onto small concrete slabs that are enclosed with timber or wire. It is not uncommon to see wooden pens built over rivers and creeks so that all dung and urine is disposed into the waterway to reduce odour and fly problems. This has obvious negative implications in terms of public health and damage to aquatic ecosystems.

Palisade

The palisade system is essentially a scaled up version of the dirt floor system whereby the animal is provided with more land and resources that enable it to be more self-reliant. The land is fenced off with a stake or stone fence and there is little or no input from the owner except for the occasional provision of feed and water. Shade trees are typically provided for stock shelter.

7.3.4.2 Semi-commercial or smallholder production system

In the semi-commercial or smallholder systems, animals are more intensively managed to achieve higher productivity through the provision of better fences and yards for husbandry practices, improved pastures and feed, greater water availability and veterinary care. The semi-commercial production system is used for all types of livestock and allows farmers to exert greater control over all aspects of production.

Pigs kept in movable pens for agroforestry Photo: Andrew Tukana

In semi-intensive pig and chicken operations the animals are housed and dependent upon their owners for all of their feed and water requirements. The housing arrangements for pigs vary, with some having outdoor fenced runs attached to the pig house while in others the pigs are kept permanently indoors. The breeds of pigs used in the semi-intensive system are normally exotic breeds or crosses between exotic and indigenous breeds.

Smallholder chicken layer operation, Solomon Islands Photo: Andrew Tukana and Aurelie Brioudes

Similar systems are employed for ruminants such as cattle (beef and dairy), goats and sheep where the owners aim to lift production via improved pasture (e.g. incorporation of legumes), the use of feed supplements and the aforementioned improvements in water supply, provision of housing, improved animal husbandry and veterinary care. In PNG and other PICTs, this system is often employed on the outskirts of provincial capitals and semi-urban localities (FAO 2004a). Farmers keep livestock as part of their broader farming system and sell most of their livestock product through the local market depending on the demand and price.

7.3.4.3 Commercial system

This system includes poultry (chicken and ducks), pigs, and beef cattle. Under this system, meat and eggs are produced using high levels of input and management with the primary aim being to generate a profit (cf. subsistence and household income in the traditional and semi-commercial systems). There is a much greater emphasis on quality control and on meeting the requirements of the target market (national and/or international).

Animals are housed in concrete or metal pens inside specially designed sheds to permit maximum control over all aspects of the animal environment and management. Waste management is required in such systems to prevent the pollution of waterways and the adjacent land. Typically, waste is stored in septic tanks or ponds where it can be subsequently used for biogas energy generation and in the production of organic fertiliser. The conversion of animal waste (plus human and other organic feedstock) into methane gas for use as an alternative household energy source is gaining popularity in a number of Pacific countries. Biogas replacement of the traditional firewood and fossil fuels provides financial and environmental (i.e. less deforestation/clearing) benefits and the digester outflow can be used as a fertiliser.

These commercial systems are based on high-performing or exotic breeds selected to optimise reproductive and growth rates. The setup will normally involve automated feeding and watering with the animals fed a specially formulated diet comprised of quality fodder combined with various targeted supplements and commercial feeds.

7.4 Optimum requirements to ensure health and productivity of livestock

Most domesticated species are homeotherms that need to regulate their body temperature within a very narrow temperature range. Their ability to balance their heat loss and their heat production is therefore important. The thermal comfort zone (TCZ) of animals is a relatively narrow environmental temperature range in which heat production offsets heat loss completely, without activation of any compensatory physiological mechanism within animals (i.e. a temperature range in which animals are neither cold, nor heat stressed). The TCZ is influenced by a range of factors including genetic potential, the life stage of the animal, and its nutritional status. Table 7.2 lists TCZ ranges for key livestock types. TCZ is normally higher in tropical breeds due to their better adaptation to heat and the lower feed intake of most domestic animals, especially in smallholder systems.

Table 7.2 Thermal comfort zones of animals (source: RCI 2008).

Animal Species	TCZ (°C)
Bos taurus (dairy)	5–20
Bos taurus (beef)	15–25
Bos indicus (beef)	16–27
Sheep (fleeced)	5–24
Sheep (shorn)	7–29
Adult pigs	16–25
Lactating sows	12–22
Piglets (newborn)	25–32
Chickens	10–20
Horses	10–24

7.5 The impact of climate change on livestock

7.5.1 Feed quality, quantity and availability

Livestock depend on access to feed and water to survive, produce and reproduce. Vast areas of the world are used for producing livestock feed, with pasture and cropland used for animal feed accounting for almost 80% of all agricultural land. The future of livestock production systems depends on the continued productivity of these areas, all of which are potentially affected by climate change (Pilling and Hoffman 2011). As highlighted in Chapter 3, Crest Ltd is the main supplier of manufactured livestock feed mixes for commercial livestock (primarily chicken) in Fiji with almost 70% of their raw ingredients, including grains such as maize, wheat and sorghum, being imported. With the global production of maize and other coarse grains likely to be adversely affected by higher temperatures, climate change could have a significant impact on the availability/reliability of livestock feed in Fiji and other countries reliant on imported grains or livestock feed itself. The recent IPCC report (Vermeulen 2014) confirmed that negative impacts of climate change on crops, such as maize and wheat, are already evident.

Predicting the effect of climate change on plant communities is very difficult. As discussed in Chapters 3 and 4, climate not only has a direct effect on plants but also influences other components of the ecosystem that influence plant growth, such as soil characteristics and the distribution of the other biological components including pests, diseases, herbivorous animals, pollinators and soil microorganisms. Various authors report enhanced photosynthetic performance and plant growth under elevated carbon dioxide (CO_2) concentrations (Bowes 1993; Taiz and Zeiger 2002). Elevated atmospheric CO_2 concentrations also lead to the partial closure of stomata, which reduces water loss by transpiration and increases water use efficiency (Wu et al. 2004). As a consequence, it is predicted that climate change will induce a shift from C_3 to C_4 grasses, as C_4 plants are more efficient in terms of photosynthesis and water use (Morgan et al. 2007). This shift would have direct implications for feed supply and quality as C_3 forage plants typically yield less but generally have higher nutritive value, while C_4 plants contain large amounts of low-quality dry matter and have a higher carbon–nitrogen ratio (Easterling and Apps 2005; Tubiello et al. 2007).

The extent to which elevated CO_2 affects growth is modified by changes in temperature and rainfall amount (IPCC 2007). The interactions between CO_2 concentration, temperature and water availability are complex, with the net effect (beneficial or otherwise) changing with latitude, species and management. Rising temperatures will typically lead to an increase in water use, which may offset gains in photosynthetic efficiency. Every species has unique upper and lower threshold temperature and moisture levels for growth. Species that are otherwise constrained by low temperatures at a given location (e.g. elevated site) may fare better under higher temperatures. Similarly, genotypes that are better adapted to dry conditions will perform better in areas where rainfall is projected to decline (Rötter and van de Geijn 1999). For this reason the seasonal and spatial distribution, composition and patterns of species in grasslands and rangelands will change under future climates (Hanson et al. 1993). These shifts will in turn influence livestock productivity through shifts in feed quality, although the effect is likely to be buffered to some extent by the ability of stock to adjust consumption and species selection (Thornton et al. 2009). An implication of this is that significant changes in management of the grazing system may be required to attain the production levels desired.

This shift in productive species under climate change may extend to other components of the agro-ecosystem, with generalist species that are able to survive in a variety of environments replacing species with more specific requirements (Foden et al. 2008). This may lead to new areas being invaded by weeds, pests, pathogens or disease vectors that will potentially influence the growth of plants on which livestock feed.

From a feed quality perspective, increasing temperatures will impact negatively on the digestibility, and hence nutritive value, of consumable biomass through the increased lignification of plant tissue (Minson 1990). The effects will apply to both pasture-based rangeland systems and mixed systems involving supplementary feeding with crop residues. Studies have also shown that elevated levels of CO_2 lead to a reduction in protein and nitrogen (N) content (and hence quality). This reflects a dilution effect where N uptake does not keep pace with the increased growth of the plant (Pleijel and Uddling 2012). These impacts on feed quality will in turn lead to reductions in animal production with negative consequences in terms of income and food security.

7.5.2 Impact of increased temperature

Generally there is little information available on the effect of heat stress on animal physiology, especially for the tropics and subtropics (Thornton et al. 2009). The deleterious effects of heat stress are due to the hyperthermia associated with high environmental temperatures or the physiological adjustments that need to be made by the heat-stressed animals. Increasingly hot and humid conditions can lead to behavioural and metabolic changes resulting in declines in physical activity and feed intake (Mader and Davis 2004), the limiting of production potential (Parsons et al. 2001; Frank et al. 2001), reduced male and female fertility and reduced fitness and longevity (Amundson et al. 2005; King et al. 2006). While in general, livestock can adapt to small increases in temperature, temperatures beyond 42°–45°C are lethal for many species. The TCZ for tropical breeds tends to be higher due to their adaptation to higher temperatures and the lower food intake in tropical smallholder systems. Because animals at lower latitudes are often well adapted to heat stress and drought, increases in temperatures will have a greater effect on animals in higher latitudes.

For this reason, the increasing use of high-producing temperate breeds (that are less adapted to heat) in livestock intensification systems (e.g. dairy production) in developing tropical countries can lead to increased vulnerability to increasing temperatures. When animals' metabolism converts feed for the production of milk, eggs, meat, offspring, etc., heat is produced as a by-product. Increased production levels demanding more feed will therefore result in increased internal heat production. High-yielding animals are therefore, as a consequence, more likely to suffer from heat stress in a hot climate, than are low-yielding ones (Thornton et al. 2009).

The effects of high temperatures on livestock can be exacerbated by the type of feed. The use of a diet rich in fibre of low digestibility (e.g. hay) will result in higher heat production in animals due to greater muscular activity in the alimentary tract and, in ruminants, increased microbial activity in the rumen. One would therefore expect that increasing the proportion of concentrate feed in diets would reduce heat stress under hot climatic conditions (Mader and Davis 2004).

Access to and availability of water is essential if livestock are to be able to manage heat stress. Indeed there is evidence that increased temperatures lead to an increased demand for water by livestock, as shown in Table 7.3. The table also highlights the role that diversity can play in reducing vulnerability. In a modelling study into the future water requirements of beef cattle in Australia, Howden and Turnpenny (1998) estimate an increase of about 13% in water demand for the climate scenarios simulated, and an increase in the number of days in a year when animals could no longer stress regulate by sweating alone. With this in mind, the same authors suggest the need for thermoregulatory control to be incorporated into future breeding programmes.

Table 7.3 Water intake per kg DM intake for *Bos indicus* breeds compared with *Bos taurus* breeds at three different temperatures, 5°C, 30°C and 35°C (source: NRC 1981).

	kg water intake/kg DM intake @ 10°C	kg water intake/kg DM intake @ 30°C	kg water intake/kg DM intake @ 35°C
Bos indicus breeds	3	5	10
Bos taurus breeds	3	8	14

7.5.3 Impact of variation in rainfall and rainfall patterns

Increased rainfall can have a deleterious effect on livestock through the effects of muddy enclosures and fields on animal mobility; the promotion of waterborne diseases, hoof rot and pests (e.g. army worm); and the reduction in feed availability and quality through the flooding of pastures and the spoilage of stored feed. Furthermore, farm structures, road access and machinery can also be adversely affected.

Conversely, declines in rainfall might be expected to reduce the quantity and quality of stock drinking water (surface and ground) and feed. In areas where the length of the growing season is shortened due to changes in rainfall distribution and amount, animals will suffer longer periods of nutritional and water stress. In addition, animals may be required to walk longer distances in search of feed and have to cope with less frequent watering. The movement of animal populations out of drought-affected areas can lead to problems of overgrazing in neighbouring areas and to problems with diseases and parasites as animals crowd together or move into areas where unfamiliar diseases are endemic. Conflict over access to grazing land and water is another potential hazard (Thornton et al. 2009).

7.5.4 Impact of extreme events

Cyclones, droughts, floods, heat waves and other extreme events such as tsunamis and storm surges can lead to reduced production, injury and the death of livestock, especially in the more intensive commercial operations involving pigs, chickens and dairy cattle. The effects can be either direct, such as damage caused by falling trees and moving debris or through the drowning of animals in flooded areas, or indirect through impacts on feed and water quality and quantity. In the short term, flooding can impede access to available pasture and if it persists, will eventually damage or kill inundated pasture. High winds and flooding can also damage management infrastructure such as roads, fencing, wells, feeding stalls, etc. which can all have a detrimental effect on livestock production. Floods can also compromise livestock and human health through the spread of waterborne diseases (Hoberg et al. 2008) and diseases that are spread by vectors that have aquatic phases in their life cycles.

The main consequence of drought, from a livestock production perspective, is reduced supply and quality of feed and water, which in turn will lead to lowered fertility, and generally increased vulnerability to disease, higher mortality and morbidity. Droughts may force people and their livestock to move, potentially exposing them to environments with health risks to which they have not previously been exposed (Thornton et al. 2009). Overgrazing of certain areas can occur in drought conditions, encouraging a change in the species composition of the grasses and favouring the development of annual grasses and woody perennial scrub (Foden et al. 2008). Restrictions to water availability can also contribute to the spread of disease, for example, when large numbers of animals congregate at a limited number of watering places (Pilling and Hoffmann 2011).

7.5.5 Impact of climate change on livestock pests and diseases

The geographical and seasonal distributions of many infectious diseases and pests are affected by climate. Pathogens, vectors, and intermediate and final hosts can all be affected both directly by the climate (e.g. temperature and humidity) and indirectly by the effects of climate on a wide range of interacting factors. These include changes in habitat (e.g. land use and cover), movement of human and animal populations, trade, and changes in management practices. Consequently, the interpretation of observed changes and prediction of future trends in disease distribution and impact is complex and not fully understood. With climate change, hosts and pathogens may be brought together in new locations and contexts, bringing new threats to animal (and in some cases human) health, and new challenges for livestock management and policy (Pilling and Hoffmann 2011).

Larger populations of pathogens may arise with higher temperatures, especially for pathogens that spend some of their life cycle outside the animal host (Harvell et al. 2002). The survival rate of other pathogens that are sensitive to higher temperatures may decrease due to warmer temperatures. Changes in precipitation may also affect pathogens sensitive to environmental moisture or dry conditions, and frequency of floods. Increases in precipitation and moisture can result in the successful survival of some pathogens in the environment, increasing chances of re-infection and spread of infections.

Similarly, the distribution and populations of known animal disease vectors (midges, flies, ticks and mosquitoes) in the tropics are affected when rainfall and temperature change, relative to the usual physiological tolerances of the vector. The ability of some insect vectors to become and remain infected has been found to vary with temperature (Wittman and Baylis 2000). Higher temperatures have been found to increase the feeding frequency of insects, which in turn increases the likelihood of disease transmission, as many vectors must feed twice on hosts before transmission is possible.

Climate change may shift or alter the lifecycle of the various organisms involved in, or potentially involved in, disease transmission. This may lead to changes in the temporal overlap of these organisms and the development of new and potentially faster modes of transmission (Pilling and Hoffmann 2011).

Climate change may indirectly affect disease transmission through influences on the patterns of international livestock trade and local transportation, farm size and intensity of animal production (Thornton et al. 2009). For example, changes in land use, and agricultural practices driven by climate changes (e.g. drought and flooding) may force people and livestock to move to new surroundings, and therefore expose these new areas to novel pathogens and disease vectors. This may also result in the emergence of new diseases and disease vectors.

Another related concern is the effect of rises in temperature on food safety. Microbial growth is temperature dependent and an increase in temperature of just a few degrees can have a substantial effect on the growth of pathogens, like *Salmonell*a and *Campylobacter*, in foods such as poultry. In the absence of refrigeration, food will spoil faster and there is likely to be an increase in the incidence of food-borne illnesses. Greater investment will be required in refrigeration along the food chain from producer to consumer to counter the projected gains in temperature. This comes at a cost both in terms of energy consumption and greenhouse gas emissions (Susuma et al 2013).

7.6 Observed climate change impacts on livestock

The complexity of factors influencing livestock production, combined with the long time frame required to separate climate variability from climate change responses, and the lack of detailed historical records, make identifying examples of observed climate change on livestock in the Pacific region virtually impossible. Chapter 2 reports that there has been no significant change in rainfall amount and distribution and in the frequency of tropical storms in recent times. However, there has been a significant rise in temperature of about 0.18°C per decade since 1961. Observed impacts of this shift in temperature are rare, anecdotal in nature and not statistically valid. For example, farmers from Sepa and Loimuni villages (Choiseul, Solomon Islands) have observed higher daily temperatures, changes in seasonal weather patterns, more frequent droughts and floods and changes in the harvest time of various food crops. They have also observed increasing pig mortality rates over the past 10 years and a decline in pig litter size from 6–7 piglets down to 4–5 piglets (Susuma et al. 2013).

7.7 Projected climate change impacts on livestock in the Pacific

In general, the high-output breeds introduced to PICTs from temperate regions are not well adapted to heat stress, and milk, egg and meat production, fertility and longevity would all be expected to decline as temperature increases (Frank et al. 2001; Parsons et al. 2001; St-Pierre et al. 2003; West 2003; Mader and Davis 2004). Such breeds are expected to be less well adapted to high temperatures than the breeds introduced from higher latitudes and the locally developed and adapted breeds. In the short term at least, the tropical and subtropical breeds are more likely to be affected by feed availability and quality changes brought about through climate change than temperature per se. While existing breeds may be able to cope with temperature projections for 2030 (up to +1.0°C, Chapter 2), breed and species substitution in some regions might be expected by 2050 (up to +2.0°C) and 2090 (up to +4°C). These shifts will be further exacerbated by the projected gains in temperature extremes. Consideration of the temperature comfort zones of key species (Table 7.2) would suggest that *Bos taurus* dairy breeds and chickens are particularly vulnerable to these future temperature shifts.

Three of the native bee species found in PICTs have only been found at altitudes greater than 800 m, with one other species widespread below this elevation. The current climate predictions are likely to have contrasting impacts on different species. The lower elevation species that responded positively to the warming climate that followed the last glacial maximum may continue to persist at lower elevations as they appear to be generalist pollinators. However, those species found at higher elevations and which are already comprised of very small populations with lower genetic diversity, are likely to be heavily impacted by a warmer climate. Their current restriction to very high elevations raises the possibility that, if mean temperatures continue to increase, they may be unable to persist by retreating to even higher habitats. As pollinators, this has broader implications for the plant species they interact with and may disrupt angiosperm reproduction in these habitats.

The European honey bee is recognised as a species with significant potential for climate change adaptation given that it is found across the world in highly diverse climates. That is, the species possesses plasticity and genetic variability that would enable it to adapt to new environmental conditions (Le Conte and Navajas 2008). Less is known about the potential impacts of climate change on Pacific bees. Studies are needed to improve baseline data on these species and to identify which plants are dependent on them. Investigating key endemic species that demonstrate plasticity, such as *Homalictus fijiensis* or *Megachile* species, and finding ways in which they can be integrated into common agricultural practice would be very useful research. As they are plastic species, it is likely that their climatic tolerances are relatively good. Maintaining traditional farming systems and adopting a more landscape approach to agricultural development would help with conserving pollinators, and would be of benefit generally in maintaining a healthy ecosystem (Groom pers. comm.).

Increases in the frequency and intensity of severe heat waves have the potential to cause substantial deaths, as experienced by feedlot animals in the United States in recent years (Nienabar and Hahn 2007; Hatfield et al. 2008). It might be expected that the estimated 60% of Pacific livestock reared in traditional systems would be more susceptible than the semi-commercial and commercial systems to extreme climate events. The traditional tethered or confined production systems are characterised by low husbandry, housing and health inputs and the animals have nowhere to go in order to escape extreme heat and flooding. The free-range traditional system, however, enables the animal to escape danger and seek alternative sources of feed and water. In contrast, the commercial operations maintain a much higher level of inputs with the animals provided with shelter, thus having the potential at least to control/regulate the production climate. The predicted increase in intensity of storm and flood events is likely to lead to increased infrastructure damage and human/animal health risks associated with waterborne diseases.

Future rainfall trends across PICTs are geographically variable with some locations becoming wetter over the remainder of the 21st century while other locations such as French Polynesia will become drier (Chapter 2). The frequency and intensity of extreme rainfall events is also likely to increase. These changes have been linked to changes in the frequency and intensity of El Niño events (Allen and Bourke, 2001) and, as with temperature, the extent of rainfall shift varies with location and the emissions scenario upon which the climate simulation is based (Chapter 2). To date there has been little research on the impacts of variation in rainfall and rainfall patterns on the livestock sector of PICTs. Suffice to say that droughts will reduce the quality and quantity of stock drinking water and potentially intensify competition between the various water users, especially as animal production intensifies and moves closer to urban centres. Similarly, the shortening of growing seasons during drought periods will reduce feed availability for livestock, and may lead to increased grazing pressure and disease in areas where feed remains, or force farmers to sell/relocate stock. In Samoa, droughts have forced farmers to sell animals below normal prices to prevent deaths due to lack of feed and water on farms (FAO 2003).

Sea level is projected to increase by up to 30 cm by 2030 and up to 60 cm by 2080 (depending on the emission scenario). This is on top of the measured rise in global sea level of 19 cm since the start of the 19th century (Chapter 2). Rises in sea level will inevitably lead to contraction in land area, which is likely to lead to increased animal–human contact and hence greater exposure to disease, especially in the smaller atoll islands. Furthermore, intensification will impose more pressure on remaining water and feed resources (Manueli 2010). Similarly, saltwater intrusion associated with sea-level rise will affect water supplies and could impair the growth of any feedstuffs along coastal areas.

The future general trends in feed production and quality described in Section 7.5.1 are relevant to PICTs. The response to changes in temperature, atmospheric CO_2 concentration and water supply will vary with species and their individual environmental tolerances. Suffice to say that future climate change will inevitably lead to changes in the composition and geographical extent of different species. This is expected to lead to a decline in feed quality associated with a shift away from C_3 to C_4 grass species, the increased lignification of plant tissues and the expansion of generalist species into areas previously dominated by regionally adapted species. In production systems where animals are fed on concentrates, rising grain prices likely under future climate change projections will increase the pressure to use animals that efficiently convert grains into meat, eggs or milk. Thus, within such systems climate change may lead to greater use of poultry and pigs at the expense of ruminants, and greater focus on the breeds that are the best converters of concentrate feed under high external input conditions. Increases in the price of grain may also contribute to the further concentration of production in the hands of large-scale producers. Similarly, the general trends and responses in the geographical extent, population, life cycle and transmission of livestock diseases and pests to future climate change outlined in Section 7.5.5, are relevant to the Pacific.

7.8 Uncertainty, gaps in the knowledge and future research

The following list is a summary of recognised knowledge gaps and research priorities relating to climate change impacts on livestock production in the PICTs, (Thornton et al. 2002; Morton 2007; Thornton et al. 2009; SPC 2011):

- Improved understanding of climate change impacts on the physiology of specific livestock and livestock feed crops
- Development and research on more climate-change ready pasture species (i.e. heat, drought, salt and flood resistant)
- Development of sustainable and resilient local livestock feeds to counter the likelihood of the supply of imported feed and/or feed components being affected by climate change
- In rangeland systems, the impacts of climate change on the primary productivity of pasture, species distribution and the carrying capacity of the system
- In mixed crop/livestock systems, the impacts of climate change on crop harvest indexes and stover (i.e. residual crop biomass after harvest used as fodder) production
- Impacts on surface and groundwater supply and resultant impacts on livestock (especially rangeland systems) and effective ways to increase livestock water productivity
- Impacts on the future prevalence and intensity of key epizootic livestock diseases, especially as livestock systems intensify
- A thorough inventory of existing animal genetic resources to address the limited current understanding of the genetic diversity, and a complimentary analysis of traditional livestock production systems to identify breeding strategies that will enhance resilience to climate change
- While the direct impacts of climate change on livestock disease over the next two to three decades may be relatively muted (King et al. 2006), there are considerable gaps in knowledge concerning many existing diseases of livestock and their relationship to environmental factors, including climate.

7.9 Management implications and recommendations

There are three main adaptation avenues available to livestock farmers: 1) the breeding or introduction of new genotypes better suited to the prevailing and future climates; 2) thermal control through modifications to the feeding regime; and 3) thermal control through the provision of shelter, water and other environmental control measures.

For the majority of PICTs, mixed crop and livestock systems are practised; therefore, the approaches highlighted above can be incorporated into those systems, contributing to increased system resilience, diversification and risk management. Despite the knowledge that these approaches and elements are important in adapting to climate change, there is limited information available to assist farmers in selecting the best strategy to follow at any one time. What is clear from the information available, however, is that no one approach will address resilience, and that all options are likely to be needed in different circumstances (Thornton et al. 2009).

This section describes the various adaptation options/approaches and institutional and policy change recommendations necessary to underpin responses to climate change and to improve livestock production more generally.

Breeding

The introduction of new traits potentially offers farmers greater flexibility in adapting to climate change. Key breeding traits associated with climate change resilience and adaptation include thermal tolerance, digestion of low quality feed, high offspring survival rate, disease resistance and various advantageous animal morphology traits (Clements et al. 2011). Potential also exists in modifying animal feed resources to improve resistance to drought and heat, tolerance to salinity and earlier maturation to shorten the growing season and reduce farmers' exposure to risk of extreme weather events (Padgham 2009).

The ability of an animal to cool is determined by its capacity to reduce body temperature by increasing its respiration rate, by its coat colour properties, and by various phenotypic attributes that dissipate heat such as large ears and excess dewlap skin (Padgham 2009). Most of these responses to heat stress are genetically mediated physiological responses and hence amenable to selection via traditional (i.e. selection and controlled mating) or more high-tech processes such as *in vitro* fertilisation or genetic engineering. New genetic resources can be sourced from breeds adapted to production environments (i.e. successful over a long period of time) that are similar to those prevailing in the areas to which they are to be introduced or which will prevail under future climate scenarios. However, most of the global gene flow is currently focused on introducing high-output breeds for use in the high-input, controlled environments of commercial production systems rather than introducing adapted types. The ability of traditional livestock keepers to experiment with new breeds and to introduce new blood into their herds will likely play an important role in adapting to climate change, provided there are no constraints to accessing relevant animal genetic resources and that relevant local knowledge and breeding expertise is available. Identifying suitable breeds for introduction is a complicated task and must take into account not only suitability for a single environmental challenge (e.g. rising temperature) but broader suitability to the target area and production system in place. This requires an intimate knowledge of the source and target environments and close consultation with the livestock keepers to gauge the suitability of new introductions (Padgham 2009).

While the existence of breeds that are more resistant or tolerant to various diseases is well established, many of the underlying physiological and genetic mechanisms are not well understood. Improving this situation through targeted disease research and structured breeding programmes is difficult in developing countries where access to and the affordability of veterinary inputs and services is limited (see previous section on constraints). PICTs must therefore strengthen the links between national and regional agencies and the relevant international organisations that carry out this type of breeding work. These linkages are especially important for accessing research outputs necessary for managing the priority diseases and parasites (FAO 2009), all of which are likely to be affected by climate change (Padgham 2009).

Feeding and nutritional adaptations

Another proven adaptation strategy for livestock thermal control is to modify the feeding regime to reduce metabolic heat buildup. For ruminants, the digestive process contributes to increased body temperature, particularly with animals fed on a low quality diet. The amount of heat generated during rumination can be modified through the use of feed additives (ionophores), supplemental feeding, and adjusting the time of feeding. For example, reducing the proportion of roughage in the diet of ruminants can mitigate the effects of elevated body temperature (NRC 1981). Other strategies include reducing the amount of feed consumed and restricting ruminant feeding to late in the afternoon rather than in the morning (Mader et al. 2002; Davis et al. 2003). Ionophore feed additives act to reduce feed intake, thereby lowering body temperature and improving feed use (Guan et al. 2006). These technologies can be strategically implemented during heat waves or feed shortages and can be combined with the aforementioned genetic modifications. A key constraint to these approaches in PICTs will be the availability and cost of the necessary feedstuffs (see Section 7.2.1 above).

Smallholder farmers would benefit from a more integrated, systems approach where 'best-bet' feed availability, quality and feed management practices are combined with improved optimal animal husbandry methods to maximise production and improve resilience to climate change impacts. Such an approach has been successfully implemented in various southeast Asian countries to improve cattle production (Lisson et al. 2010). In eastern Indonesia for example, feed availability and quality deficiencies were addressed through three strategies — improved use and management of existing fresh forages, introducing new forage grasses and legumes to increase fresh forage supply options, and better use and improvement of crop residues. Households were advised on the correct amount and composition of feed required by animals of different age, condition and activity. Strategies for addressing recognised deficiencies in the breeding cycle (i.e. where calving coincided with the dry season when feed quality and availability was poorest), access to bulls for mating, access to stock water, cattle housing and health were also identified. Other social, cultural and economic (including labour) constraints to livestock production were addressed as part of the integrated systems approach. Participatory, on-farm engagement principles were employed where farmers (and their advisors) were involved in every step of the process, including: 1) identifying the key constraints to livestock production; 2) developing 'best-bet' strategies to address these constraints (with input from relevant disciplinary experts); and 3) on-farm testing and extension to other farmers (Lisson et al. 2010). Obviously, the constraints and associated 'best-bet' strategies will vary between countries and livestock sectors within each country, but the broad principles of this integrated, systems, participatory research and development approach are applicable to PICTs.

Animal shelter and water

As the ambient temperatures increase during the day, both respiration and water consumption rates rise and animals typically seek shade. Farmers can reduce these impacts of heat stress by providing animals with shade in the form of trees planted within or around fields or stalls and man-made structures (e.g. sheds), positioning corrals so they are exposed to wind currents, allowing night-time grazing, and providing extra drinking water. There are various perennial tree species (e.g. *Leucaena* sp., *Gliricidia* sp.) that can provide both shelter and green feed throughout the year for stock (Lisson et al. 2010). In the more confined, semi-commercial and commercial systems, more elaborate stock cooling approaches may be used such as sprinklers and fans (Pilling and Hoffmann 2011). This may make such systems relatively insensitive to small-scale climate change effects, providing the cost of extra inputs (i.e. electricity and water) does not make them financially unviable.

Institutional and policy implications

Section 7.2.1 of this chapter lists the limited availability of existing and improved genetic material for breeding and production as a key constraint to livestock production in PICTs. Addressing this constraint will require greater investment in breeding research capability and the development and utilisation of molecular genetic techniques. The technical capacity of extension services will need to be strengthened to address constraints in the flow and use of information to and from farmers. Government policies need to be developed that support the wider use of beneficial livestock genetic resources, including promoting the movement of animals and germplasm among farms, regions and countries and reducing trade barriers on genetic exchange (Padgham 2009). Investment is required in animal disease diagnostic laboratory and veterinary services to address the current shortfall (see Section 7.2.1). Such a service, when combined with effective biosecurity regulations, would provide for disease surveillance and underpin countermeasures in the event of a disease outbreak. Conservation programmes need to be implemented to counter losses associated with gradual environmental changes and catastrophic losses from flood and storm events. This will involve the establishment of *ex situ* collections situated in dispersed locations. There is a recognised need for a community-level early warning system for flood, cyclone and disease outbreaks and undertaking appropriate emergency preparedness and response programmes with village communities and farmers (SPC 2011).

Table 4 Summary of projected climate change impacts.

Climate change	Projected impact 2030[1]	Projected impact 2050[2]	Projected impact 2090[3]
Rising sea level	Saltwater intrusion into groundwater will reduce potable drinking supplies for livestock and impact on quality and quantity of available feed.	Some coastal land may become unsuitable for agricultural production. Increasing stock densities and closer human/animal contact with increased risk of disease transfer especially on smaller atolls.	Further reduction of land suitable for agricultural production. Concentration of agricultural production in remaining areas. Greater reliance on food imports.
Increasing temperature	Minimal effect on indigenous, locally adapted breeds. Survival of native bee species adapted to cooler temperatures of higher elevations may be compromised with impacts on the survival of plant species dependent on these species for pollination. Actual temperature tolerances are unknown. Changes in the geographical extent, population, life cycle and transmission of livestock diseases and pests depending on the specific temperature tolerances.	Temperature gains of up to 2.0°C may lead to species/breed substitution, especially of temperate breeds/species. Seasonal and spatial distribution, composition and patterns of forage species will change. With the global production of maize and other coarse grains likely to be adversely affected by higher temperatures, climate change could have a significant impact on the availability/reliability of local livestock feed. As for 2030 re pest and disease impacts. Increased risk of food-borne disease-related illness.	As for 2050. Temperature gains of up to 4°C likely to require species/breed substitution. Livestock with low temperature comfort zones such as *Bos taurus* dairy breeds and chickens are particularly vulnerable.
Heat waves	Potential to reduce the productivity of introduced temperate latitude breeds although in commercial/semi-commercial systems the effects can be managed through climate control and other practices. Provision of shelter and water will be necessary in traditional systems to avoid a reduction in production and/or stock death.	Increased likelihood of animal death especially in tethered or confined traditional production systems. Commercial systems will need to invest more in cooling systems to avoid substantial loss of stock.	As for 2030. Likely need for species/breed substitution.

1 Temperature rise of +0.5° to 1°C regardless of emissions scenario.
2 Temperature rise will vary from +0.5 to 1°C (RCP2.6) to +1° to 2°C (RCP8.5).
3 Temperature rise will vary from +0.5 to 1.0°C (RCP2.6) to +2.0 to 4.0°C (RCP8.5).

Climate change	Projected impact 2030	Projected impact 2050	Projected impact 2090[3]
More frequent and intense droughts	Reduction in the quality and quantity of available forage. Seasonal and spatial distribution, composition and patterns of forage species will change. Increased grazing pressure on areas where feed is available may lead to environmental side effects (e.g. erosion) and increased risk of disease transfer. Reduced quality and quantity of drinking water. Increased competition between various water users.	As for 2030	As for 2030
More frequent and intense floods, higher rainfall	Infrastructure damage (roads, buildings, fences, etc.). Increased human and animal health risk from waterborne diseases. Reduced animal mobility. Reduced feed availability and quality through flooding and spoilage of stored feed.	As for 2030	As for 2030
Increasing CO_2 concentration	Unknown	Unknown	Reduction in the quality and composition of forage/ feed types due to a gradual shift from C_3 to C_4 species. Increased lignification of plant tissue (i.e. reduced quality).

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Photo: Many Strong Voices/GRID-Arendal
President Anote Tong and children undertaking mangrove replanting in Kiribati

Chapter 8

Native forests, plantation forests and trees outside forests: their vulnerability and roles in mitigating and building resilience to climate change

Lex Thomson and Randy Thaman, with Anna Fink

Contents

8.1 Introduction

Healthy forests and trees are a clear sign of environmental stability, resilience and human wellbeing — the antithesis of desertification, land degradation, vulnerability and poverty. This chapter stresses that the conservation and enrichment of Pacific Island forests and trees outside of forests in both rural and urban settings offers one of the most practicable, cost-effective, culturally and environmentally sound means of addressing climate, environmental, economic and social change, the impacts of which are clearly negatively synergistic. By conserving and enriching forest and arboreal resources, regardless of the main causes of change and the unclear extent to which human-induced climate change is currently and increasingly an important driver, we have an action that can be carried out at national, subnational and community levels. This chapter outlines some of the existing and forecast impacts of human-induced climate change in concert with other drivers of change, and how the conservation, enrichment and sustainable utilisation of forests, trees outside of forests, and arboreal resources can address the seemingly intractable impacts of climate change.

8.1.1 Types, locations and areas of native forests, planted forests and trees outside forests (including the tree component of agroforestry systems)

In the Pacific Islands, the main forest types are tropical lowland rainforest (including secondary forests at various stages of regeneration), montane rainforest and cloud forest, tropical dry forest and woodland, swamp and riparian forest, coastal forest, mangrove forest, agroforest and plantation forest (Clarke and Thaman 1993; Mueller-Dombois and Fosberg 1998; Moorhead 2011). The extent and nature of these different forests on each Pacific island depends on factors including island type, elevation, location within the ocean, climate, and impacts of human occupancy, with intact forest being less extensive on smaller, highly populated islands and near settlements.

The islands can be roughly divided into high islands, raised limestone islands and atolls. High islands, rising to mountainous peaks, are mostly of volcanic origin, such as much of Vanuatu, Fiji and Samoa, but also include islands of ancient continental origin, such as the main islands of New Caledonia and Papua New Guinea (PNG). Raised limestone islands, many of which are quite large and rise to significant elevations, include Ouvéa, Lifou and Maré in New Caledonia, Aniwa in Vanuatu, Kabara and Fulaga in Fiji, Tongatapu and most of the Tonga islands, Niue, and Nauru.

Atolls are low-lying limestone islands, normally rising no more than four metres above sea level, which have formed over sunken volcanoes and which are not associated with or near larger islands. For example, the islands of the Great Barrier Reef are similar to but not considered atolls (Thaman 2008a). The main atoll groups of the Pacific are Kiribati, Republic of the Marshall Islands (RMI), Tuvalu, Tokelau, the northern Cook Islands and the Tuamotu Archipelago of French Polynesia. The high islands have much more extensive natural forest cover and forest species diversity, with atolls having the lowest forest diversity, including the lowest agroforest diversity. On many of the smaller, highly populated islands there are scattered trees and groves, but no forests.

Agroforests, which are a traditional landscape feature of Pacific Island agricultural land use systems, include fallow forests in different stages of regeneration; deliberately planted village woodlots and tree groves; boundary plantings or living fences; scattered trees that have been planted or protected among ground crops and which are protected when shifting gardens are allowed to return to fallow; deliberately protected mangrove or coastal littoral forests that border and protect adjacent inland agricultural areas; and, increasingly (in a rapidly urbanising Pacific), urban and rural houseyard gardens (Thaman 1995, 2004b). The predominant trees in most of these areas are a mix of cultivated fruit and multipurpose trees and fast-growing native pioneer or framework species that are characteristic of young fallow forests. Increasingly, timber species are also being incorporated into agroforestry systems in Solomon Islands, Vanuatu, Fiji and Samoa.

Photo: Lex Thomson

Planted agroforest including mahogany, flueggea and sandalwood developed on degraded farmland at Laulau, Fiji.

For smaller islands and in highly populated areas, the agroforests and trees within the matrix of agricultural land-use systems provide most of the products and ecosystems services, including coastal protection, protection from erosion, wind and salt spray, animal habitat, shade and soil enrichment, that are provided by forests (Thaman 2004a, 2008b). The Japan Satoyama-Satoumi assessment (2010), one of the most innovative and comprehensive assessments of biodiversity and ecosystem services ever undertaken of 'sustainable use of biodiversity' and what underpins and threatens it, shows that a substantial percentage of all goods and services are provided from these humanised, time-tested, community-based agricultural and village land-use systems.

By comparison with native forests, plantation forests are generally far more productive in terms of wood volume, often by an order of magnitude. Accordingly, forest plantations have a commercial importance that is proportionately much greater than their area. However, they will generally be more vulnerable to climate change and interactions with pests and diseases, because of their typically monocultural composition and reduced biodiversity. Plantation forests are limited in the Pacific, with only about 0.36% of land area under tree plantations, excluding coconuts and horticultural tree crops (Table 8.1). There are many reasons for this situation. Nearly all land is under traditional or customary ownership and access to land is a major issue resulting from this type of land tenure system. In some areas land can be available but economically inaccessible. There is also high pressure on land for both commercial and subsistence agricultural production, and land is owned or used in relatively small parcels by many owners, who are often reluctant to lease land for the long tenures needed for forestry. Plantation establishment and early maintenance costs are high due to the presence of rampant, vigorous climbers, such as the native *Merremia peltata* (big-leaf) which must be weeded frequently (e.g. 15 times in the first three years in Samoa), and labour costs are higher relative to other tropical developing countries.

The major environmental threat to plantation forests comes from regular, often severe tropical cyclones (away from the equatorial zone[1]) with the potential to devastate plantations of any species and age. In the past, poor species choice and monocultural plantings, for example, *Cordia alliodora* (in Vanuatu) and *Eucalyptus deglupta* (in Samoa), exacerbated by minimal input and poor silviculture, such as low-quality seedlings and excessively wide spacing in Samoa, led to the demise of larger plantation projects. Plantation success stories include big-leaf mahogany (*Swietenia macropylla*) with about 60,500 ha in Fiji, *Gmelina arborea, Eucalyptus deglupta* and *Tectona grandis* in Solomon Islands, and *Pinus caribaea* (> 55,000 ha) in Fiji, New Caledonia, PNG and several Polynesian countries. Fiji, Samoa, Tonga and several of the other smaller countries are the only tropical countries free of mahogany shoot borer (*Hypsipyla* spp.) and thus have a major competitive advantage for growing *Meliaceae* species, such as mahogany and red cedar (*Toona ciliata*).

1 In Solomon Islands the Ontong Java atolls, situated between 5–5.6°S, might be considered outside the tropical cyclone belt as cyclones rarely form so close to the equator, but the group has experienced two damaging cyclones between 1950 and 1991 (Bayliss-Smith 1988; Blong et al. 1991).

Table 8.1 Estimated areas of forest and planted forest in the Pacific Islands.

Region	Country or territory	Population[2]	Land area (km²)	Forest[3] (%)	Planted forest (ha)	Main plantation species[4]
Melanesia (SW Pacific)	Fiji	862,000	18,270	56	177,000	*Pinus caribaea, Swietenia macrophylla, Tectona grandis,* ***Santalum yasi****, Neolarmarkia cadamba, Cordia alliodora, Maesopsis emini, Eucalyptus deglupta,* ***Agathis macrophylla, Endospermum macrophyllum***
	New Caledonia	259,000	18,575	46	9,840	*Pinus caribaea, Eucalyptus spp.,* ***Agathis spp. Santalum austrocaledonicum,*** **native spp.**
	Papua New Guinea	7,461,000	461,700	63	86,100	***Eucalyptus deglupta, Terminalia brassii, Acacia mangium, Araucaria cunninghamii, A. hunsteinii,*** *Pinus patula, P. caribaea, Tectona grandis, Eucalyptus robusta, E. grandis, E. saligna*
	Solomon Islands	561,000	28,370	79	27,000	*Eucalyptus deglupta, Gmelina arborea,* ***G. molucanna****, Tectona grandis,* ***Camnosperma brevipetiolata****, Swietenia macrophylla,* ***Terminalia calamansanii, T. brassii***
	Vanuatu	265,000	12,190	36	2,900	***Santalum austrocaledonicum, Endospermum medullosum,*** *Cordia alliodora,* ***Terminalia catappa***
Polynesia (Eastern Pacific)	American Samoa	55,000	199	89	591	*Flueggea flexuosa, Casuarina equisetifolia,* native species
	Cook Islands	15,000	240	65	1,186	*Pinus caribaea,* ***Morinda citrifolia****,* Australian *Acacia* spp.
	French Polynesia	269,000	3,660	42	6,700	*Pinus caribaea, Falcataria moluccana*
	Niue	1,800	260	72	289	*Swietenia macrophylla, Toona ciliata,* **native species**
	Samoa	189,000	2,829	60	3,200	*Swietenia macrophylla, Flueggea flexuosa, Terminalia spp,* ***T. richii****, Tectona grandis, Eucalytus pellita, E. urophylla, E. camaldulensis, Toona ciliata, Santalum album*
	Tokelau	1,450	10	0	0	
	Tonga	103,500	718	13	493	*Pinus caribaea, Toona ciliata, Agathis robusta, Eucalyptus camaldulensis,* ***Santalum yasi****.*
	Wallis and Futuna	13,000	274	42	400	*Pinus caribaea*
Micronesia (Central & North Pacific)	FS of Micronesia	101,000	702	92	158	
	Guam	161,000	549	47	208	*Acacia auriculiformis, A. mangium, Casuarina equisetifolia*
	Kiribati	106,000	717	15	0	(Note: c. 75% under coconuts)
	Marshall slands	56,000	181	70	0	(Note: c. 69% under coconuts)
	Nauru	10,000	21	0	0	
	CN Marianas	52,000	477	66	7	
	Palau	21,000	458	88	5	*Swietenia macrophylla,* native species
	Tuvalu	11,100	26	33	0	(Note: c. 54% under coconuts)
TOTAL		10,573,850	550,447			

8.1.2 The importance of Pacific Island forests

Forests and trees are integral to the culture, health and livelihoods of Pacific Islanders. In fragile island ecosystems, forests, agroforests and trees, and their associated biodiversity, hold the key to economic prosperity, adaptation to climate change and building resilience to all forms of change. The SPC publication 'Forests of the Pacific Islands – Foundation for a Sustainable Future' (Moorhead 2011) describes

2 Estimated population — July 2013.
3 FRA 2010.
4 Species in bold are indigenous/native.

the current status, threats, challenges and opportunities for forests in each of 22 Pacific Island countries and territories (PICTs). Whilst the area and type of forest and tree resources vary enormously between island nations, from about 75% in Solomon Islands to 5% in Tonga, forests and trees are integral to the future wellbeing of all nations and their peoples. Forests and trees are vital for socio-economic purposes, providing a forest food bank, traditional medicines, wood for building materials, implements and fuel, cultural traditions, and products for local sale and export. In remote islands, forests and trees act as nature's medicine chest with traditional herbal cures and remedies being used in the absence of and/or complementing Western medicines. The forests also provide vital ecological services, such as coastal and watershed protection, soil replenishment, water purification and conservation, and act as reservoirs of biodiversity (habitat for birds, bats, and countless other important plants and animals) and carbon (both as a carbon stock and sink). Table 8.2 illustrates the multifunctional utility of forests, which provide ecological and cultural security against extreme weather-related events and economic downturns.

Table 8.2 Values of coastal forests and trees to people, plants and animals in Tuvalu (adapted from Thaman et al. 2012b).

Ecological services		
Shade/protection from sun	Wind protection	Protection from salt spray
Soil improvement	Erosion control	Coastal protection
Flood/runoff control	Animal/plant habitats	Wild animal food
Spawning grounds	Nursery areas	Weed/disease control
Cultural/economic		
Timber (commercial)	Broom	Prop or nurse plants
Timber (subsistence)	Parcelisation/wrapping	Staple foods
Fuelwood	Abrasive	Supplementary foods –
Boatbuilding (canoes)	Illumination/torches	wild/snack/emergency
Sails	Insulation	Foods
Tools	Decoration	Spices/sauces
Weapons/hunting	Body ornamentation	Teas/coffee
Containers	Cordage/lashing	Non-alcoholic beverages
Woodcarving	Glues/adhesives	Alcoholic beverages
Handicrafts	Caulking	Stimulants
Fishing equipment	Fibre/fabric	Narcotics
Floats	Dyes	Masticants/chewing gum
Toys	Plaited ware	Meat tenderiser
Switch for children/	Hats	Preservatives
discipline	Mats	Medicines
Brush/paint brush	Baskets	Aphrodisiacs
Musical instruments	Commercial/export	Fertility control
Cages/roosts	Products	Abortifactents

Tannin	Ritual exchange	Scents/perfumes
Rubber	Poisons	Recreation
Oils	Insect repellents	Magico-religious
Toothbrush	Deodorants	Totems
Toilet paper	Embalming corpses	Subjects of mythology
Fire making	Lovemaking sites	Secret meeting sites

Given the multi-faceted role that forests and trees play in supporting the livelihoods of Pacific communities, it can be difficult to properly assess their economic value. Standard measures such as contribution to GDP typically don't include the environmental, cultural or health services provided by forest resources. There is, however, a growing body of literature which seeks to value ecosystem services, including those from forest ecosystems, across the Pacific. One example, looking at the value of mangroves in Lami town in Fiji, estimated that mangroves provide an indirect benefit (for example, storm surge protection) equal to FJD 471 per hectare of mangrove. These indirect benefits were more than five times the value of direct, extractive benefits (e.g. firewood) which would be included in GDP (Rao et al. 2013). Furthermore, there are moves towards the adoption of mechanisms which provide funding to governments for the carbon sequestration and storage services provided by forests (e.g. through REDD+). There is also increasing interest in the Pacific Islands in moving towards a 'Green Economy' (e.g. in Fiji and Samoa) and a new form of national accounting, the UN-supported System of Environmental-Economic Accounts (SEEA), which would seek to place greater emphasis on valuing environmental resources.

The contribution of forestry to GDP is, however, an important part of the sector's contribution to the economic wellbeing of most PICTs, particularly in Melanesia. Table 8.3 below shows the percentage of GDP supplied by forestry between 2000 and 2006 for the region's six largest countries. The table clearly demonstrates that forests are economically important for Solomon Islands and PNG and to a lesser but still significant extent in Fiji, Samoa and Vanuatu.

Table 8.3 Contribution of forestry to GDP, 2000–2006 (source: FAO 2008).

	2000	2001	2002	2003	2004	2005	2006
Fiji	2.9	3.0	2.9	3.3	3.5	3.5	3.4
PNG	6.9	6.4	5.2	4.9	5.2	5.4	6.7
Samoa	4.5	3.8	3.7	3.6	3.5	3.3	3.2
Solomon Islands	9.2	10	10.3	12.8	16	16.6	16.7
Tonga	0.5	0.5	0.5	0.6	0.5	0.5	0.5
Vanuatu	3.4	3.8	1.0	3.9	3.7	3.6	3.5

Commercial forestry is a major industry and rural employer in PNG, Solomon Islands and Fiji. In Western Melanesia the dollar value of the forestry export sector is on a par with agriculture, but most of the revenue is associated with unsustainable harvesting practices and sale of unprocessed, round logs from PNG and Solomon Islands, mainly to mainland China[5]. In PNG round log exports have fluctuated between 2–3 million cubic metres per annum between 2005 and 2010, but the value of exports has climbed fairly steadily mainly due to increases in the global price of logs.

In Solomon Islands the rates of harvesting of native forest over the past decade have been unsustainable, with accessible, high-quality, unprotected native forests now heavily logged over. In 2011, harvesting of logs reached an unprecedented high of 1.9 million cubic metres. This, combined with a high global price, meant that the export value for logs in 2011 was USD 190 million.

Table 8.4 Log exports, volume and value 2008–2011 (source: PNG Forest Authority; Solomon Islands Central Bank and Fiji Department of Forestry).

	Papua New Guinea		Solomon Islands		Fiji	
	Volume (Million m^3)	Value FOB $US Million	Volume (Million m^3)	Value FOB $US Million	Volume (Million m^3)	Value FOB $US Million[6]
2008	2.58	190	1.50	118	0.02	13.5
2009	2.09	170	1.04	84	0.13	10.06
2010	3.00	272	1.42	121	0.03	17.23
2011	-	-	1.9	190	-	-

While the value of timber exports from the Solomon Islands has increased, the share of timber in total exports actually fell from 58% in 2008 to 46% in 2011, which is mainly due to the increase in exports of fish and minerals. Whilst both the PNG and Solomon Islands Governments have policies promoting down-stream processing, the lack of progress and failure of the private sector to embrace simple value-adding opportunities such as rough sawing and kiln drying represents a major lost income-earning opportunity for resource owners, processors and governments.

In Fiji there are two major forestry plantation industries, viz. *Swietenia macrophylla* (big-leaf mahogany) in the wet zone and *Pinus caribaea* (Caribbean pine) in the drier, western parts of Viti Levu and Vanua Levu, and on some of the smaller islands, such as Gau and Kadavu. Both mahogany and pine have developed into substantial export industries, with an annual value of around FJD 30 million (mahogany timber) and FJD 18.5 million (pine chips). Mahogany has become the main hardwood in use in the Fiji furniture industry, while preservative-treated pine timber and poles are the main locally produced construction timbers, with domestic pine sales around FJD 12.5 million per annum in 2013 (George Vuki, General Manager – Operations Fiji Pine Group pers. comm.). Fiji's pine plantations have been developed on long-degraded grasslands (or *talasiga*), but suffer from indiscriminate burning with low or patchy stocking in burnt areas; the main pinewood products are preservative treated poles and timber for local construction and woodchips for export. Currently Fiji has

5 For example, in 2010 86% of PNG logs were exported to PR China (source: PNG Forest Authority/Société Générale de Surveillance (SGS) PNG.

6 The original data were provided in FJD and have been converted to USD using the annual exchange rate reported by the Reserve Bank of Fiji.

the world's most productive mahogany plantation estate at around 42,400 hectares (Fiji Forestry Department 2013; pers. comm.).

Timber exports from Vanuatu have declined substantially from high levels in the 1990s. In 2000 round log exports totalled 39,860 m^3 with a value of VUV 415 million. These declined throughout the decade from 23,870 m^3 (VUV 257 million) per year from 2001–2004, to 6,545 m^3 (VUV 271 million) per year from 2005–2008, down to 6,280 m^3 (VUV 64.5 million) per year from 2008–2009. The differences in export earnings are attributed to fluctuating international timber prices and changes to the species being exported. In both 2007 and 2012 wood exports were worth approximately USD 0.9 million[7], but the earlier figure was earned mainly from whitewood (*Endospermum medullosum*) and sandalwood (*Santalum austrocaledonicum*), and the latter figure is almost exclusively from sandalwood. Vanuatu is currently a net importer of timber products. The local importance of wood is indicated in the 2006 National Agricultural Census, which concluded that up to 90% of Vanuatu households rely daily on wood and wood products from native forests and agroforests.

Excluding coconut, sandalwood (*Santalum spp.*) and a few non-wood forest products, such as *Calophyllum inophyllum* (tamanu) oil, there are minimal forestry exports from the non-Melanesian PICTs, with Polynesian and Micronesian PICTs being net importers of forest products.

8.1.3 Science and biodiversity values at risk

The Pacific Islands' forest and tree species hold enormous scientific and biodiversity values (Collins et al. 1991), but these are at risk from various threats, including climate change, extreme climate events, such as tropical cyclones, and interacting factors, such as logging, mining, conversion to agriculture, grazing land and urban uses, invasive species and indiscriminate burning. In January 2006, fires engulfed more than 4,000 ha of rainforest near Noumea, New Caledonia, destroying rare animals and plants. The bushfires either resulted from, or were made worse by an extreme climatic circumstance — extremely low rainfall in the last quarter of 2005, associated with a neutral El Niño/Southern Oscillation state. It is noted that New Caledonia's tropical forest ecosystems are unique, and of the 44 species of gymnosperms (conifers) that exist, 43 are endemic with many at risk from climate change (drought and associated uncontrolled wildfire). Indeed, 15 endemic conifers in nine genera are considered to be threatened by fire (source: International Conifer Conservation Programme of Royal Botanic Gardens Edinburgh;[8] . The world's most primitive flowering plant is a New Caledonian endemic small tree, *Amborella tricopoda*: this species has been placed in its own order, Amborellales, and is of major scientific importance.

7 2000–2009 — Vanuatu Government data and 2012 statistics taken from ITC trade map.
8 http://threatenedconifers.rbge.org.uk/taxa/category/southwest-pacific/fire/P24)

Whilst *Amborella's* conservation status has yet to be assessed, it is considered to be at risk from climate change and fire entering previously unburnt, wet forest ecosystems in New Caledonia.

8.1.4 Roles of forests and trees in carbon sequestration and climate mitigation

Forests and trees are expected to play a central role in helping to limit and sequester atmospheric carbon to slow climate change. Increasing carbon storage in primary forests is, for example, a pan-tropical phenomenon, providing a sink of 1.3 gigatonnes (Gt) of carbon per year (confidence interval 0.8–1.6) across all tropical forests during recent decades (Lewis et al. 2009). Modelling suggests that global climate change will not reduce carbon stocks in tropical forests, with the potential positive effects of CO_2 fertilisation countering the negative effects of rises in temperature (Cox et al. 2013).

The intra- and inter-specific diversity in trees in primary forests helps to buffer them against change and destruction (whether mediated by climate, extreme weather events, biotic invasions, fire, human disturbance or combinations of these drivers) which might result in damaging releases of CO_2. Vigorously growing plantation forests also sequester vast amounts of carbon, (for example, maximally around 86 tonnes of CO_2 per hectare for eucalypt hybrids in Brazil[9]), while trees generally provide fuel for billions of people without adding to the burning of fossil fuels. Tree breeders will require genetic diversity to develop faster growing, well-adapted trees for a diverse range of environmental conditions, for a future generation of trees for fuel and carbon sequestration including through biochar, an important non-labile carbon soil additive to increase agricultural productivity.

At a global level, forests and trees play important roles in carbon sequestration. FAO (2010) estimates that the world's forests store 289 Gt of carbon in their biomass alone and that along with the carbon stored in forest biomass, deadwood, litter and soil together, this is roughly 50% more than the amount of carbon in the atmosphere (FAO 2005). PNG has 26 million ha of primary forests (2% of the world's total) with 2,306 million tonnes of carbon stock in living forest biomass in 2010 (FAO 2010). Outside of PNG and Solomon Islands (182 million tonnes) the contribution of PICTs' forests and trees to global carbon stocks, although globally negligible, is significant in terms of contributing to local understanding of the importance of carbon sequestration in smaller PICTs. Moreover, the maintenance of forests and trees for their carbon stocks has an important political dimension because the smaller PICTs are amongst the most vulnerable nations on the earth to climate change, with low-lying atoll groups such as Kiribati, Marshall Islands, Tokelau and Tuvalu especially vulnerable from extreme events and rising sea levels. The role of mangroves in forest carbon stocks and for sequestration is also significant, especially for smaller islands and coastal

9 Calculated as *Eucalyptus urograndis* hybrid growing at 80 m^3 per ha per year (Couto et al. 2011, with reports of more than 100 m^3 per ha per year in research trial plots for individual clones) x 1.2 (to include woody roots) x 0.49 (basic density for *E. urograndis* hybrid; Gominho et al. 2001) x 0.5 (proportion of carbon in bone dry wood) x 3.67 (conversion of carbon to CO_2).

communities that have little other forest. For other large atoll groups such as Ha'apai in Tonga and Tuamotu in French Polynesia, only a few volcanoes or uplifted atolls may survive rising sea levels.

Accordingly, governments and peoples have, for the most part, been keen to demonstrate their credentials by maintaining and increasing tree cover and carbon sinks. For example, the Government of Fiji has recently successfully completed a one million trees planting programme and implemented a REDD+ policy. However, globally the rate of loss of primary forest is stable or decreasing in all regions except Oceania, where it is increasing, primarily as a result of a higher reported loss from PNG over the period 2005–2010 (FAO 2010). Forest degradation and reduced forest carbon stocks due to poor logging practices, and associated activities such as burning and agricultural conversion, is occurring in PNG and Solomon Islands. In many forests, slower-growing native tree species, with more dense timbers, are being replaced by fast-growing exotic invasive tree species, such as *Spathodea campanulata, Falcataria moluccana* and *Albizia chinensis*. It is not yet clear whether these changes in forest species composition will result in reduced or increased forest carbon stocks. At the present time we do not have enough data to know whether forest carbon stocks in the PICTs are increasing or decreasing overall, but given the extensive deforestation in PNG and Solomon Islands they are likely to have decreased over the past decade. More reliable and extensive forest carbon inventories are essential and are currently in progress in key countries such as PNG, Fiji, Vanuatu and Samoa, and need to be extended to all countries as soon as possible.

8.1.5 Components of vulnerability

The components of vulnerability of forests and trees to climate change include direct impacts (such as from increasing temperatures), changed rainfall regimes, extreme weather and tidal events (such as tropical cyclones), prolonged drought and king tides (which can briefly submerge entire atolls), interactions with flooding, erosion and fire and invasive species (pests, diseases and weeds) and impacts on beneficial associates (symbionts, dispersers, pollinators). The impacts of climate change on tree species and forest ecology have been well summed up by Saulei et al. (2012, p 79):

In response to such climatic impacts, tree species and forest communities may adopt a number of mechanisms to cope with the impacts by changing their phenology, physiology or behaviour, evolve, migrate or even becoming extinct. In the past, most species have responded to such changing climates by migrating to new areas and evolving over a longer period of time coinciding with suitable climates. However, the current rate of climatic change appears to be faster than the species' ability to evolve or migrate. Further, the changes in species composition would also alter interactions among different species in regard to the following interactions: predator – prey relations, changes in inter-species competition and changes in host-plant *relationships, creation of new habitats, or extinction of species in habitats which are no longer conducive for them to occupy may result in the invasion and spread of invasive species to occupy new niches that have been developed as a consequence of such changes.*

Trees, including woody shrubs and lianas (woody vines), are perennial, often long-lived organisms which, through their evolution, needed to be able to either endure climate change and extremes and/or survive in a soil seed bank in order to persist at a particular location. The majority of both angiosperm (flowering plants/hardwoods) and gymnosperm (or conifers/softwood) tree species have high levels of genetic diversity. Angiosperms typically have high levels of genetic diversity, including a high number of genes with considerable allelic variation, while gymnosperms have very large genomes, often with an order of magnitude more DNA than other organisms. This high genetic diversity that characterises tree populations and individuals, and associated stress tolerance and disease resistance mechanisms, partly explains their capacity to persist and thrive for long periods, and may bode well for their ability to cope with climate change and new climates (FAO 2014). However, an average 1.5^{o}C rise in mean temperature, projected for 2050 under RCP8.5, (Chapter 2) may have unforeseen impacts on the tree species of PICTs.

The climatic tolerance ranges for 57 economically important or promising tree species for PICTs, including those with important end uses (food, timber, multipurpose) and services (fixation of atmospheric nitrogen, beach protection, habitat provision, soil enrichment, and which have potential for carbon sequestration) are given in Table 8.5. Compared with tree species occurring on larger continental land masses, those species restricted to PICTs generally have smaller natural climatic tolerance ranges due to the moderating effects of a large ocean on temperatures on small islands. Accordingly the impact of increasing temperatures on these tree species may be expected or predicted to be greater than for more continental species, such as those that occur on the island of New Guinea or extend into continental Asia or Australia.

Table 8.5 Climatic tolerance ranges for economically important and/or promising tree species for the Pacific Islands.

Species and major uses/services	Mean annual temperature (°C)	Max. temp. hottest month (°C)	Min. temp. coldest month (°C)	Mean precipitation (mm)	Dry season duration* (months)	Source
Acacia auriculiformis (t,n,c)	20-30	25-37	6-22	800-2500	0-7	CABI 2013
Acacia crassicarpa (t,n,c)	23-26	32-34	12-21	1000-3500	3-8	CABI 2013; Thomson (unpublished)
Acacia mangium (t,n,c)	18-28	30-40	10-24	1000-4000	0-6	CABI 2013
Acacia mathuataensis (t,n,c)	24-26	29-31	20-22	1300-1700	1-3	Thomson (unpublished)
Acacia richii (t,n,c)	25-27	28-30	19-21	2000-3500	1-3	SPRIG 2003 (Thomson)
Acacia simplex (n,b)	25-28	28-36	19-25	2500-3500	0-4	Thomson (unpublished)
Acacia spirorbis (t,n,c)	22-25	27-30	15-22	800-2600	1-5	SPRIG 2003 (Thomson)
Agathis macrophylla (t,c)	24-28	27-31	17-23	1900-6000	0-1	Thomson 2006a; Thomson (unpublished)
Alphitonia zizyphoides (t,h,m,c)	24-26	29-32	17-24	1800-4000	0-2	Thomson and Thaman 2006
Bischofia javanica (t,m,c)	18-26	22-36	15-25	900-3500	0-6	CABI 2013
Calophyllum inophyllum (b,t,o,c)	18-33	22-37	12-17	1000-5000	0-5	Friday and Okano 2006/Thomson
Campnospermum brevipetiolatum (t,c)	23-28	28-34	20-24	2500-5000	0-2	SPRIG 2003 (Thomson and Uwamariya)
Canarium harveyi (f,o,t,c)	23-28	27-32	15-24	1800-4000	0-3	Thomson and Evans 2006/Thomson
Canarium indicum (fo,t,c)	25-28	29-32	17-24	1800-4000	0-1	Thomson and Evans 2006
Casuarina equisetifolia (b,t,n)	21-29	30-40	10-24	750-3500	0-6	CABI 2013; Thomson (unpublished)
Cordia subcordata (t,b)	24-28	28-36	13-25	1000-4000	0-8	SPRIG 2003 (Thomson and Uwamariya)
Corymbia citriodora (t,c,o)	17-28	28-39	8-22	650-2500	0-7	Booth and Pryor 1991
Dacrydium nausoriense and D. nidulum (t,c)	22-25	26-30	16-20	2000-3300	0-1	Thomson (unpublished)
Dalbergia cochinchinensis (t,h,c)	20-32	27-39	12-24	1200-1650	3-6	CABI 2013
Dracontomelon vitiense (t,f,c)	22-32	28-35	16-22	1800-4100	0-3	SPRIG 2003 (Thomson, Sam and Thaman)
Endospermum macrophyllum (t,c)	22-27	25-32	18-23	2100-3800	0-3	SPRIG 2003 (Thomson)
Endospermum medullosum (t,c)	22-28	29-32	15-24	1500-5600	0	Thomson 2006c
Endospermum robbieanum (t,c)	23-26	26-31	19-22	3000-3700	0-3	SPRIG 2003 (Thomson)
Eucalyptus biterranea (syn E. pellita) (t,h,c)	25-27	32-35	17-21	1200-2500	1-4	Thomson (unpublished)
Eucalyptus camaldulensis subsp. *simulata (t,h,c,o)*	22-27	32-36	7-15	550-1250	6-9	Thomson (unpublished)
Eucalyptus deglupta (t,c)	20-32	24-33	16-26	1200-5000	0-4	CABI 2013; Thomson (unpublished)
Eucalyptus urophylla (t,c)	18-28	20-34	8-22	700-2500	2-7	CABI 2013; Thomson (unpublished)
Flueggea flexuosa (t,h,c)	22-28	29-32	19-24	1800-4500	0-3	Thomson 2006d

Garuga floribunda (t,c)	21-26	24-29	18-23	1000-3500	0-4	CABI 2013
Gmelina arborea (t,c)	21-28	24-35	14-24	1000-4500	1-6	CABI 2013
Gmelina moluccana (t,c)	24-28	28-33	20-23	1800-5300	0	Thomson (unpublished)
Gmelina vitiensis (t,c)	25-27	30-33	18-22	1800-3500	0-1	Thomson (unpublished)
Gnetum gnemon (f)	22-30	32-36	14-22	750-5000	2-7	Manner and Elevitch 2006
Hibiscus tiliaceus (b,t)	12-32	24-41	5-24	900-2500	0-6	Elevitch and Thomson 2006
Inocarpus fagifer (f,c)	26-28	29-35	20-23	1500-4300	0-1	Pauku 2006
Intsia bijuga (t,m,n,c)	26-27	23-33	20-31	1500-2300	0-4	Thaman et al. 2006
Khaya senegalensis (t,c)	22-31	32-40	11-19	700-1750	2-8	CABI 2013
Melaleuca quinquenervia (o,c)	17-27	26-34	4-20	840-5080	0-7	CABI 2013
Morinda citrifolia (m)	20-35	32-38	5-18	250-4000	2-5	Nelson 2006; Thomson (unpublished)
Pandanus tectorius (b,t,f)	24-28	28-36	17-25	1500-4000	0-6	Thomson et al. 2006
Pometia pinnata (f,t,c)	22-28	25-32	18-24	1500-5000	1-3	Thomson and Thaman 2006a
Pinus caribaea (t)	20-27	28-34	8-23	660-4000	0-6	Booth and Jovanovic 2000
Pterocarpus indicus (t,c)	22-32	29-34	18-24	1300-4000	0-6	Thomson 2006d
Santalum album (t,o)	19-32	21-37	13-25	400-1700	6-7	CABI 2013
Santalum austrocaledonicum (t,o)	23-27	29-33	16-22	800-2500	2-5	Thomson 2006e
Santalum yasi (t,o)	23-29	24-31	18-25	1400-2500	2-5	Thomson 2006e
Schleinitzia insularum (b,n)	24-27	28-34	18-24	1500-3500	0-4	SPRIG 2003 (Thomson)
Schleinitzia novo-guineensis (t,n)	23-28	28-34	20-24	2000-5000	0	SPRIG 2003 (Thomson)
Swietenia humilis (t,c)	18-25	28-36	13-22	800-1200	0-6	CABI 2013
Swietenia macrophylla (t,c)	22-28	24-32	11-22	1400-4200	0-5	Booth and Jovanovic 2000; Thomson
Swietenia mahagoni (t,c)	16-32	23-38	11-17	1100-3300	0-4	ICRAF; Thomson; CABI 2013
Tectona grandis (t,c)	22-28	25-39	12-24	1200-1400	0-6	Booth and Jovanovic 2000
Terminalia brassii (t,c)	25-28	29-32	22-24	2500-4600	0	SPRIG 2003 (Thomson and Uwamariya)
Terminalia calamansanai (t,c)	18-30	28-35	20-24	1000-5000	0-7	CABI 2013
Terminalia catappa (b,t,f,c)	23-28	25-32	17-24	1000-4500	0-6	Thomson and Evans 2006
Terminalia kaernbachii (f,t,c)	25-28	30-33	21-23	2000-7000	0	Thomson (unpublished); Bourke 1996
Terminalia megalocarpa (f,t,c)	25-28	30-33	21-24	1500-4600	0-1	Thomson (unpublished)
Terminalia richii (t,c)	25-27	29-30	20-22	2100-5100	0-1	Thomson 2006b; Thomson (unpublished)

* consecutive months with < 40 mm .

key - t= timber/wood; f= food, o=oil, h=honey, m=medicinal, b= beach protection, n=nitrogen-fixing, c= carbon sequestration long-lived or long rotation species capable of sequestering large amounts of carbon.

8.1.6 Predicted changes in key climate variables for Pacific Island' forests and trees

The Pacific Climate Futures project (www.pacificclimatefutures.net) enables projections to be made for different countries created with a variety of models, and provides an idea of the level of uncertainty that exists with current climate change predictions. Temperature and precipitation are the two main climate drivers which will impact on species composition and forest cover. Impacts can range from extreme disturbances such as prolonged drought and associated forest fires or pest outbreaks, to more subtle increases in temperature affecting physiological processes. The ability of tree species to survive climate change will depend on the capacity to quickly adapt to the new conditions at the existing site, manage the changing conditions through a high degree of phenotypic plasticity without any genetic change, and/or migrate to an environment with the desired conditions for that species (FAO 2014). There are predictions that unprecedented climates will occur earliest in the tropics; this is because tropical areas have a stable climate compared with more temperate regions, such that relatively small increases in temperature are capable of exceeding historical variability (Mora et al. 2013). Accordingly, tree species adapted to relatively stable and consistent tropical climates, such as those found in many PICTs, are likely to be more at risk from projected temperature increases and new climate regimes than trees which have evolved in more variable continental climates.

A greater intensity of tropical cyclones, extreme drought, fires, flooding and landslides has been observed in tropical forest ecosystems that have experienced increased temperatures and more frequent and extreme El Niño–Southern Oscillation (ENSO) events (IPCC 2013). As discussed in Chapter 2, climate change will also affect the storm patterns in PICTs and the associated climatic disturbance regimes which drive forest dynamics, with some authorities predicting increasing dieback of parts of moist tropical forests, including in PICTs, which would exacerbate global warming (Mueller-Dombois and Fosberg 1998). It is clear from the evidence to date that changes in the climate are already having an impact on forests throughout the world, including PICTs. Of particular concern is the upward retreat of montane cloud forests due to global warming, the resultant upward movement of the 'dew line' and the associated loss of biodiversity, 'hidden rain' and hydrologic regulation provided by cloud forest, which is the tropical island equivalent of the retreat of glaciers in higher latitudes (Thaman 2013). Also of concern is the degradation of riparian forest, which is critically important for reduced river, stream or lakeside erosion and for maintaining habitat and spawning and nursery areas for freshwater fish and other organisms. Current and future climate change impacts on forests will vary from abrupt negative impacts to more subtle negative and positive impacts that arise in some regions or at particular sites, often only for certain tree species. There is an urgent need for countries to be assisted to cope and deal with impacts of climate change on forest genetic resources and to promote and use diversity within and among tree species to help with climate change adaptation and mitigation (FAO 2014).

8.1.7 Summary

In the future sustainable production of goods and delivery of ecosystem services from PICTs' forests will be increasingly challenged by the predicted negatively synergistic impacts of climate change, extreme events, invasive species and environmental degradation and economic downturns[10]. Weather events critical to forests and forestry, such as tropical cyclones[11] and droughts, will probably be more intense, as will extremes in rainfall and associated landslips and flooding and drought-associated fires. There will also be interactions of climate change with existing and new pests, diseases and invasive weeds, and on pollinators and dispersers, the negative synergies of which will impact on production, natural selection and future forest composition. In the more species-rich native forests the genetic diversity contained within and among tree species will provide an essential buffering against these impacts on productive and service functions, while planted forests and agroforests will need to comprise several species or provenances of a given species in order to spread risks and build resilience against climate and environmental change.

The impact of CO_2 fertilisation on the growth rates of tropical forests is unclear and may vary between sites (Beedlow et al. 2004; Feeley et al. 2007; Kricher 2011; Cox et al. 2013; Clark et al. 2013). In the absence of other climate change impacts on net rates of carbon assimilation (such as rising temperatures, drought, reduced solar radiation/ increased cloud cover) an increase in atmospheric CO_2 concentrations ought to result in increased growth rates and carbon sequestration. However, trees may not be able to make use of the increased CO_2 if their growth is already being limited or approaching limitations by other plant nutrients, as is often the case in infertile, acidic tropical soils. In some parts of the PICTs, forest carbon sequestration rates will likely decline due to increased climate stress (especially from increased temperatures), while carbon stocks will increase in areas which revert from grassland or scrub to forest due to increased rainfall (and reduced firing) and deliberate reforestation programs. Ongoing research is needed in different forests to document changes in carbon sequestration rates and the extent to which such changes are related to climate change and rising CO_2 levels.

8.2 Vulnerabilities of different types of native forests to climate change

8.2.1 Mangroves

Mangrove forests are differentially distributed throughout PICTs, being most extensive in Melanesia. The most extensive areas of mangroves and highest species diversity on earth are found in PNG which has a total area of 592,900 ha (Shearman et

10 Economic downturns have the potential to decrease the capacity of global institutions, corporates and conservation NGOs to make payments for ecosystem services to the communities who are involved in protecting forests.

11 Notwithstanding that IPCC (2013) indicates uncertainty about the link between human-induced climate change and tropical cyclone activity (e.g. low confidence in early 21st century changes though 'more likely than not in western North Pacific in late 21st century). Most recently Emanuel (2013) has predicted that the frequency and intensity of cyclones will increase during the 21st century in all tropical ocean regions, with the exception of the southwestern Pacific.

al. 2010) and 33 species (Ellison 1997). Mangrove tree species richness decreases both eastwards through the Pacific, in the Solomon Islands (19 spp.), Vanuatu (11 spp.), Fiji (7–8 spp.) and American Samoa (3 spp.), and northwards to Kiribati and Marshall Islands (3–4 spp.) (Woodroffe 1987; Aga and Moorhead 2011; Natake and Moorhead 2011; Kusto 2011).

Mangroves develop in intertidal zones, between mean sea level and the highest tides, and along estuaries, especially on finer-textured sediments (clays, silts, silty clays, sandy clays). They require locations, especially protected coastlines, where wave action and currents are not too strong to prevent seedling establishment, such as tidal flats, estuaries, sheltered bays and in the lee of offshore islands and some coral reefs, and rarely develop where exposed to the open ocean (Lear and Turner 1977). Mangroves are amongst the most productive ecosystems on earth, acting as sites for marine food organisms (crabs, prawns, lobsters, molluscs and fish) and as breeding grounds and nurseries for pelagic and other fish and prawns. They play vital roles in coastal protection and sediment stabilisation, and also sequester proportionally large amounts of carbon. For example, in the Federated States of Micronesia (FSM) mangroves comprise 12% of vegetation cover, but store 34% of the carbon held in vegetation (Falanruw and Moorhead 2011). Being on the boundary between land and sea, mangroves are considered to be more impacted by climate change than most other forest communities and some of the first ecosystems to undergo spatial modification due to sea-level rise (Shearman 2010). Mangroves are directly affected by damaging storm surges associated with more intense cyclones, but with generally good opportunity to fully recover ecosystem function within 1–2 years. Under scenarios of gradual sea-level rise, mangroves and/or more salt-tolerant mangrove associates, such as *Barringtonia asiatica, Hibiscus tiliaceus, Heritiera littoralis, Intsia bijuga, Pongamia pinnata* and *Thespesia populnea*, are likely to be able to adapt reasonably well to rising sea levels and increase in area on landward sides of current distribution[12] .

A comprehensive assessment of mangrove cover in the Gulf province of PNG between 1973 and 2007 detected substantial changes in mangrove distribution but only a slight net loss of mangroves (992 ha from 260,822 ha or 0.4%) (Shearman 2010); although an increase in mangrove forest on the landward side may have compensated for these small losses. The observed trend in mangrove decline was ascribed to various possible factors such as tectonic subsidence, change in sediment supply and sea-level rise, and was predicted to accelerate due to climate change induced sea-level rise in coming decades (Shearman 2010). In other parts of the Pacific mangrove decline is being exacerbated by coastal reclamation, coastal structures and degradation of the water table. Fiji has the third largest mangrove area (425 km^2) in PICTs mainly on the northwest and southeast seashores of Viti Levu and the northern shore of Vanua Levu (Ellison 2010). Mangroves are expected to suffer disruption and retreat in Fiji mainly due to sea-level rise, with low-relief islands of mangroves remote from rivers most threatened, and exacerbated in places by local subsidence (Ellison 2010).

12 This may occur in coastal locations being impacted by king tides and storm surges, which may kill tree species less well adapted to substrate salinity especially when coupled with anoxia.

The author notes that prospective new mangrove habitats in Fiji are already mostly developed and the net effect of climate change will be a loss of mangroves in Fiji. Over the next 20–40 years there is a considerable risk of rising saline groundwater causing widespread mortality in *Bruguiera* and *Lumnitzera* mangroves as has already happened on a small scale in Solomon Islands (Basil Gua pers. comm.).

Conversely, mangrove species are the most likely to adapt to and provide protection against climate change, especially those adapted to more extreme and variable habitats. These include the widely adapted and pioneering mangroves *Avicennia marina* and *Rhizophora mangle* as well as more hardy species such as *Excoecaria agallocha*. Salt-tolerant mangrove communities may be expected to replace low elevation coastal forests, firstly freshwater and brackish estuarine communities (including *Barringtonia racemosa* and *Nypa fruticans*), and then swamp forests. These processes will occur over timescales of decades, and only in locations where tidal and sedimentation patterns permit and favour mangrove establishment.

8.2.2 Coastal and atoll forests

Throughout PICTs, coastal forests and associated beaches will be increasingly degraded by climate change and by ENSO extremes. Coastal forests are vulnerable to high sea-state events, both from increased storm surges and high waves and from damaging salt-laden winds associated with more intense cyclones, ENSO events, spring tides, and sea-level rise, particularly where the combination of these events increasingly results in higher and more frequent king tides moving further inland or completely submerging low-lying atolls. Coastal forests will also be progressively impacted by the more gradual sea-level rise. Perhaps just as concerning is accelerated coastal erosion and loss of beaches, which reinforces the loss of coastal littoral forest. Trees and shrubs are vital for coastal protection on open sea and sandy beaches. In such situations trees such as *Hibiscus tiliaceus* (Chatenoux and Peduzzi 2007) and shrubs of *Scaevola taccada* and *Pemphis acidula* helped dissipate the 2004 Indian Ocean tsunami force (UNEP 2005). Furthermore, almost all coastal trees and palms have local uses as food, medicines, cultural products and wood. Examples include *Cocos nucifera* (myriad uses including food, edible oil and drinking nuts), *Cordia subcordata* and *Thespesia populnea* (premier carving woods, medicine), *Terminalia catappa* and *T. littoralis* (nuts, bark for medicine, timber), *Calophyllum inophyllum* (tamanu oil, timber, carving) and *Pandanus tectorius* (food, thatch and building timber on atolls) (Thaman 1990, 1992a,b; Thaman 2013; Thaman and Whistler 1996).

The majority of near-coastal/strandline tree and shrub species have a degree of tolerance to both sea-salt spray and salinity in the root zone, but salt tolerance varies depending on species and the type of salt stress. Most tree and shrub species growing close to the seashore are likely to be classified as salt tolerant non-halophytes whose tolerance mechanisms involve restricting the movement of salt (mainly sodium chloride) into the shoot through both passive (morphological) and active (oxygen-requiring) means (Thomson 1988). The majority of breadfruit cultivars are highly susceptible to even short periods of sea-water inundation and have been observed to be killed by a single king tide event in Kiribati (see Chapter 4 for discussion on genotypic variation in salinity tolerance). Coconuts are much more resistant to sea-water inundation on such short timescales as king tide events or tsunamis. However, established mature coconut palms are killed by shallow inundation or sea-waterlogging, as observed on the island of Pangaimotu in Tonga and elsewhere where sea levels have apparently already risen or where freshwater lenses have been depleted. Coconuts are also vulnerable to rising sea levels coupled with wave action which can wash away the sand/soil from around their root ball and cause them to topple over. More extensive coverage on the vulnerability and impacts of climate change on breadfruit and coconut is given in Chapters 4 and 5.

Photo: Lex Thomson (l) John Bennett (r)

Breadfruit cultivars are highly susceptible to even short periods of sea-water inundation and have been observed to be killed by a single king tide event in Kiribati (with Ms Kinaii Kairo, Head of Agriculture) (l). Coconuts are also vulnerable to rising sea levels coupled with wave action, which can wash away the sand/soil from around their root ball and cause them to topple over (r).

8.2.3 Swamp and riparian forest

In the islands of the western Pacific, low elevation swamp forests, riparian forest and vegetation have important economic and ecological functions. Climate-induced rises in sea level and more frequent sea-water incursions threaten lower elevation swamp forests (i.e. those below 2–3 m above sea level). These include some sago palm swamps, such as the threatened sago (*Metroxylon vitiense*) in Fiji, *Terminalia brassii-Campnosperma brevipetiolata-Syzigium tierneyanum* swamp forests in PNG and Solomon Islands and *Terminalia carolinensis-Horsfieldia nunu* swamp forests in Kosrae (FSM). An economically important component of swamp forest and lower riparian forest in Fiji, Vanuatu and other areas in the Pacific is Tahitian chestnut (*Inocarpus fagifer*), an important seasonal cash crop and minor staple food. In parts of PNG and Solomon Islands, sago palms are important as a food staple providing both starch and sago palm grubs; sago palms also provide roofing thatch in Melanesia (PNG, Solomon Islands and Fiji). Many swamp forest species, including *Campnosperma brevipetiolata*, *Horsfieldia nunu*, *Terminalia brassi* and *T. carolinensis* are valued timber species both locally and for export; for example, *S. tierneyanum* and *T. brassii* from Solomon Islands for export to China. In Solomon Islands, swamp forests with substantial commercial timbers have already been penetrated by strong waves, allowing saltwater incursion and causing widespread tree death (Basil Gua pers. comm.). Such observations confirm the real threat to the Solomon Islands native timber industry posed by climate change, specifically sea-level rise superimposed on other extreme events such as storm surges, king tides or ENSO events.

As indicated above, riparian forests are also critical to protecting and providing important ecosystem services in the face of climate change and the loss of biodiversity. Riparian forests provide important ecosystem services such as erosion control, water purification, and the provision of habitat and spawning and nursery areas for freshwater fish and other threatened freshwater diversity. Logging within and felling into riparian 'buffer zones', agricultural clearance of riparian vegetation and other reclamation have seriously undermined the ability of riparian forests to continue to provide goods and services and protection against extreme weather events.

8.2.4 Lowland, moist tropical forests

The most extensive, economically important and biodiverse forests are the lowland, moist tropical forests (or rainforests) in Melanesia; notably in PNG and Solomon Islands, but also in Fiji and Vanuatu and further west in Polynesia (Niue and Samoa). Due to the species-richness of such forest types, at least in the western Pacific, there is a high level of ecological redundancy such that in an otherwise undisturbed state they would be expected to adapt reasonably well, at a functional and environmental services level, to moderate climate change. High levels of tree species diversity increase the likelihood that one or more of several species will have features to suit changing climatic conditions. However, many of these forests have been commercially heavily logged over several decades. In Fiji, Samoa and Vanuatu, lowland tropical forests are effectively now commercially exhausted and are rapidly approaching exhaustion in Solomon Islands, but they are still in comparative abundance in PNG and almost untouched in Niue (due to small resources, remoteness, high logging/transport costs and a previous conservation commitment). Despite the promotion of sustainable logging practices by national governments, SPC, FAO, AusAID, GIZ (Germany) and other donor agencies, lowland tropical forests have, for the most part, been exploited in an unsustainable manner and sometimes illegally in PNG and Solomon Islands, with harvesting conducted to maximise immediate returns and with minor regards to advanced growth, future regeneration and later harvests. Too often, Melanesian rainforests have been opened up to invasive species, including smothering by vines, which results in an arrested succession and/or favours regeneration of short-lived pioneers and so-called increaser species which are less valued timber species. Such logged-over forests, if located in cyclone-prone regions, are highly susceptible to further damage by cyclonic winds, which are projected to intensify (Chapter 2). A particularly instructive example of the damaging interaction of heavy logging and cyclones is provided in Samoa where intensive harvesting, coupled with clearing for commercial taro plots, was followed by the destructive Category 5 cyclones Val and Ofa in the early 1990s, resulting in the development of open, low-quality, secondary forest draped in *Meremmia* vines. The same response was seen after a destructive cyclone in Vanuatu in the early 2000s. Of serious concern in lowland forests, including secondary and agroforests, is the rapid spread of African tulip (*Spathodea campanulata*), an invasive tree species that has replaced many culturally important indigenous fallow trees, and the removal of which is conservatively estimated here to have already cost the Pacific forestry sector and farmers tens of millions of dollars.

8.2.5 Wet/dry tropical forests and woodlands

Wet/dry tropical forests and woodlands (10–30% canopy cover) are widespread vegetation associations, especially on the leeward sides of larger islands. They are typically found in areas with less than 2000 mm annual rainfall that have a pronounced dry season. Drier forest types are vulnerable to climate change, mainly indirectly from increased wildfire associated with more intense El Niño events and associated droughts, but also from physiological shocks to forests (Mueller-Dombois and Fosberg 1998). Increased rainfall will likely promote increased fuel loads among ground vegetation such that dry-season fires may burn more intensely and spread further and more rapidly. Drought caused by El Niño in the region is serious and common, with El Niño conditions occurring every two to seven years, and lasting for between 12 and 18 months (OCHA 2012). In an FAO forestry report (FAO 2010), Oceania also reported a net loss of forests (about 700,000 ha per year over the period 2000–2010), mainly due to large losses of forests in Australia, where severe drought and forest fires have exacerbated the loss of forests since 2000[13]. In 1997 and 1998, droughts associated with El Niño conditions affected most PICTs, with Fiji and PNG being severely affected (OCHA 2012). Both countries experienced considerably increased fire activity during this period, with damage to forests and loss of forest cover. Fires also occurred elsewhere, for example, damaging newly established coastal forest plantings on Ha'apai, Tonga. Fires were also considered the main threat to the success of coastal littoral reforestation on the main island of Tongatapu in the 1990s (Thaman et al. 1995, 2011). It is predicted that forest fire activity could increase as a result of climate change and will continue to damage more forests given that these countries have limited capacity to contain and suppress fire. In order to minimise damage and reduce risks from uncontrolled fire, new forest plantations and agroforests in dry and intermediate rainfall zones will need to incorporate a higher proportion of fire tolerant species, such as *Bischofia javanica*, *Casuarina equisetifolia* and teak.

13 It is unclear whether the mapped losses in forest cover in Australia due to drought and fire are permanent.

8.2.6 Montane rainforests, including cloud forests

Montane rainforests, of lower stature and rich in epiphytes, are found on moist hilltops and mountain slopes of more recent volcanic origin, including PNG, Solomon Islands, Samoa and French Polynesia (Mueller-Dombois and Fosberg 1998). At higher altitudes montane rainforests are displaced by a low canopy, small-leaved forest frequently shrouded in cloud or fog and often referred to as cloud forest. Atherton (2013) has assessed the impact of predicted climate change on forest types and tree species in Samoa and found that by 2090 there is potential for montane forest to move upslope to higher elevations on Savai'i due to an increased temperature and rainfall regime, but it could be diminished on Upolu due to loss of suitable habitat to colonise. Cloud forests are likely to be reduced in area due to increased temperatures and competition from montane forest species, and may disappear completely from Upolu. Whilst most native Samoan tree species are considered to have a high capacity to adapt to future climate change, three montane/cloud forest species, viz *Dysoxylum huntii*, *Reynoldsia lanutoensis*, and *Reynoldsia pleiosperma*, were considered to have a low to medium capacity to adapt (Atherton 2013).

As mentioned above, with predicted increases in temperature (Chapter 2), altitudinal vegetation patterns will shift upwards such that certain montane rainforests and cloud forests will contract or disappear altogether. These vegetation changes are unlikely to have any major immediate or medium-term economic impacts, with most ecosystem service functions of these areas being maintained. The noted exception is a major impact on biodiversity conservation due to loss of whole ecosystems and associated endemic species. Also of concern is the possible negative hydrologic impact of the upward retreat of cloud forest and the associated loss of the ability of such forests to absorb moisture from the clouds and equitably distribute this 'hidden rain' throughout the year to watersheds below, thus exacerbating the impact of drought at lower elevations (Thaman 2013).

8.3 Vulnerabilities of tree species – in planted forests including agroforests

The following section discusses the vulnerability of individual and groups of forest tree species which are important planted species in PICTs. The focus is on those genera/species with the greater potential to adapt to projected new climates and includes species/genera with the highest potential for carbon sequestration[14]. Information has also been provided on selected tree genera/species that are likely to be most vulnerable to climate change. The range for key climatic variables, based largely on natural distribution for these species is given in Table 8.5.

14 This takes into account that considerable areas of grassland in PNG, Solomon Islands and Fiji (e.g. 300,000 ha) are now being actively targeted by government programmes, the private sector and donors for reforestation.

8.3.1 *Acacia*

Tropical *Acacia* species are distributed throughout the PICTs and together with *Casuarina* constitute some of the most important and useful nitrogen-fixing pioneer and successional species. Acacias are used for provision of building timbers and fuelwood. *Acacia crassicarpa* (northern red wattle) and *A. mangium* (mangium), originating from PNG and north Queensland, are extremely fast-growing (e.g. early height growth rates of 5–7 m per year and woody biomass of 25–40 m^3 per ha per year) and widely planted in the tropics for pulpwood and timber. However, both of these *Acacia* species are highly susceptible to stem breakage and wind throw during cyclones and should generally be avoided for timber plantations in cyclone-prone regions, especially given predicted increase in the more intense categories. Both of these species are ideal for re-establishing rainforest successions on degraded grasslands and carbon sequestration, and PICTs have a comparative advantage in that they are free from several diseases of *Acacia* such as *Ceratocystis* spp., which are emerging in the main plantation areas in Asia (Tarigan et al. 2010).

Acacia auriculiformis (earpod wattle) is extremely well adapted to variable rainfall, growing most rapidly in wet areas with rainfall of > 2000 mm per annum (early height growth of 4–5 m per year and woody biomass of 17–25 m^3 per ha per year), and capable of growing in areas with low rainfall, down to 800 mm per annum, and tolerating drought once established. Trials in southeast Viti Levu have demonstrated that certain forms of *A. auriculiformis* have excellent bole form and wind resistance, such as those originating from Oriomo River (PNG) and north Queensland, and are well suited to inclusion in mixed species agroforestry systems throughout PICTs. Weediness has been suggested as problematic for some *Acacia* species: in PICTs, natural *Acacia* regeneration will principally occur following fire and in such situations a quick recovery of plant cover, followed by build-up of carbon and nitrogen in soil is desirable. Native South Pacific Island *Acacia* species such as *A. spirorbis* (gaiac; Vanuatu and New Caledonia), *A. richii* (qumu) and *A. mathuataensi*s (*Macuata tatagia*) from Fiji; and *A. simplex* (tatagia; a widespread strandline species) are expected to have wide climatic adaptability and be reasonably well pre-adapted to new climates, including higher temperatures and variable rainfall, in the areas where they are now found. PICTs' acacias should be incorporated to a greater extent into agroforestry systems in their native areas, in order to provide wood and nitrogen inputs. Additionally, these *Acacia* species are also ideal hosts for sandalwood. *A. simplex*, a common salt-tolerant coastal littoral species from Samoa and Tonga in the east through Fiji to Vanuatu and New Caledonia in the west, offers considerable potential for deliberate planting in beach and coastal forest enrichment programmes for adaptation to climate change and increased coastal erosion.

8.3.2 *Alphitonia zizyphoides* (toi, doi)

A. zizyphoides is an under-used multipurpose tree species for planting in the Pacific Islands, both in agroforestry and mixed planted forests. In more closed situations the trees have good self-pruning character and the fallen twigs/branches are excellent firewood. The timber has good technical properties and is a high quality fuelwood. The bark is widely used in traditional medicine, and in Niue bees foraging on *Alphitonia* blossoms have been observed to produce excellent honey flows (Api Taliu pers. comm.). The tree grows quickly with an estimated growth rate of 12–16 m^3 per ha per year (Thomson and Thaman 2006) and has demonstrated exceptional cyclone resistance in Vanuatu and Samoa. *A. zizyphoides* is considered to have low vulnerability to predicted climate change. In drier locations that are marginal for its survival and growth (< 1800 mm annual rainfall), only more drought-tolerant populations, such as those from the Nadi hinterland (Fiji), should be used as seed sources for new plantings.

8.3.3 *Bischofia javanica* (Java cedar, koka)

Koka is another promising, highly resilient, multipurpose, easy-to-propagate agroforestry tree for planting in lowland, humid and dry sites, including riparian sites. The tree has a wide climatic envelope and grows rapidly in favourable environments with a reported growth rate of 13–22 m^3 per ha per year (CABI 2013). It is widely planted in agroforestry systems for the production of moderately durable posts and poles, firewood, the main dye for tapa cloth, trellising for yams, wind protection and soil improvement. Koka is a favoured tree in Tonga, Fiji and Vanuatu when clearing land for shifting agricultural systems, where it shows strong resilience to the repeated burning, a characteristic feature of the local shifting agricultural systems. It is widely planted as a windbreak and street tree in Okinawa, Taiwan and Hong Kong because of its renowned resistance to recurrent typhoons. It is also considered an important riparian species that offers promise for riverside planting to reduce erosion and sedimentation of rivers, lagoons and reefs, which will probably intensify with climate change. Studies after Cyclone Isaac in Tonga in 1982 showed that koka was virtually unaffected by Category 4 winds, salt spray and extensive saltwater incursion in the capital, Nuku'alofa (Thaman 1982). Most agroforestry plantings of koka, such as those in Fiji, Tonga, Samoa and Vanuatu, would not be affected by sea-level rise. The species is generally considered to have a low vulnerability to predicted climate change, including increased temperatures and altered rainfall regimes, with the caveat that the species should not be planted in lower rainfall areas, that is, less than about 2000 mm annual rainfall and/or more than three months dry season (Thaman 1993a,b; Thaman 2002).

8.3.4 *Calophyllum inophyllum* (Alexandrian laurel, beach calophyllum, tamanu, dilo, hefau, fetau, fet'a'u, te itai)

Beach calophyllum occurs throughout PICTs, principally growing on beaches and in low elevation riverine locations. In more fertile, rocky and sandy beach locations, such as on Rotuma in Fiji, it grows into a massive, long-lived tree. It produces a beautifully marked timber with excellent technical properties, but the trees are usually only used for timber when they die or fall over, as they are more valuable alive, being vital for coastal protection and shade. They also produce copious nuts, which yield a valuable pressed oil for cosmetic and medicinal uses. All around the Pacific, beach calophyllum trees will be on the front line of climate change, and few tree species are better adapted to cope with gradual climate change and extreme events by protecting rocky coast lines and inland areas from erosion, wind damage and salt spray. The tree has an exceptionally broad climatic range as indicated by wide amplitude in key bioclimatic factors (Table 8.5). Beach calophyllum trees survive up to Category 3 cyclones with minimal damage, but at higher categories trees may lose small and large branches (Calvert 2011).

Photo: Lex Thomson

Calophyllum inophyllum – In more fertile, rocky and sandy beach locations, such as on Rotuma in Fiji, it grows into a massive, long-lived tree.

They may also be uprooted on beaches through sand removal and extreme storm surge generated by the most intense cyclones, but are less prone to uprooting than coconuts in such situations; and even bare rooted beach calophyllum trees with broken limbs and stripped of bark recover rapidly (Calvert 2011). In assessments after the 2009 tsunami in Samoa, calophyllum trees were found, along with *Manilkara dissecta* and *Bruguiera* mangroves, to be almost unmovable and unscathed by the massive tsunami waves that reached over 10 m high and destroyed most other vegetation and infrastructure (Dominey-Howes and Thaman 2009). In the smaller, especially low-lying islands, *C. inophyllum* ought to be a major candidate for carbon sequestration plantations, and should be established at wider spacing, such as 100 trees per hectare, to enable full canopy development and maximise tree health and nut yield for oil production.

8.3.5 *Canarium*

Canarium almond trees (galip nut, nanggai, kaunicina, 'ai) including *Canarium indicum* and *C. salomonense* (both native to PNG, Solomon Islands and Vanuatu) and *Canarium harveyi* (widespread in Melanesia and Polynesia) are excellent trees for wider forestry, horticultural and agroforestry plantings. Mature trees are exceptionally cyclone-resistant — loss of both small and larger limbs during more severe cyclones acts as natural pruning (Thomson and Evans 2006a) and induces heavier fruiting in subsequent years once the canopy has recovered. In the case of *C. harveyi*, trees completely defoliated by a cyclone[15] on Vava'u, Tonga were observed to refoliate and initiate flowering within four weeks. The same vigorous and early floral regrowth, followed by fruiting about eight months later, has been observed in *C. indicum* after cyclone damage[16] in South Santo, Vanuatu (Thomson and Evans 2006a). *Canarium* nut trees are well adapted to continue to grow vigorously and produce heavy nut crops under medium-term climate change predictions, including warmer temperatures and more intense cyclones. However, planting at the lower rainfall end (< 1800 mm per year) of *Canarium's* climate envelope is best avoided, as higher temperatures coupled with high solar radiation levels and prolonged drought will increasingly pose greater risks of water stress. Department of Forestry/SPRIG[17] field trials on Kolombangara, Solomon Islands have demonstrated that *C. indicum* can grow surprisingly fast in open conditions, fruiting heavily at 3–4 years, and earlier than previously thought. Given their development of a large woody biomass and longevity (more than 100 years), *Canarium* trees are also ideal for carbon sequestration projects.

Photo: Lex Thomson

Canarium harveyi trees completely defoliated by a Cyclone Waka on Vava'u, Tonga were observed to refoliate and initiate flowering within four weeks.

15 Cyclone Waka on 31/12/2002 with winds of 185–260 km per hour.
16 Cyclone Dani on 19/1/1999 with winds around 150 km per hour.
17 SPRIG — the AusAID-funded South Pacific Regional Initiative on Forest Genetic Resources.

8.3.6 Casuarinaceae (*Casuarina equisetifolia* and *Gymnostoma species*)

The more common, normally coastal casuarina and the more inland, often endemic *Gymnostoma* spp. constitute one of the most important groups of fast-growing, multipurpose, nitrogen-fixing trees for protecting coastlines, rejuvenating degraded soils and providing timber and firewood. *C. equisetifolia* (casuarina, beach she-oak, nokonoko, toa) is a common shore-line tree species in the western Pacific and tropical Asia. A highly genetically distinctive form, with totally different isozyme patterns (Gavin Moran pers. comm), is present in the eastern part of its range, in Fiji and Tonga: this form has evolved a capacity to regenerate and colonise upland, drought-prone degraded sites, including regularly fired grasslands, such as Fiji's talasiga grasslands. *C. equisetifolia* has a wide climatic range and is exceptionally well adapted to cope with future climate change. This species grows rapidly (e.g. 4.4 m tall in Fiji at age two years) (Bell et al. 1983), and ought to be much more widely grown in agroforestry systems to provide nitrogen inputs and for production of fuelwood and very hard, dense building timbers. It is an excellent windbreak, with the semi-permeable canopy slowing and dissipating the energy of strong winds, and ideal for protecting crops and fruit trees. Beach she-oak is also one of the best hosts for sandalwood which can be planted right next to the base of *Casuarina* plants. Sandalwood saplings and trees growing up through the canopy of beach she-oak are afforded some protection during cyclones, especially less severe cyclones.

In March 1983 Cyclone Oscar (Category 3) caused little or no damage to *C. equisetifolia* in western Fiji (Bell et al. 1983), while in Tonga introduced seed sources of *C. equisetifolia* were observed to be more susceptible to wind damage during cyclones than the local seed sources (Tevita Faka'osi pers. comm.). In northern Australia, *C. equisetifolia* trees have been badly damaged, through branch breakage, during cyclonic winds at and exceeding Category 2 but recover quickly (Calvert 2011). Similar observations have been made in Mauritius where *C. equisetifolia* trees were windfirm in places but badly damaged near the eye of two severe cyclones, Alix and Carol (with winds of 200–240 km per hour) in February and March 1960 (Brouard 1960; Sauer 1962). However, after a recent destructive tropical cyclone in Tonga, lines of *Casuarina* planted as part of a coastal protection project to protect coastal farming areas from wind and salt spray showed little damage other than minimal crown snapping (Thaman,1995; 2011). Beach she-oak is exceptionally tolerant of salt-laden winds and short-term salt inundation such as from storm surges and king tides, but is killed by longer-term sea or brackish water inundation or waterlogging. Its tolerance to fire is generally considered to be low and it is frequently recorded as intolerant of fire or highly sensitive to burning (NRC 1984; Mueller-Dombois and Fosberg 1988; Whistler and Elevitch 2006) but the upland form in Fiji tolerates low to moderate intensity burns. In western Viti Levu trees recover after being burnt by fire, producing many sprouts along branches and main stems (Tevita Evo pers. comm.). The species has been reported as susceptible to extended periods of low rainfall, with widespread drought-related tree death being observed in India and the Dominican Republic (Gupta 1956; Knudson et al. 1988). Accordingly when planting in lower rainfall zones, care should be taken to use local and/or more drought tolerant provenances of *C. equisetifolia*, such as those from western Viti Levu, Fiji. The deliberate plantings of some 20,000 trees along two kilometres of coastline in the Houma blowholes area of Tonga have shown that *Casuarina* is one of the most important candidates for planting as windbreaks to protect inland garden lands and villages from winds and salt spray (Thaman,1995; Thaman et al. 2011).

Photos: Lex Thomson

Gymnostoma vitiensis (dark green bushy trees) *Casuarina equisetifolia* (tall, sparse trees) growing at Laulau, Naitasiri, Fiji. *Gymnostoma* is better adapted to this inland, high rainfall location, with the *Casuarina* appearing off-site (l). *Casuarina equisetifolia* is well suited to seaside plantings, and can survive occasional seawater inundation in well aerated soils, Tarawa, Kiribati (r).

The easy-to-grow *Casuarina oligodon* (yar) has been deliberately planted in highly populated, degraded areas of PNG since about 500 AD as an adaptation to overpopulation, soil degradation and the need for timber and firewood, with intensification of *Casuarin*a-dominated fallows over the past 150 years (Bourke 1997). The more inland, often endemic, casuarina-like *Gymnostoma* are found growing from sea level to highland PNG, from Malesia (including the islands of Indonesia, Philippines, PNG) to northern Australia, New Caledonia (where there are reportedly eight species; Jaffré et al. 1994) and Fiji, where its native generic range ends with the endemic *G. vitiensis* (velau). In Fiji, *G. vitiensi*s is one of the most commonly regenerating trees in fallow garden areas, and is an important timber and one of the most highly desired fuelwoods. It is easy to propagate from seed and has been one of the main species distributed as part of the 2010–11 Fiji Plant a Million Trees campaign and the associated USP Plant One Thousand Trees campaign (Thaman et al. 2012a). *Gymnostoma* species are considered to be among the more promising species for inclusion in intensified agroforestry systems to address the future negative impacts of climate change, declining soil fertility, firewood and timber shortages.

8.3.7 Conifers (native genera)

The native conifers of PICTs, in the family *Podocarpaceae* (podocarps), include many valuable timber species such as *Agathis, Araucaria, Dacrycarpus* and *Retropyllum* (syn. *Decussocarpus*). In general these species are considered to be at low risk from climate change. Faster-growing, broadly adapted coniferous genera and species warrant greater planting both in timber plantations and agroforests. The exceptions are species and populations which have adapted to grow in narrower ecological zones, especially more montane forests, such as the threatened and slow-growing *Dacrydium nausoriense* (highlands yaka) in Fiji. Podocarps with imbricate, scale-like foliage such as *Dacrydium* species may have already been 'cornered' in terms of their ecological limits, being unable to compete or co-exist with productive canopy-forming angiosperms in the humid tropics (Biffin et al. 2011). Accordingly, they are at risk of extinction from higher temperatures, especially if coupled with an increase in precipitation.

The impacts of more climatic extreme events on conifers, such as water stress (associated with extended drought and higher temperatures) and more intense cyclones, are discussed below. Water stress, arising from extended drought or below average rainfall, and coupled with higher temperatures, is a major predicted impact of climate change in PICTs. Approximately 70% of all plant species operate with narrow hydraulic safety margins against damaging levels of drought stress and therefore potentially face long-term reductions in productivity and survival if temperatures and aridity increase as predicted for many regions across the globe (Choat et al. 2012). *Gymnosperms* (conifers) are more tolerant of drought than angiosperms (flowering plants): this is likely due to a different xylem structure and an associated ability to survive lower conductivities (Choat et al. 2012). Accordingly, Pacific conifers are expected to be better able to tolerate droughts coupled with higher temperatures, and contribute to their greater longevity, compared with angiosperms. Moreover, gymnosperms evolved during a time when global atmospheric CO_2 concentrations were higher than at present (Lammertsma et al. 2011) and their leaf morphology and photosynthetic architecture may be comparatively better adapted to higher CO_2 environments than angiosperms.

8.3.8 *Agathis* species (kauri) and *Araucaria columnaris*

Agathis species are exceptionally well adapted to cyclones and strong winds. In support of this, large numbers of *Agathis robusta* planted in Tonga in the 1960s showed little or no damage from Cyclone Isaac, a Category 4 storm in 1982 (Thaman 1982). Initially kauri canopies develop slowly, resulting in high root to shoot ratios at sapling and pole stages. In maturity the boles of kauri pines are typically single with fine horizontal branching and a low form factor (thick at base and strongly tapering) which is the ideotype for resistance to strong winds. There is provenance variation in canopy architecture (stem form, branching, self-pruning and canopy density) in *A.*

macrophylla (Pacific kauri; Solomon Islands, Vanuatu and Fiji; Thomson 2006a) such that trees originating from Temotu province (Solomon Islands) are less well adapted to strong winds: in areas experiencing cyclones, the Vanuatu and Fiji seed sources of *A. macrophylla* are much preferred for planting. The main areas to date for *Agathis* are Fiji (181 ha of *A. macrophylla*), New Caledonia and Tonga (agroforestry/boundary plantings of *A. robusta*, notably on Vava'u). Particularly resilient and suited to coastal areas and seemingly almost totally resistant to salt spray and cyclonic windfall is *Araucaria columnaris* (columnar araucaria pine), which has been widely planted in Hawaii, Fiji and Vanuatu. *A. columnaris* is also seen growing extremely well in Nauru and Tuvalu, on limestone and sandy soils near coastal areas, and is one of the most widely planted windbreak and street trees on the Penghu Islands in the South China Sea, an area renowned for strong typhoons and extreme strong salt-laden monsoon winds. One only has to witness this very distinctive tall, narrow bending tree growing within metres on the lagoon and coral reefs on the Isle of Pines (for which it got its name) to appreciate its resilience in highly exposed coastal settings (Thaman et al. 2008a, 2012b).

Photos: Lex Thomson

Agathis robusta (kauri pine) boundary planting on Vava'u, Tonga shortly after Cyclone Waka (Jan 2002): trees lost many smaller side branches but almost all survived with main boles intact (l). Rapid growth and recovery of *Agathis robusta* two years after Cyclone Waka (r).

8.3.9 *Pinus caribaea* (Caribbean pine, Honduras pine, Fiji pine)

The most widely planted conifer is the exotic *P. caribaea* var. *hondurensis* (Honduras pine) with commercial scale plantings in Cook Islands, Fiji, French Polynesia, Guam, New Caledonia, PNG, Tonga, and Wallis and Futuna. Fiji has the largest area of *Pinus* plantation in PICTs, comprising about 47,000 ha. Honduras pine originates in cyclone-prone areas of Central America, and certain coastal provenances have higher resistance to cyclonic winds (Bell et al. 1983). More windfirm seed sources need to be used for future plantings to minimise damage from more intense cyclones. Thick stands of young *P. caribaea* are highly vulnerable to fire and often killed outright by wildfire, as regularly observed in western Viti Levu, Fiji, when fires escape sugar-cane burnoffs. Older *P. caribaea* trees with thicker bark may survive moderately intense fires, although suffering severe crown scorch. Given the increasing risk of more intense and uncontrolled wildfires, associated with hotter temperatures and drought, it would be prudent to develop improved fire control and management strategies and to conduct research to identify alternative plantation species to *P. caribaea*. The Fiji Pine Group's plantation estates in drier parts of Fiji already appear to be bearing the brunt of more extreme climate events and altered climate, including high and more intense rainfall over the past decade occurring at a time previously regarded as the dry season. During a period of unprecedented intense rainfall in April 2012, numerous landslips affected the Fiji Pine plantations near Lautoka (Waqa and Waqanisau, 2012) with about 181 ha damaged.

Photos: Lex Thomson

During a period of unprecedented intense rainfall in April 2012, numerous landslips affected the Fiji Pine plantations near Lautoka (Waqa and Waqanisau, 2012) with about 181 ha damaged (l). Ms Verenaisi Rokobale, Environmental Officer with Fiji Pine Group, who was fortunate to survive the landslides after being swept away in a 2012 landslide at, Lololo (r).

8.3.10 *Dalbergia cochinchinensis*

D. cochinchinenis (Thai rosewood) is a moderately-fast growing nitrogen-fixing tree that produces an exceptionally valuable heartwood timber. Trials in Naitasiri Province, Viti Levu, Fiji have shown the species to be well adapted to humid lowland parts of PICTs, and likely to adapt well to any warming of temperatures and increases in rainfall associated with climate change. Thai rosewood warrants wide replanting in agroforestry systems and mixed timber plantations (e.g. mixtures with mahogany and teak). Young trees may be blown over during cyclones, but respond by vigorous re-shooting from the base: the stem form of the coppice is typically straighter than the original seedling-derived stem. Small diameter pieces including heartwood are highly valuable, or alternatively basal resprouts can be thinned down to the 1–3 most vigorous stems with future growth increment concentrated on these.

8.3.11 *Endospermum* (whitewood, kauvula, PNG basswood)

Native *Endospermum* species, notably *E. medullosum* in Vanuatu and *E. macrophyllum* and *E. robieannum* in Fiji, are highly valued timber species, with export markets in Japan. However, for almost all in-service uses in the Pacific, whitewood timbers require preservative treatment. Several *Endospermum* species have outstanding plantation potential, growing rapidly, 15–23 m^3 per ha per year depending on species/germplasm and site, and with potential for rotations of 15–20 years for sawlog production. *Endospermum* spp. generally have wide climatic tolerances, and the planting range will increase in many PICTs with moderate increases in temperatures. Growth rates will increase in sites with higher rainfall, if solar radiation levels are not much reduced, and also with higher CO_2 levels. *Endospermum* species originating from cyclone-prone PICTs have evolved attributes which reduce the risk of breakage of the main bole. In the case of whitewood seedlings and saplings, these first lose leaves and have small branches stripped away, such that the main stem/trunk has a reduced wind resistance when the main force of the cyclone hits. Some breakage of tops of young whitewood trees may occur during cyclones (Thomson 2006c), such as on Santo during Cyclone Zuman (when Category 3 struck with winds of 150 km per hour). Larger whitewood trees drop or lose major branches, especially lower limbs, during cyclones, reducing the wind resistance on and the likelihood of the main trunk snapping or being blown over. *Endospermum* introduced into Vanuatu from PNG under the SPRIG project in 1997, as *E. medullosum*, were in fact a different species, *E. myrmecophilum*, and whilst the latter grew exceptionally fast in early years they proved far more susceptible to cyclone damage than the local *E. medullosum* and accordingly were rogued from the trials.

8.3.12 *Eucalyptus* and *Corymbia*

Certain eucalypt species have high potential for planting in the Pacific Islands and will be minimally impacted by predicted climate change. A small number of fast-growing tropical eucalypts, notably *Eucalyptus camaldulensis* ssp. *simulata* (Kennedy River red gum) and *Corymbia citriodora* (lemon-scented gum), have excellent potential for planting in in dry and intermediate rainfall zones for production of fuelwood, building timber and honey. These species are well adapted to higher temperatures and periodic drought, but have proven susceptible to new fungal pathogens in Asia such as leaf spot and shoot blight caused by *Cryptosporiopsis eucalypti*, now ranked the most severe disease for eucalypt plantation in Thailand (Singchada et al. 2006). *Eucalyptus camaldulensis* ssp. *simulata* has a light canopy which makes it less prone to cyclone damage, but accordingly it needs good weed control in early years.

Eucalyptus deglupta (rainbow gum) is native to PNG and has been widely planted in the western Pacific Islands, but has only been successful commercially outside of cyclone-prone regions in PNG and Solomon Islands (Western Province). It produces an excellent timber and has outstanding potential for carbon sequestration projects with growth rates of 25–40 m^3 per ha per year (and up to 60 m^3 per ha per year on the best sites). *E. deglupta* is reputedly quite site-sensitive so care will need to be taken in locating all future plantings, taking into account changing climate, although the species is predicted to thrive under hotter temperature regimes (Palma and Carandang 2012).

During the 1990s *E. deglupta* plantations and trial plots suffered major cyclone damage in both Fiji and Samoa; 78% of *E. deglupta* plantations in Samoa were written off after Cyclone Ofa struck in February 1990 (Martel and Fyfe 1991) and commercial planting was discontinued in both countries. However, this author observed that there were a considerable number (in excess of 100 individuals) of mature isolated *E. deglupta* trees which had survived the ravages of two Category 5 cyclones in Val and Ofa and which might form the basis of a breeding programme for increased cyclone resistance (especially given the relative ease of striking vegetative cuttings of mature *E. deglupta*, a unique characteristic amongst more than 1000 eucalypt species).

In 1988 *Eucalyptus urophylla* (Timor mountain gum) was jointly rated with *Flueggea flexuosa* as the top reforestation/plantation species for Samoa of 47 timber species evaluated (Nile 1989), but in the early 1990s the *E. urophylla* plantations at Masamasa, Savai'i were devastated by Cyclones Val and Ofa, and the species has fallen out of favour. *Eucalyptus pellita* (large-fruited red mahogany) was trialled as a replacement for *E. deglupta* and *E. urophylla*, as it was considered to be more cyclone resistant (Wilcox 1991). In Samoa the *E. pellita* trial plantings have exhibited variable performance and proven to be site-specific with satisfactory growth only in lowland, humid locations (Woods and Peseta 1996). Trials of *E. pellita* in Naitasiri, Fiji revealed that the fastest-growing provenances, families and individuals from PNG were much more likely to be blown over or broken during even moderate cyclones. Accordingly, *E. pellita* and *E. urophylla* can only be recommended for planting in humid, lowland parts of western Pacific Islands (PNG and Solomon Islands) which have no or minimal cyclone risk.

8.3.13 *Flueggea flexuosa*

F. flexuosa (poumuli) is one of the most promising small trees for planting in lowland, humid sites, notably in agroforestry systems for the production of durable poles. Poumuli can be grown on short or very short rotations (minimally 3–4 years on best sites) and farmers in Samoa widely plant it along boundaries and in small blocks for poles. Furthermore, there is a good match between demand/need for posts and poles for post-cyclone reconstruction and supply, such that any trees blown over in cyclones can be used immediately. Due to its high durability, the round timbers can be stored for many years without degrading. There is a question mark on the species' ability to recover following cyclones; established *Flueggea* trees on Vava'u, Tonga, died following defoliation by Cyclone Waka (Thomson 2006d) while the species proved moderately susceptible to stem snap or severe broken tops due to category 5 Cyclone Pam on Efate, Vanuatu (Tungon and Tabi, unpublished report). *Flueggea* is often found growing naturally within a few metres of the seashore, for example, in Western (New Georgia), Isobel (Fera, Tasia and Santa Isobel) and Temotu Provinces, Solomon Islands, and many native populations are at risk from rising sea levels. *Flueggea* is, however, also capable of withstanding waterlogged conditions in fresh water, as evidenced by a monospecific stand inundated at Garanga, Santa Isobel (Gideon Bouru pers. comm.). Most agroforestry plantings in PICTs, such as Fiji, Samoa, Solomon Islands and Vanuatu, would not be affected by sea-level rise. The species is generally considered to have a low vulnerability to predicted climate change, including increased temperatures and altered rainfall regimes, with the caveat that the species should not be planted in lower rainfall areas (less than about 2000 mm annual rainfall and/or more than three months dry season).

8.3.14 *Gmelina*

Gmelina arborea (white teak or gmelina), originating from south and southeast Asia, has a wide climatic adaptability both in terms of temperature, rainfall and its variability (Table 8.5). *G. arborea* has recently come back into favour for export-orientated timber plantations on Kolombangara, Western Province, Solomon Islands by Kolombangara Forests Products Ltd (3,300 mm annual rainfall with no dry season) and its growth performance is not expected to be negatively impacted to any extent by any predicted climate change, at least until well after 2050. The species is apparently well adapted to seasonally dry and intermediate rainfall zones (1,700–2,000 mm with short 2–3 months dry season) such as the northern and western parts of Viti Levu, Fiji where it has become invasive in secondary and disturbed forest. Observations in both Fiji and northern Australia (Anon 2013) indicate that the species has moderate to good resistance to cyclonic strength winds. Given the high value of its timber, its climatic adaptability and comparative advantage[18] for planting in PICTs, the species should be more widely planted including in mixed timber plantings with other similarly adapted high value timber species, such as teak, *Khaya senegalensis* and *Acacia auriculiformis* in seasonally dry zones and *Dalbergia cochinchinensis*, *Pterocarpus*

18 The species is highly susceptible to insect attack when grown in plantation in its native range (FAO 2002), and unable to be satisfactorily grown in plantation in Asia.

macrocarpus, Swietenia macrophylla and *Vitex cofassus* in high rainfall zones. Two native *Gmelina* species, viz. *G. moluccana* (canoe tree; PNG and Solomon Islands) and *G. vitiensis* (rosawa; Fiji) are both excellent timber species, which should be more incorporated into agroforestry plantings and more widely trialled to confirm their putative high plantation potential and climate adaptability.

8.3.15 Mahogany

Swietenia macrophylla (big leaf mahogany) is the most commercially important timber plantation species in Fiji, where there are currently 42,419 ha planted (with 24,937 ha on Viti Levu and 14,782 ha on Vanua Levu). Several PICTs, including Fiji, Samoa and Tonga, are the only tropical countries suitable for growing mahogany and free of the *Hypsipyla* (mahogany shoot borer), the larva of which makes its culture impossible in monoculture or in any reasonable planting density elsewhere in the tropics. Young mahogany trees whose terminal shoots are repeatedly attacked by shoot borer over several years have become extremely deformed (Howard and Meerow 1993), more resembling branchy shrubs than trees in Kalimantan, Indonesia. The impact of predicted climate change on mahogany plantations in Fiji has recently been examined by Booth and Jovanovic (2014). These authors found that the potential impact of projected climate change on *S. macrophylla* in Fiji was low. Even when using a pessimistic climate change scenario (RCP8.5), Booth and Jovanovic (2014) found little or no loss of climatically suitable areas before 2080. In 2080, many of the current mahogany plantation areas in Fiji (including Nukurua and Naboutini) may fall marginally outside the range of suitable climatic conditions; on the other hand some high elevation areas in central Vitu Levu may become more climatically suitable, by as early as 2030, as conditions warm.

In drier areas consideration should be given to growing a more drought- and fire-tolerant mahogany species such as *Khaya senegalensi*s (African mahogany), *Swietenia humilis* (Pacific or dry zone mahogany) or *S. mahagoni* (West Indian mahogany). This includes areas currently marginal for planting of *S. macrophylla*, such as much of the western parts of Viti Levu in Fiji. *Khaya* is more cyclone sensitive than *Swietenia* (which evolved in cyclone-prone areas of Central America); large canopied *Khaya* trees are particularly susceptible to windthrow, perhaps related to lack of taproot development (Calvert 2000, 2006; Cameron et al. 1981). However, a shorter rotation period (e.g. 20–25 years cf. 30–40 years for *Swietenia* spp.) reduces the likely number of cyclones to be experienced during the life of any given *Khaya* rotation. Furthermore, it is likely that selection and breeding can be used to select wind-resistant *K. senegalensis* planting material (Nikles et al. 2012).

8.3.16 *Pandanus*

The multipurpose *P. tectorius* (beach pandanus) is extremely well adapted to diverse climates and adapted to future climate change including warmer temperatures, drought, saltwater incursion and fire. The species is highly drought- and salt-tolerant and well adapted to atoll environments (Figures 8.12 and 8.13). Pandanus provide timbers, leaves for thatch and edible fruits (selected varieties with low levels of oxalates) albeit in smaller quantities during drought (Thomson et al. 2006). Pandanus is far more drought tolerant than coconut on atolls (Stone et al. 2000). On atolls, while breadfruit trees may die, and coconuts fail to produce nuts during droughts, pandanus survives and becomes an even more important food, handicraft, medicinal and timber plant (Thaman and Whistler 1996; Thaman et al. 2012b). Plants growing along the beach or in near coastal locations are able to cope with periodic, short duration saltwater incursion from king tides (Thomson et al. 2006), but may die or die back if exposed to longer duration saline/brackish waterlogged conditions, depending on factors such as soil type and plant age. Mature pandanus palms growing in less well-aerated substrates are at greater risk from rising sea levels. *Pandanus* spp. have been noted as being resistant to strong steady winds and gale-force winds associated with Category 1–2 cyclones (Thomson et al. 2006). During low to moderate intensity cyclones (Category 1–3), Calvert (2011) reported that beach pandanus was either mostly undamaged or merely suffered broken branches. During more intense cyclones, beach pandanus may be uprooted as a result of beach sand being washed away during storm surge (Calvert 2011). Plants generally recover from branch and stem damage, with about 10% of larger individuals in exposed sites being broken and dying following moderate to severe cyclones (Category 3–5) (Thomson et al. 2006).


Photos: Lex Thomson

Pandanus tectorius growing on eroded makatea, Ha'apai, Tonga (l). *Pandanus tectorius* growing on Butaritari Atoll, Kiribati (r).

8.3.17 *Santalum* (sandalwoods)

In several PICTs, *Santalum* species have long provided income to resource owners and others involved in harvesting them, along with valuable export income and royalties to government (Thomson and Doran 2010). The native Pacific Island sandalwoods, viz. *Santalum austrocaledonicum* (New Caledonia and Vanuatu), *S. insulare* (Cook Islands and French Polynesia), *S. macgregorii* (PNG) and *S. yasi* (Fiji and Tonga) are all threatened by overharvesting and lack of regeneration (due to heavy rat predation of fruits in the case of *S. insulare*; Meyer and Butaud 2009). In French Polynesia, high elevation populations of *S. insulare* are likely to be threatened by increasing temperatures over the next 50 years. The highest populations of *S. insulare* (*var. alticola*) are at 2,240 m elevation on the summit of Mount Orohena, the highest point on Tahiti. Jean-Francois Butaud (pers. comm.) considers that populations of *S. insulare var. alticola* are at risk from warming because of their narrow altitudinal range, 1,600–2,240 m (Figure 8.14). *S. insulare* (var *marchionense*) occurs at around 1,100 m elevation in the Marquesas (with limited potential to migrate to higher elevations under warming scenarios given the summits are around 1,200 m elevation).

Photo: Jean-Francois Butaud

Santalum insulare var. *alticola* on summit of Mount Aorai, Tahiti, French Polynesia.

The threats from overharvesting are of far more concern than those from future climate change, although possible interactions would threaten native populations of *Santalum* with the risk of extinction. An example is provided by the Nausori Highlands (western Viti Levu, Fiji) population of *S. yas*i. Plants in this population produce exceptionally valuable heartwood, and were heavily exploited most recently during the 1980s. When the author visited the region in 1997 there was abundant sandalwood regeneration (medium to large shrub size) but no mature trees. On a subsequent visit a few years later and after two severe fires, it was difficult to find any surviving *S. yasi* plants. The combination of overharvesting plus drought-induced firing (possibly an early indicator of climate change) appeared to have led to local extinction of *S. yasi* in the Nausori Highlands. Sandalwoods are often planted close to the seashore where they generally grow well, sometimes surviving complete defoliation from wind and salt burn following cyclones. However, sandalwood trees can be totally defoliated and killed during cyclone-driven storm surges, as happened to *S. austrocaledonicum* planted on Mangaia in Cook Islands, when the island was hit by Category 4 Heta in January 2004, (Figure 8.15), and then a succession of Category 4 and 5 cyclones, Meena, Nancy, Olaf and Percy in February–March 2005. Accordingly the main threats to planted sandalwoods from predicted climate change are likely to result from extreme events such as intense cyclones and El Niño drought-connected wildfires. The native *S. austrocaledonicum* and *S. yasi* have proved more wind tolerant during cyclones, being less susceptible to stem snap and windthrow than the introduced East Indian sandalwood (*S. album*) and its hybrids. Planting a diversity of host tree species, including those with wide climatic adaptability (such as *Acacia auriculiformis*, *Casuarina equisetifolia, Eucalyptus camaldulensis* ssp. *simulata*) will reduce the risks to new sandalwood plantings from both incremental climate change and climate extremes.

Photo: Lex Thomson

Santalum austrocaledonicum – planted on Magaia, Cook Islands in 2000. In this row of three two-year old trees, the tree nearest to the sea (on RHS) was killed by salt-laden winds and the storm surge associated with Cyclone Heta, while the tree in the middle suffered considerable dieback (with forester Mr Teuanuku Koroa).

8.3.18 Teak

Tectona grandis produces a highly valuable, multipurpose, durable timber. Teak has become one of the most widely planted tropical hardwoods both worldwide and in PICTs. It is increasingly planted by commercial forestry companies and small holders in Solomon Islands, and also on a smaller scale in Fiji, PNG, Vanuatu and Samoa. The total area of teak plantings in PICTs is now estimated to exceed 10,000 ha. The species has a wide climatic tolerance to periodic hot spells (maximum average daily temperature in the hottest month of 39^{o}C) and seasonally dry conditions (up to six months dry season). Older specimens are well adapted to fire, and in natural teak stands the understorey may be burnt almost every year. Both young and mature teak trees have moderately good wind resistance to intense tropical cyclones, as shown during Cyclones Val and Ofa in Samoa, and Cyclones Tracey and Yasi in northern Australia. Closer spaced plantings of teak of intermediate age, especially where thinning has not been carried out or has been delayed, are susceptible to cyclonic strength winds. Accordingly, the species is considered to have a low to medium vulnerability to climate change. This was confirmed in the recent study of Booth and Jovanovic (2014) who found little change in the climatically suitable areas (based on temperature and rainfall) for *T. grandis* in Fiji, PNG and Solomon Islands in the regions where the main plantations are currently located even to 2080 using a pessimistic climate change scenario (RCP8.5). In fact, a general warming of 2^{o}–3^{o}C and increase in atmospheric CO_2 levels may well slightly increase teak growth rates as long as solar radiation levels were not diminished. Moreover, for over a century teak has shown to be particularly well adapted to intercropping with other food and multipurpose crops, and can be coppiced to provide polewood, firewood and timber for other purposes, thus allowing cropping to continue as the trees mature from the coppice, another distinct advantage given the importance of building food, fuel and livelihood security in the face of climate change.

Photo: Lex Thomson

Tectona grandis (teak) grows extremely rapidly in Solomon Islands – this open-grown tree had reached a diameter of 52 cm at 10 years with excellent bole form (with forester Mr Montrose Ngoro).

8.3.19 *Terminalia*

Native *Terminalia* species are economically important trees in PICTs, including *Terminalia brassi* (brown terminalia in PNG and Solomon Islands for timber), *T. calamansanai* (yellow terminalia PNG and Solomon Islands, formerly planted in Samoa for timber), *T. catappa* (beach almond throughout coastal Pacific for edible nuts, timber, medicine; Thomson and Evans 2006b), *T. kaernbachii* (okari nut in PNG, planted in Solomon Islands for edible nuts), *T. megalocarpa* (to'oma in Solomon Islands and PNG for edible fruits and timber) and *T. richii* (malili in Samoa, American Samoa and Niue for timber; Pouli et al. 2002; Thomson 2006b). Other edible *Terminalia* nut species in PNG include *T. copelandii*, *T. impediens* and *T. sepicana* (also in Solomon Islands).

The most commercially important timber species of *Terminalia* in Melanesia, *Terminalia brassi*, commonly occurs in low elevation swamp forest. These stands are vulnerable to saltwater ingress and death associated with rising sea levels. In Samoa planted *T. calamansanai* has been badly damaged by cyclones, and the species cannot be recommended for planting in any cyclone-risk regions. *Terminalia catappa* naturally occurs as a component of strandline and inland limestone vegetation and is vital for coastal protection, with near-surface spreading lateral roots providing soil and sand protection. The open, pagoda-like tree architecture of beach almond reduces wind loading, but in more intense cyclones (above Category 1) trees experience variable levels of branch breakage, trunk breakage and uprooting (Calvert 2011). *T. catappa* trees growing close to the shoreline are at considerable risk of being negatively impacted by climate change (storm surges and rising sea levels). However, the species should continue to be planted near coastal locations given its rapid growth, multiple uses and otherwise low vulnerability to predicted climate change (from rising temperatures and changed precipitation). *T. catappa* trees also refoliate extremely quickly after defoliation by cyclones, e.g. with in three weeks of Category 5 Cyclone Pam in Vanuatu (Tungon and Tabi, unpublished report).

T. kaernbachii would appear to have low vulnerability to climate change, given its wide climatic tolerances (temperature and rainfall), and that flowering appears to be initiated by seasonal changes in day length, rather than temperature or rainfall (Bourke and Harwood 2009). Planting of *T. kaernbachii* in near-coastal areas should be avoided, possibly due to a preference for higher diurnal temperature variation (Bourke 1996), but trees have been observed growing well at low elevation locations (Kokopo, East New Britain and Aru islands, Indonesia). Putative hybrids between *T. catappa* and *T. kaernbachii* have been observed in the Solomon Islands, and such hybrids may have excellent nut production potential in near-coastal locations.

Terminalia richii (malili) grows rapidly with good single bole form: early height growth rates are 2–2.5 m per year with trees reaching an average diameter at breast height of about 50 cm at 27 years growth, by which time they are ready for harvest for sawn timber. The estimated growth rate is 13–17 m^3 per ha per year. Malili produces a general purpose timber with excellent technical properties. It also appears to be the most cyclone-resistant tree species in PICTs, and certainly amongst the most wind-resistant tropical tree species in the world. Mature 30-year old planted malili trees at Masamasa, Samoa withstood the ravages of two Category 5 cyclones (Ofa and Val) in the early 1990s largely intact, with very little damage to boles, whilst neighbouring native forests and trials of many different forest plantation species were devastated. Subsequent trials by the Forestry Division/SPRIG project demonstrated that young malili trees of different ages were also highly resistant to the strong winds, in excess of 200 km per hour, of Category 5 Cyclone Heta in January, 2004. The only serious damage to young malili trees was from neighbouring trees, many of which blew over or had major branches broken. An important strategy for minimising future losses ofagroforests and plantations in more extreme cyclones will be to incorporate *T. richii* into such plantings.

Photo: Lex Thomson

Terminalia richii (malili) – planted stand that has survived several major cyclones, Masamasa, Samoa.

Terminalia megalocarpa (sometimes confused with *T. solomonensis*) produces a nutritious fruit which can be substituted for avocado and ought to be more widely planted given its expected low vulnerability to predicted climate change. *T. samoensis* (or *T. litoralis*) is also important for coastal protection. It is a useful coastal littoral species in many parts of Micronesia, Polynesia and Fiji, where it is a medicinal plant and more strictly coastal and adapted to salt spray than *T. catappa* (Thaman et al. 2012b).

8.4 The future — impacts, uncertainties and management actions

8.4.1 Overall assessment of vulnerability

Generally the major commercial production forests in PICTs, including timber plantations, are not particularly vulnerable to climate change until late this century. Notable exceptions are forests and trees at low elevation (<1–2 m above sea level) in near-seaside or coastal locations. These trees and forests will be strongly negatively impacted by several climate change factors related to their proximity to the sea, and many coastal littoral forests and individual tree species are already being impacted by extreme events, overuse and coastal reclamation. Littoral and atoll forests will be among the most seriously threatened type of forest in many areas of the Pacific, such as the Tuamotu archipelago in French Polynesia (Butaud 2009), undercutting their proven ability to provide coastal protection (Thaman 2013). Firstly, depending on local tidal patterns, seaside forests are already being periodically impacted by king tides, which can uproot native species and kill salt-sensitive tree species such as breadfruit and sandalwood. These events are projected to become increasingly damaging in coming decades. Secondly, storm surges associated with more intense cyclones are projected to cause much greater destruction, washing out sand and undermining trees, ripping off leaves, branches, bark and directly smashing smaller and regenerating trees as a result of powerful wave action. Finally, these forests will be killed by rising sea levels. The timetable for tree death will be dependent on the localised rate of sea-level rise which is, in turn, dependent on factors beyond the predicted average rise in sea levels.

The impacts of climate change on rainfall are uncertain and variable in the Pacific Ocean (see Chapter 2), with most models predicting an increase in rainfall near to the equator and within the Intertropical Convergence Zone (ITCZ), especially in the May–October season. Any predicted increases in rainfall are unlikely to improve growth, as these are mostly in humid regions where rainfall is not a factor limiting tree growth. However, the predicted decrease in the average incidence of drought in PICTs near the equator (such as Kiribati and Nauru), will be generally beneficial to tree survival and growth in these areas, given low risks of waterlogged conditions in atoll environments. Any marked increase in cloud cover could lead to a reduction in tree growth. Risks of damage to trees from flooding/waterlogging, raging waterways and localised landslips are likely when increased rainfall is concentrated as downpours or intensively over 2–3 days.

Rising temperatures as a result of increased atmospheric greenhouse gas concentrations are unlikely to have major adverse effects on tree growth rates this century. Any adverse impacts of higher temperatures and extreme heat events on tree growth will likely be, at least partly, counterbalanced by increases in CO_2 levels (carbon fertilisation) which have the potential to generally promote higher rates of photosynthesis, especially in drier forest types. Rising mean temperatures will, however, almost certainly lead to the diminution and eventual loss of mountain and cloud forest ecosystems with negative impacts on biodiversity, at levels of forest ecosystem, tree species and genetic diversity, and on the stability of ridge-to-reef hydrological cycles.

Some models predict a decrease in rainfall and an increase in drought at the eastern edge of the South Pacific Convergence Zone (SPCZ) including the northern Cook Islands, and this may adversely affect tree survival and growth in such regions. Water stress will also be increased due to warming temperatures. There is increasing evidence that global warming may be energising the El Niño-Southern Oscillation (ENSO) climate system with ENSO phenomena being more active and intense during the 1979–2009 period than at any time in the past 600 years (McGregor et al. 2013). More severe droughts, associated with more intense El Niño and coupled with higher temperatures, will lead directly to increased plant stress and mortality (especially in new tree plantings), and favour more destructive wildfires. Over time, fire has been the main driver of loss of forest and conversion to degraded grassland and fernland, such as in Fiji's talasiga grassland areas and New Caledonia's threatened dry forest. In some parts of PICTs a marked increase in flammable grasses and reeds, both native and exotic, has reinforced and shortened the cycle of burning. The most at-risk areas for more frequent and/or intense burning will be those that already experience periodic wildfires and broadly match the distribution of sandalwoods, which require drier, more open vegetation associations such as the drier parts of PNG, Vanuatu, New Caledonia, Fiji, Tonga, Cook Islands and French Polynesia as well as Guam and northwestern Savai'i in Samoa. The capacity for El Niño-linked wildfires to enter previously unburnt ecosystems considerably increases the fire risks to the region's biodiversity including, for example, unique forest ecosystems and tree species, especially endemic conifers, in New Caledonia.

In tropical cyclone-prone regions (between about latitudes 5°–30°N and S of the equator, and excluding PNG) almost all forests and trees, especially those in exposed coastal locations, are projected to be subjected to more intense cyclones. IPCC (2013) predicts that there is a greater than 50% chance that there will be a human-caused increase in intense hurricanes by 2100 in some regions, including the western North Pacific. The western North Pacific Ocean is the most active cyclone basin globally, and more intense cyclones will adversely impact on forests and trees in northern Pacific Islands including Guam, FSM, Palau and the Commonwealth of Northern Marianas. In all likelihood, the greatest threat from climate change to Pacific forests and trees is from more intense cyclones and associated storm waves and surges, which as discussed, will negatively impact many coastal forests. Major cyclones are already a cause of enormous damage to forests, both natural and planted, as well as agroforests and trees in other settings.

Photos: Niu Tauevihi

Category 5 Cyclone Heta caused enormous devastation on Niue including almost total defoliation of trees, except coconut palms (l). Regrowth on some canopy trees two months after Cyclone Heta (r).

The damage to forest ecosystems from cyclones is magnified when coupled with other disturbance and damage factors such as intensive logging, burning and exotic invasive weeds. Of particular concern is the increase in seed production of native forest-smothering vines, notably *Merremia peltata* and exotic trees such as African tulip (*Spathodea campanulata*)[19]. Furthermore, in any given year or consecutive years, tropical cyclones may follow similar paths, such as happened in Fiji in early 1985 (Eric, Nigel, Odette, Gavin and Hina), Samoa in 1990 and 1991 (Ofa and Val) and Cook Islands in early 2005 (Meena, Nancy, Olaf, Percy and Rae). Cyclones in rapid succession reduce both the capacity and time for repair of native forest ecosystems. The increasing threats posed by tropical cyclones will increasingly impact on decisions on what species and provenances to grow in planted and artificially regenerated forests, and the silvicultural systems employed, including thinning regimes and rotation length.

The planted forests considered to be more at risk from climate change are monocultures, including *Pinus caribaea* in Fiji (from cyclones, fire and landslides), *Eucalyptus deglupta* in Solomon Islands (cyclones) and *Swietenia macrophylla* in Fiji (from cyclones, especially if *Hypsipyla* shoot borer were to reach Fiji and cause a multi-stemmed habit).

8.4.2 Uncertainty, gaps in the knowledge and future research

There is considerable uncertainty with respect to future impacts of climate change on PICTs, including rate of change and impacts on particular climate factors in different regions. There is also uncertainty on how forests and trees, and pests and diseases will be impacted by climate change. Many endemic trees have seemingly narrow climatic envelopes but most are likely to be well adapted to cope with rises in temperature of several degrees (2^{o}–$3^{o}C$). The major introduced exotic plantation species are also well adapted to cope with increasing temperatures, although up

19 Casual observations by the author on African tulip in Fiji over the past thirty years reveal that its flowering and fruiting period has extended from a concentrated flowering in August–September to now include sporadic flowering throughout much of the year, presumably due to changes in the climatic factors associated with stimulating flowering.

until two decades ago, cyclone-sensitive species were being planted with disastrous consequences. Research is needed on:

1. development of compatible, if not optimal, mixtures of tree species in plantation and agroforestry systems in different parts of the PICTs region. A key consideration is to develop systems that will resist and defray strong winds during higher intensity cyclones. Also important is the development of systems that will cope with variable, more extreme events, such as prolonged drought and fire through to periods of intense rainfall and/or flash flooding in combination with other factors such as accelerated soil erosion, loss of fertility and invasive species. Assessment of agroforestry systems needs to explore and document compatibility with intercrops (food and income generating crops);
2. breeding, including production of seed, of all major tree species needed for agroforestry and reforestation, and especially native species noted for their cyclone and wind resistance such as *Agathis macrophylla, Alphitonia zizyphoides, Bischofia javanica, Casuarina equisetifolia*, *Endospermum* spp. and *Terminalia richii*;
3. any significant pests or diseases that need attention and that have potential to become more damaging as a result of climate change, especially increased temperatures and forest disturbance; for example, brown butt rot (*Phellinus noxius*).

In sites where there is a high level of uncertainty concerning direction and rate of climate change then it will be desirable for planted forests to include a mix of tree species with different overlapping climate envelopes and tolerances.

8.4.3 Management implications and recommendations

FAO has prepared two publications on impacts of climate change for forest policy and management, which outline general approaches and provide guidelines. The first is directed at policy-makers and provides a practical approach to the process of integrating climate change into national forest programmes (FAO 2011), while the companion publication provides guidelines for forest managers (FAO 2013). The second publication informs on forest management practices to address new climate change-related needs and challenges. FAO's Forest Management Division has also produced a series of excellent publications and voluntary guidelines for forest fire management (FAO 2006) which are highly relevant to managers of drier Pacific forest associations given the predicted increase in more extreme fire danger days and periods as a result of global warming. The following discussion is focused on climate change implications for forest management for particular forest types in PICTs, along with specific technical recommendations.

8.4.3.1 Mangroves and coastal forests

In PICTs a key strategy to both adapt to climate change and mitigate its effects ought to be to protect existing mangroves and littoral forest. In suitable locations there is a need to replant, re-establish or enrich existing mangrove and coastal forest and scrub communities. Kiribati, through the example of President Anote Tong, is leading the way. There is a need to properly identify which mangroves and other coastal forests should not be cleared under any circumstances, due to their role as a natural barrier or bioshield to reduce storm surges and provide protection from tsunamis. In Tonga, a SPREP initiated project in 1993 successfully planted thousands of coastal littoral species along some two kilometres of coastline at Houma to address the increasing impacts of salt spray on agriculture and a local village because of the previous removal of coastal trees to extend a banana plantation (Thaman et al. 1995, 2011; Figure 8.21).

Photo: Lex Thomson

Coastal windbreak planting of *Casuarina equisetifolia*, *Pandanus tectorius* and *Tournefortia argente*a, with Mr Tevita Faka'osi (Head of Forestry, Tonga) at Houma, Tonga.

As a consequence of climate change, vegetation in coastal zones of PICTs may need to be replanted more frequently due to escalating damage from cyclonic winds, storm surges, higher king tides and rising sea levels. For the most exposed and at-risk coastal sites, plantings should be focused on fast-growing, easily established species, such as *Hibiscus tiliaceus* and *Pandanus tectorius* through branch cuttings, including those species that can be direct seeded and/or easily transplanted from nearby strandline seedling regeneration beds, and more expendable, short-lived species such as *Acacia simplex*. In less vulnerable coastal sites, replanting will need to focus on mixtures of appropriate tree species, which combine tolerance to salt and high winds, and provide a useful product(s) or service. The most appropriate species for coastal replanting will vary with location, with the highest priorities including *Calophyllum inophyllum, Casuarina equisetifolia, Pandanus tectorius, Excoecaria agallocha, Hibiscus tiliaceus, Barringtonia asiatica, Thespesia populnea* and *Terminalia catappa* (especially superior edible nut morphotypes from certain places in PNG, Solomon Islands and Vanuatu). Coconuts, both local tall varieties and local dwarf varieties (such as niu leka in Fiji), should also be densely replanted in near-coastal areas, due to their valuable products and protective effect from tsunamis. Coconuts have a compact fibrous root system and are not ideal in the most exposed beach locations that are vulnerable to sand erosion from wave action, as these sites will be first affected by storm surge and rising sea levels.

8.4.3.2 Native forests

In general terms, inland native forests and plantation forests will be less impacted by climate change than coastal forests. The exceptions are:

Forests in riverine situations

These forests will be at more risk of damage from flash flooding. The only management strategies are to ensure that runoff is reduced, through for example, installation of retarding basins, and preventing natural features that slow runoff, such as boulders in creek lines, from being extracted, mined or otherwise destroyed. In lower parts of the landscape dredging, albeit a very costly measure, can improve the water-carrying capacity of the drainage line, and reduce damage to riverine forests (in addition to crops, buildings and other infrastructure). There is also great scope for the protection and enrichment of riverine forests, with species such as *Hibiscus tiliaceus* and *Inocarpus fagifer*, as a means of shoring up degraded stream banks and reducing erosion and sedimentation. River flats and flood plains are often used for agricultural cropping but appropriate forestry and agroforestry systems would be better land use, providing similar or better returns at much lower risks to short-term crops. Examples of systems that can work well in different locations include (i) Polynesian chestnut (*Inocarpus fagifer*) plantations for nut production and for bee fodder: this species naturally occurs in low-lying waterlogged and shallowly flooded sites, is very long-lived (and a good candidate for carbon sequestration) and cyclone resistant (Pauku 2006), (ii) Sago palm (*Metroxylon* spp.) plantations for sago and thatch, (iii) *Terminalia brassi* plantations for timber, (iv) *Melaleuca* plantations for essential oil production, especially selected chemotypes of *M. cajuputi* and *M. quinquenervia*, (v) coconut plantations with grazed understory, and (vi) fruit/nut tree or timber plantations on slightly raised mounds (e.g. breadfruit, jackfruit, mango, canarium for fruit/nuts and *Agathis macrophylla*/*A. robusta, Acacia auriculiformis, Flueggea flexuosa*, bamboos and, in particular, *Swietenia macrophylla* for timber).

Seasonally dry forests and woodlands

These forests and woodlands are at greater risk of increased firing (both frequency and intensity of burning) with reduced forest quality for provision of useful products and ecosystem services. In many PICTs there is a need for updating existing legislation and introducing more effective fire legislation. Management options to reduce increasing wildfire hazards are limited to controlled/prescription burning in areas at high risk of fire initiation, such as along roadsides and adjacent to cane farms (in Fiji), establishing and/or better equipping fire services (especially in rural areas and developing, training and tapping into volunteers) and better educating the general public on fire hazards. New tree plantings in fire-prone areas should incorporate a high proportion of indigenous species that are both fire resistant and drought tolerant, such as *Bischofia javanica* and *Casuarina equisetifolia*, as well as commercially important exotics for timber such as *Eucalyptus camaldulensis*, *Gmelina arborea*, *Khaya senegalensis* and *Tectona grandis* and for fruits/multipurpose such as mango (*Mangifera indica*), neem (*Azadirachta indica*) and tamarind (*Tamarindus indica*).

Montane and cloud forest

Due to increased temperatures these forest ecosystems are expected to contract and have altered distributions: over long periods of time (many decades), they will progressively move upslope, in areas where this possibility (higher elevation habitats with similar soils) is available. Damage to montane forests from climate change will impact on water catchment and adversely impact on the region's biodiversity, including, for example, several unique, endemic gymnosperms in New Caledonia's montane forests. The alpine vegetation of French Polynesia, only found on Tahiti, and cloud forest at the summit of other French Polynesian islands (viz. Rapa in Austral Islands; the six largest Marquesan Islands and the Society Islands) are threatened by increasing temperatures, as are montane and cloud forests elsewhere, and notably in the PNG highlands.

Photo: Jean-Francois Butaud

Threatened cloud forest on Mount Aorai, Tahiti, French Polynesia

It is recommended that genetically representative seed collections be undertaken for those PICTs' tree species, and populations at risk of extinction due to warming temperatures. These seed collections ought to be placed under duplicated secure long-term storage (e.g. SPC Pacific Islands Tree Seed Centre [PITSC] and Millennium Seed Bank, Kew Gardens). If and when suitable new habitats develop, or are identified in the same region, then a portion of these seedlots can be propagated and planted in the field.

8.4.3.3 Planted forests including agroforests

Generally, existing forestry plantings are at low risk of being adversely affected by climate change during their current or next rotations (up to about 2090). This includes both current forest plantations and agroforests. The main negative impact to planted trees is likely to be the result of periodic damage due to increased cyclone intensity and of course to any trees planted close to the sea. These negative impacts may be partly offset by increased photosynthesis and growth rates due to elevated CO_2 levels. The greatest damage to forestry plantations has occurred from cyclones impacting on exotic species (with low or moderate wind resistance), especially where they have been planted at close spacing (i.e. > 1000 stems per ha) and left unthinned or not thinned in a timely manner. Existing, especially young, plantations need to be regularly thinned, ideally after the risk of cyclones has passed in a given season, taking care not to remove too many stems at any one thinning as the retained rather spindly stems are especially vulnerable to wind damage prior to thickening. Plantation management organisations need to be better equipped and prepared during the dry season to fight fires and artificially water new plantings in case of prolonged drought. They need to be better organised and ready during the cyclone season to respond to cyclone damage; both to prop up young stems — especially important and beneficial in young mahogany and sandalwood stands — and to harvest/utilise any wind-thrown trees in mature stands before they suffer damage and decay.

Future commercial forestry and horticultural plantations can minimise risks to projected climate change by planting mixtures of two or preferably three adaptable, compatible species, for example:

4. *Alphitonia zizyphoides, Dalbergia cochinchinensis, Endospermum spp., Flueggea flexuosa, Bischofia javanica*, *Casuarina* and *Gymnostoma* spp., *Swietenia macrophylla*, and *Terminalia richii* for timber in humid zones;

5. *Artocarpus altilis, Calophyllum inophyllum, Cananga odorata, Canarium* spp. and *Terminalia catappa* for non-timber forest products (e.g. nuts, food, perfume, oil) in humid zones; and

6. *Acacia auriculiformis, Eucalyptus camaldulensis* ssp. *simulata, Gmelina arborea, Khaya sengalensis, Pinus caribaea* and *Tectona grandis* for timber/wood in seasonally dry zones.

Appropriately selected clumping-type bamboo species can provide a multitude of useful products and are well adapted to recover and regrow quickly after extreme climate events such as flash floods and gale force winds. Furthermore fallen bamboo poles, especially durable species, can readily be used in the rebuilding efforts following cyclones. Another strategy to reduce and minimise risks from climate change to planted forests is to design and develop shorter plantation rotation systems. Reduced rotation periods will be based on optimised silvicultural systems, (e.g. wider spacing and good nutrition), appropriate fast-growing species combinations (which have a balanced root:shoot development) and improved/selected germplasm. Shorter rotation periods will reduce the likelihood of any given rotation overlapping with extreme climatic events and also reduce the likelihood of the climate appreciably altering over the course of the rotation. Short rotations also provide an earlier opportunity to alter and adjust species mix in response to any observed climate change(s).

Future agroforestry plantings will need to incorporate mixtures of climatically adaptable species capable of providing diverse revenue streams. In this regard government forestry and agricultural planning and extension services will need to advise tree growers and landowners appropriately so that tree resources are developed which are either of sufficient scale to attract processors and buyers, and/or can be processed and used on a smaller, local scale for domestic uses and markets. Export market-oriented timber and export crop plantation operations, including smallholder plantings as part of a nucleus estate[20] model, will almost always need to focus on a few high value species well known in the international market place, such as mahogany, teak, sandalwood, Thai rosewood and *Intsia bijuga* (merbau or vesi) given the small scale, by global standards, and high shipping costs of forestry operations in PICTs. Important agroforestry crops, such as coffee, cocoa, coconuts, bananas, kava and other crops must also, where possible, be intercropped with timber trees and other resilient and useful plants, to spread risks related to climate and environmental change. A balance must be struck between developing a critical mass of a particular forestry plantation timber resource(s), cash crop plantings and the risks from pests and diseases, climate change and changing market demands associated with concentrating planting on just one (or two) species.

8.4.3.4 Trees outside forests and agroforests

The main negative effects of predicted climate change on trees planted outside forests and agroforests will be on those trees which have been or will be planted close to the sea (within 1–2 m of normal high tide) or in areas susceptible to prolonged drought and wildfires. In these areas it is important to consider the configuration of tree plantings to maximise protection of increasingly vulnerable shorelines, crops and infrastructure, especially houses. As well as being windfirm, resistant to salt spray, periodic seawater inundation and wave action, the selected tree species for replanting will need to supply products in high demand such as coconuts for food and drinking, nut and fruit trees, traditional medicines and building timbers in order to provide

20 Central estate supplemented by production from smallholders in same general area.

for the growing populations of many communities. For example, strategically and closely planted coconuts can reduce tsunami damage to buildings, but are easily undermined by wave action and perhaps should no longer be planted right on the beach. In beach sites useful multipurpose trees, notably *Calophyllum inophyllum, Casuarina equisetifolia, Cerbera manghas, Cordia subcordata, Neisosperma oppositifolium, Pandanus tectorius, Terminalia catappa* and *Thespesia populnea*, are prime candidates for replanting. Fast growing, readily propagated and established expendable plants such as *Acacia simplex, Vitex trifoliata, Hibiscus tiliaceus, Polyscias* spp. and *Gliricidia sepium* can also be used for seaside plantings with minimal effort and expense — the first two species can be transplanted from strandline beds of regeneration while the latter three species can be propagated by large branch cuttings. Management actions to protect and maintain seaside vegetation may need to include seashore restoration work and replenishment of sand around exposed tree roots following major storms.

In addition to vulnerable coastal areas, there is also a critical need to maintain species diversity and to protect and plant resilient multipurpose trees in both rural and urban agroforestry systems — trees that can withstand tropical cyclones, flood and waterlogged conditions, prolonged drought, fire, increasing salinity and invasive species. This will, however, be made difficult by the increasing failure among the current generation of agriculturalists to plant, protect and replace trees as part of the traditional shifting agricultural system, a process referred to as 'agrodeforestation'. Agrodeforestation has led to considerable loss of agrobiodiversity, which seriously undermines the resilience of agricultural areas to climate change, extreme events and invasive alien species and diseases (Thaman 1989, 1992c, 2002, 2008b). In Samoa, and indeed other PICTs, agrodeforestation has often occurred along rivers that are part of critical water catchments and in several sensitive watersheds, thus impacting on the delivery of key ecosystem services. These watersheds are especially vulnerable to climate change (i.e. an increase in soil erosion, flooding, lower water quality and quantity), and need to be a primary target of climate change-related efforts for rehabilitation and sustainable agroforestry (Francois Martel pers. comm.). In short, whether in coastal, riverside or inland areas, or in rural or urban areas, excessive deforestation and agrodeforestation must be reversed and the protection and planting of trees, using the best mix of traditional and modern technologies and knowledge, must be encouraged by all entities at every level in all ecosystems, because forests and trees are the antithesis of deserts, and a sign of a healthy and resilient Pacific in the face of unprecedented climate, environmental and economic change.

Within agricultural areas, whether they are coastal areas (bordering grasslands and other flammable vegetation) or other inland sites with existing forests or destined for restoration, emphasis must be placed on protection from fire and the selection of species (particularly pioneer or framework species) that are fire resistant. As stressed above, the threat of fire as a direct or indirect result of climate change (drought and increased fuel loads produced during wetter periods) is perhaps one of the most under-recognised threats posed by climate change, particularly to forests and trees and to the sequestration of carbon.

8.5 Summary

As in the Pacific fisheries sector (Bell et al. 2011), land and forestry planners and managers will need to work with resource owners, tree growers and farmers 'to strengthen existing and planned adaptations, and develop new interventions, to minimise threats and harness opportunities associated with the direct and indirect effects of climate change' on terrestrial ecosystems, especially forests, woodlands and agroforests. However, given the uncertainties of the magnitude and timing of the inevitable impacts of human-induced climate change on Pacific forests and trees, and interactions with other factors, the emphasis must be placed on the roles of good forestry management and agroforestry practices as a way of building resilience to all forms of environmental change, economic change, invasive species and human-induced climate change. Furthermore, it is evident that there will never be sufficient resources available to undertake all desired research, modelling, planning, mitigation, adaptation and monitoring to address the impacts of climate and global change on PICTs' forests, trees and the vast array of goods and services which they provide.

More research is needed to better quantify the economic, environmental and social impacts of climate change on the forests and trees sector. The main economic impacts may be indirect, related to fire, pests and diseases, and damage to ecosystem services (especially water supply) provided by forests (from fire, cyclones and flooding), and impacts on the less easily quantified informal/subsistence sectors (forest food banks, traditional medicines, rough building timbers and fuelwood). There may also be flow-on consequences on agriculture due to climate change impacts on forests, such as through a reduction in beneficial predators and pollinators. Accordingly, while more research is being conducted and climate change impacts better understood, it is recommended that a limited number of high priority actions, identified in this chapter and elsewhere, need to be undertaken as follows:

1. Development and consistent application of good forestry practices, including enforcement of codes of logging practice, silvicultural prescriptions and reduced impact logging guidelines. This will require better resourcing of national forestry departments both from government budgets and donors. It is especially critical to prevent logging within and felling into riparian 'buffer zones' and agricultural and other clearance of riparian vegetation, watersheds and steep slopes. Such activities have seriously undermined the ability of riparian forests to continue to provide goods and services and protection against extreme weather events.
2. Improved land use planning — governments working with land owners, farmers and communities in landscape approaches (also referred to as whole catchment or ridge-to-reef approaches) to identify those areas most susceptible and contributing to soil erosion. Those areas should preferably be either reforested and/or placed under an appropriate agroforestry/arboricultural system, including vetiver grass strips. The alternative is to implement costly and less effective engineering measures.

3. Encourage the development of multispecies forest plantations and climatically-resilient agroforestry systems through use of a greater number of widely adaptable species (including more cyclone- and wind-tolerant species). In order to minimise damage and reduce risks from uncontrolled fire, new forest plantations and agroforests in dry and intermediate rainfall zones will need to incorporate a higher proportion of fire tolerant species, such as casuarina, koka and teak. These actions will require a more effective collaboration between government and private sectors, including provision of technical and market advice and diverse and improved tree germplasm.

4. PICTs (governments, communities and tree growers) need assistance in managing the impacts of climate change on forest genetic resources to access, promote and use diversity within and among tree species to help with climate change adaptation and mitigation. This would be best done through a donor-funded collaboration of SPC's Pacific Islands Tree Seed Centre and Pacific Island Forestry Departments (with inputs from the CSIRO Australian Tree Centre and Kew Gardens Millennium Seed Project). A key objective would be to collect and evaluate populations of the most important tree species for PICTs in the face of climate change (refer Section 8.3). High priority species would include *Agathis macrophylla, Bischofia javanica, Canarium indicum, Calophyllum inophyllum, Casuarina equisetifolia, Endospermum* spp., *Flueggea flexuosa, Tectona grandis, Terminalia richii, Santalum* spp. and *Pandanus tectorius*. There is also a need to improve and streamline sharing protocols and agreements within the region.

5. There is urgent need for better surveillance, monitoring and control of exotic forest pests and diseases and environmentally invasive weeds by government forestry and biosecurity agencies. The highest priority at present for Pacific Island forest ecosystems is the development of biological control measures for the African tulip (*Spathodea campanulata*). In the meantime, its human-aided inter-island spread needs to be halted, including total elimination of any small populations where the species has yet to gain a foothold.

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Chapter 9

Implications of climate change for contributions by agriculture and forestry to Pacific Island economies and communities

Andrew McGregor, Anna Fink and Brian Dawson

Contents

9.1 Introduction

This chapter will consider the implications of climate change on the contribution of agriculture and forestry to PICTs' economies and communities, with the focus largely at the aggregate national level. Chapter 1 benchmarked the current contribution of agriculture and forestry to various economies and communities. This chapter considers these contributions in the light of climate change projections (Chapter 2) and their impact on the various agriculture sub-sectors and forestry sector as detailed in Chapters 4–8. It consolidates the information from these earlier chapters to consider how these changes will impact on socio-economic development in the Pacific.

Projections on the potential impact of climate change on agriculture and forestry to economies and communities have been made taking into account both the short-term (up to 2030) and the medium-term (up to 2050) climatic scenarios as described in Chapter 2. This chapter will also follow the breakdown of countries into groupings according to the relevance of agriculture for their economies as categorised in Chapter 1. These are:

- Group 1: relatively large PICTs of Melanesia
- Group 2: mid-sized PICTs of Polynesia
- Group 3: land-poor micro-states that are predominantly atolls.

For each group only a subset of countries will be considered in the analysis. These countries are representative of the impacts on the wider group and will act as case studies for other similar Pacific Islands. For each grouping the contribution of agriculture and forestry will be considered across four broad areas: GDP and growth; trade and balance of payments; food security; and employment and livelihoods. Agriculture's contribution to government revenue, unlike fisheries, is minimal in most PICTs so there is only limited discussion on this.

There are important caveats to highlight when undertaking such an exercise. Measuring social and economic impacts well into the future can be very difficult because they are influenced by many factors. Chapter 1 discussed some of the most important factors impacting PICTs' economies and communities in the future, as follows:

- Population growth and the rate of urbanisation
- The rate of depletion of extractive non-renewable resources
- The price of imported petroleum products
- The incidence of non-communicable diseases
- The trade, aid and immigration policies of major partner countries.

Precisely separating out the influence of climate change's impact on agriculture and forestry from these other factors some 15 and 35 years into the future presents a near-impossible task, particularly given data availability constraints. It makes little sense, and could be quite misleading, to try to do this for the longer term (beyond 2050). Furthermore, as noted by Sundström et al. (2014) the ability of individual countries to compensate for national losses in agricultural production is dependent on several factors, such as overall global agricultural production and food availability. In the medium term (approximately 2050) these conditions could be quite different from today.

In the previous chapters, scenarios were identified where climate change is likely to have negative productivity impacts but farmer revenue could improve because of offsetting price impacts. Some food staples, for example breadfruit, could fit into this category because of the negative impact of climate change on grain production in some other parts of the world, particularly Asia. Furthermore, some Pacific agricultural industries may continue to grow in the future despite the adverse impacts of climate change; however, the growth may have been greater had there not been climate change impacts. Fiji's future horticultural exports could be such an example. There are some industries that would have continued to decline despite any negative impacts of climate change; however, their decline may not have been as rapid had it not been for climate change. The Fiji sugar industry, or Solomon Island log exports, might fall into this category where more significant adverse factors are at play.

Table 9.1 provides a summary of the expected impact of climate change on production within the subsectors covered in Chapters 4–8. The following sections use this information to expand upon the potential socio-economic consequences of climate change on agriculture within the Pacific.

Table 9.1 A summary of projected impact of climate change on the production of agricultural and forestry products.

Crop	Assessment of the overall short-term (approx. 2030) production impact	Assessment of overall medium-term (approx. 2050) production impact
Staple food crops		
Sweet potato	Moderate	Moderate to high
Cassava	Insignificant to low	Low to moderate
Taro	Low to moderate	Moderate to high
Cocoyam	Insignificant	Low
Giant taro	Insignificant	Low
Swamp taro	Moderate to high	High
Yams (domesticated)	Moderate to high	High
Yams (wild)	Insignificant	Low
Breadfruit	Insignificant to low	Low to moderate
Rice	Moderate to high	High
Banana	Low	Low to moderate
Aibika/Bele	Low	Low to moderate

Crop	Assessment of the overall short-term (approx. 2030) production impact	Assessment of overall medium-term (approx. 2050) production impact
Export commodities		
Coconuts	Low	Low to moderate
Coffee	Moderate	High
Cocoa	Low	Moderate to high
Oil palm	Insignificant	Insignificant to low
Sugar	Low	Moderate
Horticulture		
Papaya	Low to moderate	Moderate to high
Mango	Low to moderate	Moderate
Citrus	Insignificant to low	Low
Pineapple	Insignificant	Low to moderate
Watermelon	Low to moderate	Low to moderate
Tomato	Moderate	Moderate to high
Spices		
Vanilla	Insignificant	Low to moderate
Ginger	Insignificant to low	Low to moderate
Stimulants		
Kava	Insignificant to low	Low to moderate
Betel nut	Insignificant	Low
Forestry		
Mangroves	Low to moderate	Moderate to high
Coastal forest & atolls	Moderate	Moderate to high
Swamp forest	Moderate	Moderate to high
Lowland rainforest	Low	Low to moderate
Wet/dry forests & woodland	Low	Low to moderate
Upland (montane & cloud forest)	High	Very high
Agroforests	Moderate	Moderate to high
Plantation forests	Low to moderate	Moderate
Livestock		
Cattle	Low	Moderate
Pigs	Low	Moderate
Poultry	Moderate	High
Bees	Low	Moderate to hHigh

9.2 How will the impact of climate change on agriculture affect the economies and communities of the larger Melanesian PICTs?

Group 1: Melanesia

PNG, Solomon Islands, Vanuatu (considered as western Melanesia) and Fiji are taken as representatives of the larger Melanesian countries, which could also include New Caledonia.

9.2.1 GDP and growth

As discussed in Chapter 1, the growth performance of the Melanesian countries has, over the last decade or so, been erratic and sluggish. All of these economies will face major growth challenges in both the short term (to approximately 2030) and medium term (to approximately 2050) irrespective of the impact of climate change. These include:

- high rates of population growth (PNG, Solomon Islands and Vanuatu);
- rapid urban population growth (all countries);
- depletion of extractive non-renewable resource-based industries (minerals, petroleum and native forest logging) (Fiji, PNG and Solomon Islands) without sufficient investment in long-term sustainable industries, including agriculture; and
- the debilitating impact of non-communicable diseases (NCDs) (all countries).

Nevertheless, agriculture is a large contributor to GDP within these countries, and both negative and positive consequences of climate change on the production of key crops, livestock and forestry are expected to impact negatively on the growth and GDP of these countries, which could be significant beyond 2050.

A recent study by ADB (2013) attempted to model the impact of climate change on Pacific Island countries. The study concluded that 'under the business-as-usual scenario, climate change may cost the Pacific region 2.2%–3.5% of its annual gross domestic product (GDP) by 2050, and as much as 12.7% by 2100'. The negative effect of climate change on agriculture, according to the ADB study, contributes the most to these costs and is projected in the study to amount to approximately 5.4% of GDP annual equivalent by 2100 under a high emissions scenario. To define this degree of precision in such forecasts is not credible given the long time frame involved, the interacting variables at play and the lack of data. However, it is clear that the macro-economic impact of climate change, via its influence on agriculture in Melanesia, is expected to be negative overall, although the evidence is not available to state by how much with any quantitative precision.

Agricultural value-added products contribute 36% to PNG's GDP, 23% to Vanuatu's, and 39% to Solomon Islands' (see Table 1.4 in Chapter 1). As discussed in Chapter 1, the figure for Vanuatu is possibly somewhat misleading as the calculation of self-sufficiency agriculture may significantly underestimate its importance. For Fiji, agriculture contributes 13% to GDP and its importance has declined over time, but Fiji's sugar production and exports are still important for GDP and employment. Fiji has also managed to establish a regional comparative advantage in the export of some horticultural products, particularly papaya and taro.

Agriculture contributes to GDP in the Melanesian countries through the self-sufficiency sector and also through commercial agricultural production including cash crops such as coffee, cocoa, coconut and sugar. Forestry is also a large contributor to GDP for PNG and Solomon Islands, a moderate contributor to GDP in Fiji and a small contributor in Vanuatu (see Table 8.3 in Chapter 8). Some of the most significant impacts of climate change on GDP are outlined below. On balance it seems that the impact of climate change on cash crops is likely to have the largest direct impact on GDP compared with forestry or self-sufficiency agriculture.

A major negative impact on GDP for PNG is expected to come from the impacts of climate change on Arabica coffee. Coffee is PNG's most important industry in terms of value adding and income distribution. A decline in production of coffee will have far-reaching socio-economic consequences. For other tree crops the story is likely to be mixed. In the medium term PNG and Solomon Islands may find temperatures for efficiently growing cocoa become too high (see Chapter 5). For other cocoa producers such as Vanuatu, the temperature may become more conducive, but increases in rainfall and possibly more intense cyclones could remove any advantage.

Palm oil production is not expected to be significantly negatively affected by climate change. In fact, negative impacts elsewhere may push up the price of palm oil leading to higher revenues from palm oil production, which would particularly benefit PNG and Solomon Islands.

In terms of self-sufficiency and domestic production, the impact of climate change on sweet potato production is likely to be felt in PNG and Solomon Islands. Sweet potato is the most important food staple in terms of calories provided in PNG and Solomon Islands. Tuber yield is already vulnerable to high rainfall and is expected to fall in the medium term, particularly in PNG's lowlands. On the other hand, other traditional staples such as cocoyam, cassava and breadfruit are not expected to be particularly affected by climate change. This will be to the advantage of self-sufficiency producers in Melanesian countries. In fact, it is possible that expected price increases in imported grains could lead to increasing demand for domestically produced staples. This effect is discussed more in the following sections but it means there may not be any significant overall negative impact on the contribution of traditional self-sufficiency crops to GDP.

An important element to note is the impact of climate change on the intensity of cyclones and the subsequent impact on GDP and growth. The 2007 IPCC report noted that an increase in the intensity of cyclones would be particularly damaging in Fiji due to the location of Fiji's main crop-producing areas (ADB 2013). A report by the Government of Fiji (2013) estimates the economic impact of Cyclone Evan, a category 4 cyclone, which hit northern Vanua Levu and western Viti Levu in December 2012. Despite early warnings of the cyclone, losses and damage to agriculture alone were estimated to be around USD 21 million. The same report estimated that the total economic impact of the cyclone was equal to around 2.6% of Fiji's GDP in 2012, and resulted in a revision of Fiji's GDP growth forecast for 2013 down by 0.1 percentage point. The negative consequences of an increase in the intensity of cyclones would, however, dwarf this as the experience of Typhoon Haiyan in the Philippines in November 2013 indicated. On balance it is expected that the negative impact of more intense cyclones will more than offset the positive benefits from less frequent cyclones. However, a useful area of research would be to measure the trade-off between less frequent and more intense cyclones to the region's agriculture. Such research could be expected to derive a weighted average of the risk of loss over various time periods.

Equally, climate change models predict an increase in the intensity of rainfall in some areas. Flooding is also a major cause of economic damage in the Pacific. Heavy flooding of key rivers in Fiji in April 2004, for example, is estimated to have damaged between 50% and 70% of crops (Barnett 2007).

In regards to forestry, both PNG and Solomon Islands get a significant amount of GDP from forestry, principally from the export of round logs (see Table 8.3 in Chapter 8). However, for PNG, the GDP share of forestry has fallen over time due to the rapid growth in mineral exports. For PNG and Solomon Islands, the greatest threat to this source of national income is poor logging practices, but more extreme climatic events (e.g. intensity of cyclones or El Niño droughts) can be expected to have a negative effect on the industry through canopy opening, increased burning and the spread of environmentally invasive weed species. Climate change is therefore likely to have a negative impact on the contribution of forestry to GDP but it will be extremely difficult to separate out this impact from the decline of the industry due to unsustainable logging.

GDP forecasting, even for a time frame of several years, is notoriously inaccurate. The econometric models used to provide the precise forecasts cited above suffer from multiple modelling and data limitation challenges; they are not seen as being particularly useful and could be misleading. Trying to quantify the various interacting variables and countervailing forces well into the future, such as those mentioned here, is beyond the capability of existing models and data availability. However, based on the evidence presented in Chapters 4–8 on the various agricultural sub-sectors, qualitative short and medium projections for the Melanesian countries on how the impact of climate change on agriculture will affect economic growth can be made (see Box 1). Even qualitative projections, however, are not realistic for the longer term (approximately 2100).

***Box 1** Impact on GDP of climate change's effect on agriculture in Melanesian countries*

SHORT TERM (APPROX. 2030)	MEDIUM TERM (APPROX. 2050)
PNG	
Small negative impact on GDP overall A moderate negative impact on coffee production is expected from climate change. This smallholder-based industry is PNG's most important industry in terms of its employment and value-added contribution. Thus the negative impact on GDP is likely to exceed any positive impacts from the climate change induced increase in the value of palm oil exports and the value of domestically traded food. Other climate change impacts on GDP are expected to be relatively minor.	**Moderate negative impact on GDP overall** The substantial negative impact on GDP of reduced coffee production is expected to more than offset the significant positive gains expected from palm oil exports and the increased value of domestically traded food.
Solomon Islands	
Neutral impact on GDP overall Small GDP gains expected from the increased value of palm oil and domestically traded food may be approximately offset by the small negative consequences for cocoa and copra.	**Neutral impact on GDP overall** Increasing positive gains expected for palm oil and domestically traded food expected to be offset by the increasing negative consequences for cocoa and copra.
Vanuatu	
Neutral to small negative impact on GDP overall Small positive gains for domestically traded food probably not quite sufficient to offset the expected small negative consequences for cocoa and copra.	**Small negative impact on GDP overall** Increasing positive gains for domestically traded food will probably not be sufficient to offset the expected negative consequences for cocoa and copra.
Fiji	
Neutral to small negative impact on GDP overall Small GDP loss expected overall from reductions in exports of sugar and horticultural products. Gains in domestically traded food unlikely to fully compensate.	**Small negative impact on GDP** The positive GDP impact of domestically traded food is likely to increase more than the negative impact on horticultural exports. Possible larger negative GDP impacts from more intense cyclones or flooding.

9.2.2 Trade and balance of payments

As shown in Table 9.2 all of the Melanesian countries, with the exception of PNG, operate substantial mercantile trade deficits. PNG has been able to maintain a significant trade surplus due to the exploitation of mineral resources; however, in all countries, agriculture makes a significant contribution to export earnings. The impact of climate change on agriculture will therefore affect the Melanesian countries' balance of payments through the value of both imports and exports.

Table 9.2: Melanesia trade statistics, summary 2007–2012 (USD equiv. million) (source: Central and Reserve Bank Reports for respective countries).

	2007	2008	2009	2010	2011	2012
Fiji						
Total exports (FOB)	534	557	464	582	554	589
Total imports (CIF)	1,863	2,041	1,455	1,904	2,148	2,257
Trade balance (exports – imports)	-1,329	-1,484	-991	-1,322	-1,594	-1,668
Exports as a % of imports	29%	27%	32%	31%	26%	26%
PNG						
Total exports (FOB)	4,575	5,301	4,256	5,515	6,742	5,992
Total imports (CIF)	1,597	2,129	2,837	3,524	4,254	4,758
Trade balance (exports – imports)	2,978	3,172	1,419	1,991	2,488	1,234
Exports as a % of imports	286%	249%	150%	156%	158%	126%
Solomon Islands						
Total exports (FOB)	159	200	149	208	406	475
Total imports (CIF)	293	312	268	379	473	500
Trade balance (exports – imports)	-134	-112	-119	-171	-67	-25
Exports as a % of imports	54%	64%	56%	55%	86%	95%
Vanuatu						
Total exports (FOB)	29	35	24	32	46	41
Total imports (CIF)	200	296	276	294	289	326
Trade balance (exports – imports)	-171	-261	-252	-262	-243	-285
Exports as a % of imports	15%	12%	9%	11%	16%	13%

9.2.2.1 Impact on exports

Drawing on the information provided in Chapters 4–8, a summary is made in Table 9.3 of the projected impact of climate change on the export earnings of the Melanesian countries. These are presented for the short term (approximately 2030) and medium term (approximately 2050). A summary of the conclusions for the four countries regarding export earnings is outlined here.

Papua New Guinea

Two strong counteracting forces involving the major industries of coffee and palm oil are expected to be at play with respect to export earnings. A substantial negative impact is expected due to the reduction in coffee production. This will only be partially offset by expected price increases due to global supply impacts. The annual FOB value of PNG's coffee exports over the period 2007 to 2012 averaged around USD 265 million. In comparison, palm oil productivity is not expected to be significantly adversely affected by climate change and is also likely to enjoy more favourable prices. Thus, a continuing expansion of PNG's palm oil industry is anticipated. This could, however, bring negative environmental impacts with it depending on the previous use of the converted land. The annual FOB value of PNG's palm oil over the period 2007 to 2012 averaged around USD 470 million. Cocoa and coconuts are somewhat less important industries in terms of export earnings (average combined FOB value around USD 172 million, 2007 to 2012). The impact of climate change on these industries is likely to be less than for coffee, but overall is expected to be negative.

The impact of climate change on export earnings from timber is dwarfed by the impact of poorly conducted logging and conversion of the land to alternative uses. It is likely that the interaction between poor logging and climatic events caused by climate change will lead to increased burning and spread of invasive species which could reduce the value of the resource. Overall, however, plantation forests are not expected to be heavily negatively affected by climate change. As discussed in Chapter 8, it is unclear what the impact of elevated CO_2 (eCO_2) will be. Growth rates and carbon sequestration should increase, but if other factors are limiting, such as plant nutrients, as is often the case in infertile, acidic tropical soils, or other aspects of climate change such as drought are causing stress, these will offset the potential benefits of eCO_2.

Overall, it is not possible to estimate what the future balance of these various impacts is likely to be on PNG's export earnings; however, at best probably somewhat negative.

Solomon Islands

Apart from fish and minerals, Solomon Islands' exports are made up principally of timber, palm oil, coconut products and cocoa. The proportion of timber in total exports has fallen over time but in 2012 it still constituted nearly half of all exports. Furthermore, the value of forestry exports increased significantly between 2005 and 2012 (see Table 8.4 in Chapter 8). This increase has largely been achieved by unsustainable logging of the remaining lowland rainforests and it is expected that the contribution of timber to the export earnings of Solomon Islands will fall dramatically in the next few years as remaining resources are exploited. Climate change will likely have a further negative impact on the contribution of timber to exports as excessively logged lowland rainforest will be at greater risk of climate change disturbances, with canopy destruction and subsequent opening being followed by ingress of environmentally invasive weeds such as African tulip, *Merremia* and *Mikania*.

Over the period 2007 to 2012 the average annual FOB values of palm oil, coconut products and cocoa were approximately USD 29 million, USD 17 million and USD 12 million, respectively. It is projected that climate change will have a significant positive impact on the revenue obtained from the existing oil palm area. Some expansion in the area devoted to oil palm might also be expected if the projected increase in real price materialises. Climate change can be expected to have some negative productivity impacts on coconuts and cocoa, although some positive offsetting export price benefits might be expected.

Thus on balance, it can be expected that climate change could increase agriculture's contribution to the Solomon Islands' export earnings in absolute terms. The export value of timber logged from native forests will fall dramatically due to unsustainable logging and climate change may exacerbate this decline. However, the overall future contribution of timber to the export earnings of Solomon Islands will depend on the level to which plantation forests can be developed.

Vanuatu

Vanuatu's agricultural exports are made up almost entirely of coconut products, kava, beef and cocoa. Over the period 2007 to 2012 the average annual FOB values of these exports were approximately USD 19 million, USD 7 million, USD 5 million and USD 3 million, respectively. The production of all of these products is expected to be adversely affected to some degree by climate change. While some compensating improvement in price might be expected, an overall negative net impact on Vanuatu's export earnings could be anticipated.

Fiji

Fiji's agricultural exports are largely made up of sugar and molasses, fruit and vegetables, taro and coconut products. Over the period 2007 to 2012 the average annual FOB values of these exports were approximately USD 102 million, USD 21 million, USD 12 million and USD 4 million, respectively. The production of all of these products is expected to be adversely affected to some degree by climate change, although the main agricultural export earner, sugar, will probably be least affected. Some compensating increase in world market sugar prices could be expected, although probably not sufficient to offset the negative production impacts and the loss of EU preferential price for sugar. As highlighted in Chapter 6, climate change may enhance the competitive position of Australia's papaya industry in the medium term. This could result in Fiji losing market share in what is currently a burgeoning export industry.

Forestry products also account for an increasing percentage of Fiji's total exports (around 6% in 2010 up from 4% in 2003). In 2012 the total value of forestry products

Table 9.3 A summary of projected impact of climate change on crop, livestock and forestry based export earnings of Melanesian countries.

Crop/Product	Assessment of overall short term (approx. 2030) export revenue impact	Assessment of overall medium term (approx. 2050) export revenue impact
Export tree crop commodities and sugar		
Coffee	Countries affected: PNG (very substantial industry); Vanuatu (small industry) Production impact: yield – small to moderate: total production moderate negative for PNG; insignificant to small negative for Vanuatu Price impact: moderate positive Overall export revenue impact: moderate negative for PNG; insignificant for Vanuatu	Countries affected: PNG and Vanuatu Production impact: yield – substantial negative for PNG; insignificant to small negative for Vanuatu Price impact: considerable positive Overall export revenue impact: substantial negative for PNG; small for Vanuatu
Cocoa	Countries affected: PNG, Solomon Islands and Vanuatu Production impact: yield – insignificant for PNG, Solomon Islands and Vanuatu. Increasing temperature likely to have less of an impact in Vanuatu; however, this might be offset by increasing intensity of cyclones and higher rainfall Price impact: small positive Overall export revenue impact: small negative	Countries affected: PNG, Solomon Islands and Vanuatu Production impact: yield – small to moderate negative for PNG, Solomon Islands and Vanuatu. Price impact: moderate positive Overall export revenue impact: moderate negative
Coconuts	Countries affected: All the Melanesian countries Production impact: negligible PNG and Solomon Islands; small negative Vanuatu and Fiji Price impact: small to moderate increase in coconut oil prices expected Overall export revenue impact: negligible for PNG and Solomon Islands; small negative for Vanuatu and Fiji	Countries affected: All the Melanesian countries Production impact: negligible to small negative for PNG and Solomon Islands; small negative Vanuatu and Fiji Price impact: moderate positive increase Overall export revenue impact: negligible for PNG and Solomon Islands; small negative for Vanuatu and Fiji
Palm oil	Countries affected: PNG and the Solomon Islands Production impact: none in terms of yield; possible increased planting in response to higher prices leading to an overall increase in oil production Price impact: real price increase expected Overall export revenue impact: substantial positive	Countries affected: PNG and the Solomon Islands Production impact: none or negligible impact on yield, with further increase in planting and thus a significant further increase in production Price increase: further real price increase expected Overall export revenue impact: further positive impact expected
Sugar	Countries affected: Fiji (substantial industry) PNG (small industry) Production impact: small negative Price impact: small positive Overall export revenue impact: neutral	Countries affected: Fiji and PNG Production impact: moderate negative Price impact: small positive Overall export revenue impact: small negative

Horticulture and other fresh produce		
Cassava	Countries affected: Fiji Production impact: yield – insignificant to low negative; total production – positive low to moderate Price impact: likely positive but probably insignificant Overall export revenue impact: positive but insignificant although there could be some substitution of cassava exports for taro	Countries affected: Fiji, although some medium- to long-term prospect of other Melanesian countries becoming cassava exporters Production impact: yield – low negative; total production – positive moderate Price impact: low Overall export revenue impact: positive small to moderate depending on whether cassava becomes a significant substitute for taro exports
Taro	Countries affected: Fiji Production impact: could range from low to high negative , depending on the incursion of TLB and whether resistant varieties are in place Price impact: would range from low to high depending on the production impact and the Samoan export response Overall export revenue impact: low to high, depending on TLB. Taro is Fiji's main agricultural export earner after sugar so would have significant export earning consequences	Countries affected: Fiji Production impact: could range from medium to high negative, depending on the incursion of TLB and whether resistant varieties are in place. The longer the time period the greater the likelihood of a damaging pest and disease incursion Price impact: would range from medium to high depending on the production impact and the Samoan export response Overall export revenue impact: medium to high, depending on the type of pest and disease incursion
Cocoyam	Countries affected: currently only very small exports from Fiji but prospects for expansion from Fiji and possibly Vanuatu Production impact: yield – insignificant to low negative; total production – positive low to moderate Price impact: low to moderate depending on the extent cocoyam substitutes for taro on export markets Overall export revenue impact: negligible	Countries affected: Fiji and possibly other Melanesian countries Production impact: overall moderate positive Price impact: moderate depending on the extent cocoyam substitutes for taro in export markets Overall export revenue impact: small positive
Breadfruit	Countries affected: Currently only very small exports from Fiji but prospects for significant expansion from Fiji and possibly Vanuatu Production impact: yield – negligible; total production low positive Price impact: negligible to small Overall export revenue impact: insignificant to small positive.	Fiji, probably Vanuatu and possibly Solomon islands Production impact: overall moderate positive Price impact: small Overall export revenue impact: small positive
Papaya	Countries affected: Fiji Production impact: low to moderate negative Price impact: low to moderate positive Overall export revenue impact: small negative as comparative advantage shifts in favour of Australia	Countries affected: Fiji Production impact: moderate negative Price impact: moderate positive Overall export revenue impact: moderate negative as comparative advantage shifts in favour of Australia

Temperate horticulture products (e.g. asparagus snow peas, citrus, broccoli, persimmon, floriculture products)	Countries affected: No countries growing these products for exports. Climate change could mean that in the future some locations in the PNG Highland are suitable Production impact: low to moderate positive Price impact: low to moderate positive depending on climate change's impact on Australian horticultural products Overall export revenue impact: potentially a small positive impact depending on the impact in Australia and PNG's ability to overcome infrastructure and marketing constraints	Countries affected: potentially PNG Production impact: moderate positive Price impact: moderate to substantial positive depending on climate change's impact on Australian horticultural products Overall export revenue impact: potentially a moderate positive impact depending on the impact in Australia and PNG's ability to overcome infrastructure and marketing constraints
Spices and stimulants		
Vanilla	Countries affected: PNG, Vanuatu and small Fiji industry Production impact: negligible to small negative Price impact: small to moderate positive depending of the climate change's impact on Madagascar's vanilla Overall export revenue impact: insignificant to small positive	Countries affected: PNG Vanuatu and Fiji Production impact: small negative Price impact: Moderate to substantial positive depending of the climate change's impact on Madagascar's vanilla Overall export revenue impact: small to moderate positive
Ginger	Countries affected: Fiji Production impact: negligible to small negative Price impact: Small to moderate positive Overall export revenue impact: insignificant to small positive	Countries affected: Fiji Production impact: small negative Price impact: moderate positive Overall export revenue impact: Small positive
Kava	Countries affected: Vanuatu and Fiji Production impact: small negative Price impact: small positive Overall export revenue impact: Small negative	Countries affected: Vanuatu and Fiji Production impact: small to moderate negative Price impact: small to moderate positive Overall export revenue impact: small to moderate negative
Forestry products		
Timber	Countries affected: PNG, Solomon Islands, Fiji Production impact: small negative Price impact: small positive Overall export revenue impact: neutral to small negative	Countries affected: PNG, Solomon Islands, Fiji Production impact: moderate negative Price impact: moderate positive Overall export revenue impact: small negative
Livestock products		
Beef	Countries affected: Vanuatu Production impact: small negative Price impact: small positive Overall export revenue impact: neutral to small negative	Countries affected: Vanuatu Production impact: moderate negative Price impact: moderate to substantial positive depending on the climate changes impact on the Australian beef industry Overall export revenue impact: potentially a moderate positive impact depending on the impact of climate change on Australia's beef industry

was estimated at approximately USD 36 million (Fiji National Statistics). As with PNG and Solomon Islands a possible increase in the intensity of cyclones and El Niño droughts could degrade the value of plantation forests. The most severe impact is expected to be on pine plantations from increased wind damage, fire and localised land slippage. Mahogany plantations may also suffer from more intense cyclones if they occur during their most vulnerable years of growth (about age 3–10 years).

Consequently, an overall negative impact on Fiji's agricultural and forestry export earnings is expected. Such consequences will be less significant for Fiji than for Vanuatu because of Fiji's much higher proportion of non-agricultural exports.

9.2.2.2 Impact on imports

The evidence presented in Chapter 4 indicates that over the course of coming decades the price of imported grain, particularly rice, is likely to increase sharply in the face of decreasing global supply (climate change) and increasing demand (population). Changing global conditions would suggest a permanent structure shift to the conditions that prevailed in 2008 during the world food crisis, with imported grain becoming increasingly more expensive relative to the traditional staples grown in PICTs. The net impact on the balance of payments of this price increase will depend on a number of interrelated factors including:

- the magnitude of the price increase;
- how consumers respond to the higher imported grain prices (the price elasticity of demand for imported grains);
- the inter-relationship of domestic staple prices to imported grain prices (the cross price elasticity); and
- the supply response of domestically grown staples to domestic price increases.

Disentangling these various interrelated impacts would require data availability and econometric modelling far beyond the scope and the resources available for this book. However, 20 years of time series data from PNG give some insight as to what the response of consumers from Melanesia might be to higher real prices of imported grains and of producers to higher staple food prices. Statistical analysis of these data suggests there will be a significant increase in the demand for domestically grown staples in response to an increase in the price of rice. This analysis is presented in Box 2.

***Box 2** Consumer response to higher imported grain prices: model for PNG*

Estimating the demand for rice in PNG

The demand for rice in PNG in a given year is taken to depend on the price of rice, the price of available substitutes, income available to purchase rice, and population. In some years other factors can significantly impact on rice consumption. For example, in 1997 there was a surge in rice consumption due to food aid in response to the extreme drought and frosts in the Highlands.

The model

A simple demand equation for rice in PNG is specified as: RD = f (RRP, RSPP, RI, Pop, D) where:

RD = Rice demand. Measured as tons of rice imported. (The insignificant volume of local rice production has not been included).

RRP = Retail rice price. Measured as the average annual Madang price toea/kg. Madang is seen as a somewhat representative town and thus a reasonable proxy for rice prices in all locations.

RSPP = Retail sweet potato price. Measured as the average annual Madang price toea/kg

RI = Real income. Measured as GDP million Kina deflated by the CPI (1977 = 100)

Pop = Population (,000)

D = a dummy variable for years when there were extraordinarily high rice imports (1986 and 1997; 0 = 1997 and 1986; 1 = all other years.) In 1997 a severe drought and frosts affected much of PNG. As a result villagers and their urban 'wantoks' bought substantially more rice, as villagers had a greatly reduced self-sufficiency food supply.

The estimated equation and statistical results

The demand equation was estimated by ordinary least squares (OLS) using annual data from 1977 through 2007 (Bourke et al. 2008; Appendix A2.5.1). The data were converted into logarithms to allow for the direct estimates of the price and income elasticities of demand. The estimated equation (with t values in parenthesis)

$$\text{Log RD} = -7.85 - 0.55 \log \text{RRP} + 0.49 \log \text{RSPP} + 0.48 \log \text{RI} + 2.01 \log \text{Pop} + 0.35\,\text{D};\ R2\ \text{adjust} = .95$$

(-1.75) (-4.17) (2.87) (2.92) (4.63) (6.61)

The estimated equation

- The estimated equation provides a good fit of the data, with the model explaining around 95% of the variation in the rice consumption.
- All the variables have logical signs and magnitudes.
- There is a strong negative relationship between the demand for rice and the retail price of rice after controlling for the influence of income, the price of the main substitute, population and severe climatic events.
- There is a strong positive relationship between the prices of sweet potato, the main substitute, and the demand for rice.
- There is a strong positive relationship between the demand for rice and income and population.
- All the variables are highly statistically significant.

Interpreting the estimated coefficients

The price elasticity of demand for rice in PNG is estimated at -0.55; that is, a 1% increase in the retail price of rice leads to a 0.55% decrease in rice consumption (and vice versa), after controlling for the price of sweet potato, real GDP and population and the impact of the severe drought. The estimated coefficient shows that people's rice consumption is quite responsive to changes in the price of rice.

The cross price elasticity of the demand for rice to the price of sweet potato in PNG is estimated at 0.49; that is, a 1% increase in the retail price of sweet potato leads to a 0.49% increase in rice consumption (and vice versa), after controlling for the price of rice, real GDP and population and the impact of the severe drought. The estimated coefficient shows that people's sweet potato consumption (the main domestic staple and a proxy for all domestically grown staples) is quite responsive to changes in the price of rice.

The income elasticity for rice in PNG is estimated at 0.48; that is, a 1% increase in real income (measured by real GDP) is estimated to lead to a 0.48 % increase in the demand for rice. The result shows that real GDP provides a good proxy for the household income in determining the demand for rice in PNG. Rice was found in PNG to be a superior good with reasonably high income elasticity. The estimated demand equation explains why per capita rice consumption in PNG has increased in recent times despite the substantial increase in rice prices. The positive income effect of the booming PNG economy has more than offset the negative price effect of increasing rice prices.

Rice demand and population growth: The results show that for every 1% increase in population the demand for rice increased by 2%, after controlling for the impact of price and income. This would seem to be an excessively high coefficient. However, it is highly statistically significant with a t statistic of 4.65. This suggests that population growth will be the main predictor of the future demand for price in PNG.

The statistical analysis presented in the box for PNG suggests that an increase in the real price of imported rice will lead to a decrease in rice consumption and an increase in the consumption of locally grown staples after controlling for the impact of income and population growth. Sweet potato is seen as a reasonably close substitute for rice by consumers. The estimated cross elasticity of demand between rice and sweet potato over the period was estimated to be 0.49 and was statistically significant. Based on this analysis a rise in the price of rice could be expected to lead to a substantial increase in demand for sweet potato. Sweet potato can be seen as a proxy for all locally grown staples. Such high quality time series data are not available to undertake a similar quantitative analysis for the other Melanesian countries; however, it is assumed that similar results would be obtained.

The significant increase in the sale of fresh produce in PNG in years following the large devaluation of the kina in 1994 indicates that PNG farmers are responsive to changes in prices despite marketing infrastructure constraints (Allen et al. 2009). If demand for staples does increase and prices increase then we might expect PNG farmers to respond to this through greater production.

Perhaps the greatest impact resulting from the increase in the real price of imported grains will be to encourage rural households to grow more staple foods for their own consumption rather than use their cash income to purchase imported food. Governments should also be encouraged to support this trend by encouraging urban gardening and promoting and supporting the processing of locally produced agricultural products.

For some crops in some locations climate change will limit the response of farmers to improved prices, as summarised in Chapter 4 (Table 4.2). It is likely that by 2050, because of climate change, some staple food crops will be more important (e.g. cassava, cocoyam and breadfruit) while the importance of others will decline (sweet potato and taro). Such adjustments would represent a continuation of the ongoing process of the changing mix of traditional staples in response to changing environmental conditions and other factors.

Climate change is projected to have a moderate short-term impact on Pacific Island poultry production and a high medium-term impact. This could be expected to result in an increase in poultry imports from countries where poultry is grown in more controlled environments.

9.2.3 Food security

As discussed in Chapter 1, food security is defined by the availability of domestically produced food or imports; access of individuals to resources to acquire food; adequate food supply (use); and the stability of access and availability. In Melanesia, with such a high proportion of the population living in rural areas and growing their own food, any negative impacts of climate change on domestic food production could have large subsequent impacts on food availability. Furthermore, access to food is quite different between rural and urban populations. In all Melanesian countries the urban poor and low income landless rural dwellers are particularly vulnerable to the impact of climate change on agriculture globally because of the potential effect on the price of food imports.

9.2.3.1 Availability

In Melanesia, carbohydrate is generally available for most people: almost all villagers grow their own food and there are growing domestic markets (McGregor et al. 2009). Fiji and Vanuatu have a high level of self-sufficiency in food production, such that the supply of energy (carbohydrates) is adequate. This is also largely true for PNG and Solomon Islands, although both countries have sections of the population (mainly rural villagers) that do not have adequate intake of protein and concentrated energy foods such as oils and fats. This is particularly true for areas between the coast and central highlands in PNG and areas such as the Guadalcanal Weather Coast in Solomon Islands. There is also a vigorous and growing domestically marketed food sector. In PNG, increasing amounts of staple foods are being moved away from the highlands to coastal urban centres, thereby increasing the availability of these foods in urban centres. In Solomon Islands, a similar movement of produce is occurring from the Guadalcanal Plains and Malaita to Honiara. Fiji has a strong commercial food production sector supplying domestic markets.

Negative impacts on this domestic production as a result of climate change will have a significant impact on food availability. As highlighted earlier, in PNG and Solomon Islands, sweet potato is the most important crop in terms of calorie provision. Tuber yield is vulnerable to high rainfall and it will be difficult for most growers to counter further increases in precipitation. Any impact is expected to be limited in the short term. However, in the PNG lowlands, tuber yields are already vulnerable to high rainfall, therefore sweet potato cultivation in these areas could be affected sooner. In the medium term wetter conditions are expected to have a significant negative impact on sweet potato production.

As discussed in Chapter 4, the occurrence and spread of taro leaf blight (TLB) is correlated with minimum night-time temperatures. Rising temperatures will increase the chance of incursions in Vanuatu and Fiji which, unlike Solomon Islands and PNG, currently do not have TLB. In the medium term the chance of an incursion in these countries is high. Taro-based cropping systems dominate staple food production in Vanuatu's wetter locations so an incursion could be expected to have a significant negative impact. For Fiji TLB would severely affect the production of the main taro export variety as well as production for domestic consumption. In PNG a spread of TLB can be expected to areas not currently affected. In Vanuatu and Fiji the long-term impact will depend upon the success of taro breeding programmes, which are working to increase the use of TLB-resistant varieties by farmers.

Apart from taro and sweet potato, yams are most likely to be affected by hotter, wetter conditions, particularly due to anthracnose disease. Other food staples such as bananas, aibika, cassava, breadfruit and coconut are expected to experience only a minimal impact in the short term. The impacts of ENSO cycles are likely to remain the largest influence on domestic supply of these crops. That said, the future impact of pests and diseases as a result of increasing rainfall and temperatures is relatively unknown. In the medium term the impact of hotter, wetter conditions can be expected to adversely impact production and climate change will accentuate the impact of the existing ENSO cycles. In Chapter 7 similar negative impacts of livestock production were identified, particularly for poultry production at the village level.

Shortfalls in domestic food production are made up for by imports. As outlined in Chapter 1, the western Melanesian countries have a relatively low dependency on imported foods; however, they do rely on agriculture for export earnings, particularly from cash crops such as coffee, cocoa and coconuts, to pay for these imports. Export earnings from these crops are expected to decrease overall. The ability at the national level for these countries to continue food imports will therefore depend on whether other sectors can compensate for lost export earnings. For Solomon Islands and PNG this might come from exports of palm oil and minerals but for Vanuatu this would need to come from non-agricultural sectors such as tourism. Similarly, Fiji will be reliant on the tourism industry to help boost foreign exchange earnings.

9.2.3.2 Access

Within Melanesian countries, access to food is quite varied between urban and rural populations and they are likely to be affected differently. As highlighted above, rural self-sufficient producers may suffer negative impacts if they are reliant on sweet potato or taro for their energy consumption, but the most vulnerable households are the urban poor and low income landless rural dwellers. This is because they are vulnerable to the impact of climate change on food prices (both domestic and imports). Within these poor households, women and children tend to be most vulnerable.

9.2.3.3 Use

Climate change is expected to increase the price of imported food. Imported grains make up a large percentage of Melanesian diets, particularly in urban populations. Growing consumption of imported food, which tends to be nutritionally inferior to local staples, has been a contributor to high rates of obesity, heart disease and diabetes across the Pacific. If consumers respond to higher prices of food by substituting imports with locally grown food, it is feasible that this could lead to health improvements. It is also possible that consumers will react by buying even cheaper and lower quality food products (Russell 2009). The relative price change between locally grown and imported foods is therefore likely to play an important role in food use.

9.2.3.4 Stability

In the medium term, climate change can be expected to accentuate the impact of existing ENSO cycles, which are currently the greatest factor in the stability of agricultural production. Climate change-induced increases in rainfall and temperatures are also expected to lead to increased flooding and droughts in some areas, which will negatively affect self-sufficiency and commercial agricultural producers. Equally, a rising intensity of cyclones could have a devastating impact on agricultural and forestry production.

9.2.4 Employment and livelihoods

For the countries of Melanesia, particularly western Melanesia, agriculture is overwhelmingly the most important industry in terms of employment and livelihoods. Climate change will affect employment and livelihoods through its impact on the export of agricultural commodities and domestic market and self-sufficiency production.

9.2.4.1 Export commodities

The negative impact of climate change on the production of export commodities has the potential to have a significant negative impact on employment and livelihoods of rural households within Melanesia. The largest negative effects of climate change on agricultural exports earnings are expected to be felt in the coffee sector, and to a lesser extent in cocoa and coconut production. In PNG more than 50% of rural households generate an income from Arabica coffee (Bourke and Hardwood 2009). In lowland locations, a further million derive their income from the sale of cocoa and or copra. In Vanuatu, the 2007 Agricultural Census states that 71% of Vanuatu's rural households earn income from coconuts and receive little or no income from tourism. In Solomon Islands most rural households generate income from copra and cocoa with little coming from the export of logs. Consequently, climate change is likely to negatively impact the export commodities that provide a substantial amount of income for rural households. In the Pacific, rural households are also often the poorest. Within PNG it is estimated that 94% of the poor live in rural areas (ADB 2012).

9.2.4.2 Domestic and self-sufficient production

As discussed previously, it is expected that the price of imported grains such as rice (which currently forms a large component of Pacific Island diets) will increase. The impacts of that on the livelihoods of Pacific Islanders are twofold. Firstly, it is possible that increased demand for domestically grown food staples will increase domestic food prices, leading to an increase in income for those households who supply this food. Increasing populations and urbanisation (particularly for western Melanesian countries) will probably further add to demands for domestically produced food. This could lead to an improvement in the livelihoods of domestic producers. Secondly, increases in the price of imported food may increase the amount of self-sufficiency agriculture that households undertake. Urban households or rural households with no access to land will not be able to increase their agricultural production self-sufficiency. A large percentage of such households in Melanesia already live below the poverty line (Chapter 1). For these households a real increase in staple food (imported and domestic) prices will mean a decline in their real disposable income. With reduced income, households will need to redistribute their meagre family expenditure budget. This involves a combination of buying less food, or substituting poorer quality lower priced food, or going without other basic needs. Such adjustments tend not to be spread evenly across the household, with women and children bearing a disproportionate share of the burden. Rising food prices resulting from climate change thus bring with them the prospect of disruptions at the household and community level that could have flow-on political and economic consequences.

At the same time, climate change is predicted to negatively impact on the contribution of forest resources to Pacific livelihoods. The greatest impacts are expected to come from the effect of rising sea levels on coastal forests, particularly mangroves, atolls and low elevation swamp forests. Coastal forests play a vital role in supporting the livelihoods of coastal communities of Melanesian countries. Mangroves are sources of protein-rich foods (especially fish, crustaceans and shellfish), high quality timber and fuel wood. They also act as fisheries nurseries and provide a vital service in terms of storm surge protection. Mangroves are highly resilient in the short term but over time sea-level rise will reduce their overall productivity and their ecological services are expected to decline. Atolls such as Ontong Java are already affected by rising salinisation. In Vanuatu almost all rural households collect firewood for their own use or for sale, and a significant number gather timber from forests for building and repairing their own houses (Vanuatu National Statistics Office 2008). This situation is likely to be the same for many other rural households in Melanesia. As discussed in Chapter 8, the extractive uses of coastal forests provide, arguably, only a fraction of their real value, when their wider benefits such as storm surge protection and watershed management are considered. Flooding and the negative impact of extreme climatic events have a significant impact on economic growth within the Pacific. Decreasing effectiveness and productivity of natural protections such as mangroves will leave some populations more vulnerable to extreme climatic events and undermine the sustainability of their livelihoods. Active mangrove planting programmes and better management will be an essential adaptation response.

9.3 How will the impact of climate change on agriculture affect the economies and communities of the mid-sized PICTs of Polynesia?

In Group 2, Tonga and Samoa are taken as representatives of the larger Polynesian countries, which could also have included French Polynesia.

9.3.1 GDP and growth

In recent years the Tongan economy has experienced minimal growth and the Samoan economy has slowed considerably. These two economies will face major growth challenges in both the short term (up to 2030) and medium term (up to 2050) irrespective of the impact of climate change on agriculture. These include:

- very low levels of exports and a severe trade imbalance;
- exceptionally high dependency on remittances; and
- the debilitating impact of NCDs.

Agriculture is considerably less important for the mid-sized Polynesia countries than for the Melanesian countries, but it still contributes 20% to GDP in Tonga and 10% in Samoa (Table 1.6, Chapter 1). Both countries have relatively strong self-sufficiency sectors and the increasing comparative advantage of traditional staple crops is expected to have a positive impact on the domestic traded food sector in both countries. As detailed in the following sections, Samoa's taro industry is also well positioned to take advantage of any comparative advantage it might receive through negative impacts of climate change on the taro industry in Fiji.

As with Fiji and Vanuatu, if the intensity of cyclones increases as projected (Chapter 2) the resulting economic costs are expected to negatively affect GDP, even if there are less frequent cyclones. The cost to the Samoan Government of rehabilitating the crop and livestock sector after Cyclone Evan in 2012 was estimated at USD 2.7 million (Government of Samoa 2013). A very strong cyclone in 1991, Cyclone Val, severely affected local food production and the resulting food aid encouraged a marked increase in rice and wheat imports that have never been reversed (Galanis et al. 1995). It also spelt the final demise of Samoa as a significant cocoa exporter.

Overall, it is hard to determine a net positive or negative impact on GDP and growth in the Polynesian countries. Tonga and Samoa may be able to benefit from an increasing comparative advantage in staple crops but this will require increased and more focused support to the traditional food crop sector. Without this, it is likely that the impact of increasing intensity of cyclones and frequency of weather extreme events will have a net negative impact.

9.3.2 Trade and balance of payments

Both Tonga and Samoa currently face severe trade imbalances as shown in Table 9.4 below. Climate change is likely to exacerbate this situation although there are scenarios under which both Samoa and Tonga could increase their agricultural exports.

Table 9.4 Samoa and Tonga trade statistics, summary, 2007–2012 (source: Central Bank of Samoa and Tonga Department of Statistics)

	2007	2008	2009	2010	2011	2012
Samoa ('000 tala)						
Total exports (FOB)	37,098	26,986	29,471	57,476	57,009	71,512
Total imports (CIF)	593,639	659,181	558,778	694,602	739,048	706,794
Trade balance (exports – imports)	-556,541	-632,195	-529,307	-637,126	-682,039	-635,282
Exports as a % of imports	6%	4%	5%	8%	8%	10%
Tonga ('000 pa'anga)						
Total exports (FOB)	15,769	17,511	17,927	20,218	24,867	27,399
Total imports (CIF)	281,032	324,445	303,798	318,630	372,575	344,686
Trade balance (exports – imports)	-265,263	-306,934	-285,871	-298,412	-347,708	-317,287
Exports as a % of imports	6%	5%	6%	6%	7%	8%

In Samoa the value of food imports is three times the value of food exports. Per capita consumption of imported rice and wheat flour has doubled over the last 25 years. Samoa now imports around 10,000 tonnes of wheat flour and 3,000 tonnes of rice annually. The annual foreign exchange outflow for the purchase of this grain was approximately USD 6 million in 2013. As discussed in previous chapters, climate change is expected to result in an increase in the real price of imported grain, possibly returning to the level reached during the global food crisis of 2008, which saw the foreign exchange outflow for the purchase of grain from Samoa valued at USD 7.5 million. As with the Melanesian countries, higher prices may lead to some substitution of imported foods with domestically grown staples. The increase in domestically grown staples would, however, need to be considerable if it were to offset the increase in the value of imports to a significant degree.

Agricultural exports from Samoa are currently minimal. These exports have been in decline since the early 1990s, mainly as a result of a series of severe cyclones and the arrival of TLB in 1993. Depending on the impact of climate change on Fiji taro production, it is however, conceivable that taro exports will again increase. Following the TLB outbreak in 1993 Fiji replaced Samoa as the main supplier of taro to New Zealand. The preferred export variety in Fiji is genetically vulnerable to TLB and as highlighted previously, the probability of a TLB incursion in Fiji in the medium term is high. Samoa on the other hand, as discussed in Chapter 4, has diversified its taro production to TLB-resistant varieties and has recommenced exports on a small scale. If Fiji is unable to sufficiently protect its export industry from the potential negative effects of TLB, Samoa will be well placed to again become the dominant supplier of taro to the New Zealand market.

For Tonga the value of food imports is currently 7.5 times that of agricultural exports and it has a similar grain import profile as Samoa. As with Samoa there may be a small increase in domestic production as a result of rising import prices, but it is unlikely to be large. The value of livestock product imports, particularly for poultry, for both countries is expected to increase as a result of the production impact of climate change (Chapter 7).

Tonga, as yet, does not have TLB and its cooler temperatures make it less susceptible to the disease than Fiji or Vanuatu. Taro is also a relatively less important staple in Tonga. Yam is a more important crop and is expected to experience negative production impacts with climate change, in particular with increasing rainfall. In recent years Tonga's agricultural exports have been declining and are equivalent to only a very small percentage of imports. It is possible that the negative impacts of climate change in Madagascar, which has experienced some extreme cyclones in recent decades, could boost Tonga's exports of vanilla. This possibility for Tongan vanilla, however, is much less clear cut than the scenario described for Samoa for taro. Tonga and Samoa do not receive a significant amount of export revenue from forestry exports. As shown in Table 8.3 (Chapter 8) forestry contributed about 3% to GDP in Samoa in 2006. Export figures from the Central Bank of Samoa estimated that timber exports were equal to approximately USD 4700 in 2006 but this fell to nothing in 2009 and 2010. In addition, it is expected that the greatest negative impacts of climate change on forests in Samoa will be on coastal forests. Samoa's agroforests are expected to cope well with climate change due to work to optimise multispecies plantations and use climate-resilient (including wind-resistant) native species. Consequently, climate change is not expected to have any noticeable impact on the contribution of forestry to the balance of trade of Samoa or Tonga.

9.3.3 Food security

Food availability is determined by both food imports and domestic production. Expected increases in the real price of imported grain will have some adverse impact on the availability of food if there is not a compensating increase in remittances, export earnings and tourism receipts. As discussed previously there is a scenario under which Samoa's taro exports could increase, which would improve its ability to import food. Despite a high reliance on imported grains there is a relatively strong self-sufficiency base in Samoa and Tonga. Overall, agricultural production is not anticipated to be significantly impacted by climate change although production may shift towards crops which are likely to be less affected in the long term, such as banana, cocoyam, breadfruit and cassava. As with Melanesia, rising prices of imported foods may also lead to an increase in the consumption (and therefore production) of locally produced staples. It is anticipated, however, that in the future, livestock products, particularly poultry at the village level, will become more difficult to produce.

The expected rise in imported grain prices due to climate change is not likely to impact on the urban population of the Polynesian countries to anywhere near the same extent as that described above for the Melanesian countries. The large low-income squatter settlements that now characterise Port Moresby, Honiara, Port Vila and Suva are largely absent from Apia and Nuku'alofa. Generally Polynesian urban households are more closely linked to their rural villages and their food production than their counterparts in Melanesia. These links will provide some cushion to the impact of the likely increase in imported grain prices. Also, unlike their Melanesian counterparts, these households have, to date, had access to substantial cash remittances sent from their relatives living overseas.

In Samoa, taro is the most important food staple in terms of calories provided. As discussed in Chapter 4, the destruction of taro production in 1993 was described at the time as being equivalent to Ireland's potato famine in the late 17th century (McGregor et al. 2009). Fortunately, such a catastrophe did not materialise thanks to the inherent strength of Samoa's traditional cropping systems and the country's ability to import grain. Since 1993 substantial public investment in taro breeding has enabled Samoa to develop TLB-resistant varieties that are now firmly integrated into the Samoan cropping system. This breeding programme is now starting to give priority to drought tolerance. Because of this investment Samoa's most important food staple is not expected to be severely affected by climate change, at least in the short term. A study undertaken by the International Union for Conservation of Nature (IUCN), which made projections through to 2030, estimated the benefit-cost ratio of this germplasm investment as between 15.1 and 16.4, depending on the selected discount rate (McGregor et al. 2011).

Samoa's 1999 Agricultural Census estimated that the area of land under taro production had fallen to 2600 hectares from 12,900 in 1989 (before TLB). By the 2009 Agricultural Census taro planting had increased to 7340 hectares due to the development of TLB-resistant varieties acceptable to local consumers. Over this decade there has been a three-fold increase in domestic taro consumption (Samoa Agricultural Census 2009). Further development of taro production in Samoa, both for the domestic and the export market, would support livelihoods.

For Tonga, taro is also an important staple, although relatively less important than for Samoa. As mentioned earlier, Tonga is also probably less susceptible to TLB than Samoa was, although in the longer term TLB might reasonably be expected in Tonga by 2050 because of warmer average temperatures. A small negative impact on food availability might therefore occur in the medium term.

Other important food staples for Samoa and Tonga are cocoyam, giant taro, breadfruit, banana and coconuts. Yams are also important in Tonga. Yams are expected to suffer small declines in productivity in the short term. For plantains and bananas, hotter and wetter temperatures in the long term will decrease productivity. The least affected crops are likely to be cocoyam, cassava, breadfruit and coconuts (although senile coconuts will be severely affected by more intense cyclones). That said, it is difficult to predict changes in pests and disease and the impacts of potentially more intense cyclones. However, it remains reasonable to assume that, in the medium term, staples such as cassava, breadfruit and coconuts will have assumed greater importance in domestic food production.

As with the Melanesian countries, the stability of domestic supply is affected principally by ENSO-induced climate events and not climate change per se. Nevertheless, an increase in intensity of extreme climatic events could have negative consequences on the stability of food supply in larger Polynesian countries.

In regards to access to food, the same difference between urban and rural households as in Melanesia exists, but due to lower population growth, immigration and less rapid urbanisation, the future divergence in access is likely to be less stark.

The increased number of low income households living in urban centres is expected to be far less in Polynesia than in Melanesia or in the micro-states of Micronesia. Populations in Samoa and Tonga are increasing at a rate of 0.3% annually. Equally, the urban population is increasing by 0.5% annually in Tonga but actually decreasing by 0.6% in Samoa. This compares with growth rates of urban populations of 4.7% in Solomon Islands (ADB 2012).

Increases in expenditure on imported food at the household level could be expected to be offset in the short term by increased remittances. Whether this will continue in the medium term is harder to predict. It is possible the re-establishment of exports of taro and potential growth of horticultural exports would also boost household incomes in Samoa.

9.3.4 Employment and livelihoods

The percentage of household income derived from agriculture in Samoa is estimated at 19.5% in 2008 and 13.3% in Tonga in 2009 (SPC, NMDI database). This demonstrates that agriculture is important for livelihoods in the Polynesian countries but is significantly lower than in Melanesian countries.

Since agricultural exports in these countries are currently minimal, this household income from agriculture is mainly derived through domestic production for sale and consumption. Prior to 1993, 96% of agricultural households in Samoa grew taro, of which 38% grew it at least partly for sale (Chan et al. 1998). The 2009 Agricultural Census, however, showed that while 9000 households grew taro, only 176 (2%) of them grew it mainly for sale. Crop production is therefore currently principally for home consumption. Households that do engage in the sale of locally produced staples may experience a positive effect on household income as rising import prices increase the comparative advantage of domestic staples. This could incentivise households to increase their production for domestic sale.

It is also possible that a continued resurgence in Samoa's taro industry and increases in exports could have a beneficial impact on household livelihoods. Currently agriculture accounts for 33% (2011) of employment in Samoa and 25% (2009) in Tonga. The taro industry traditionally played an important role in employment in Samoa. If Samoa increases its exports the overall benefit from increased employment could be considerable.

As with the Melanesian countries, forest resources play an important part in supporting the livelihoods of communities in Tonga and Samoa. While there is relatively little contribution to livelihoods from employment within the forestry sector or income from the sale of forestry goods, households do rely on forests for food, fuel, medicines, garlands and perfumes, and many other products. In Tonga it is estimated that more than half of households collect wood for cooking fuel (Moorhead 2011). As with the Melanesian countries, the forests most likely to be negatively impacted by climate change are coastal forests. Degradation of coastal forests could occur from an increase in the intensity of cyclones and also rising sea levels. Two cyclones in the early 1990s, Cyclone Ofa (1990) and Cyclone Val (1991), were responsible for significant destruction of trees in Samoa. Some estimates are that up to 50% of the trees were damaged on Upolu (Moorhead 2011). Clearly, stronger winds would reduce the productivity of forest resources and their ability to support livelihoods in Samoa and Tonga.

9.4 How will the impact of climate change on agriculture affect the economies and communities of the micro-states?

This discussion for Group 3 covers many of the micro-states but puts particular emphasis on Kiribati and Tuvalu as examples of land-poor atolls.

9.4.1 GDP and growth

The growth performance of the micro-states has been highly erratic and, on average, poor and below the growth in population. These economies will face major growth challenges in both the short term (to approximately 2030) and the medium term (to approximately 2050) irrespective of the impact of climate change on agriculture. These include:

- for the atolls, the overall impact of sea-level rise on infrastructure and residential housing;
- insignificant exports and a severe trade imbalance;
- exceptionally high dependency on remittances, donor funding and income derived from offshore trust funds;
- high rates of population growth (e.g. Kiribati, Nauru, CMNI);
- high rates of urbanisation (e.g. Kiribati, FSM); and
- the debilitating impact of NCDs.

In Kiribati and Tuvalu agriculture contributes 17% (2008) and 15% (2011) to GDP respectively. This contribution is mainly through household self-sufficiency activities and the relatively high figure is more a sign of the material impoverishment in these countries rather than the strength of the agricultural sector. For Cook Islands, Nauru and Palau the contribution of agriculture to GDP is much lower at 2.7% (2010), 1.2% (2009) and 4.9% (2011) respectively (SPC NMDI)[1]. Given the relative lack of importance of agriculture for these economies, the impact of climate change on the sector is likely to have minor implications for growth and GDP. This finding is in stark contrast to the impact of climate change on the fishery sector. The inland and offshore fisheries play a hugely important role in the economies of many of the smaller islands, particularly those with large exclusive economic zones (EEZs). Seventy-nine per cent of the Cook Island's exports come from the fishery sector; this is even higher for Palau, where 92% of exports come from fisheries (SPC NMDIs). Climate change models predict a

1 SPC National Minimum Development Indicators http://www.spc.int/nmdi/

migration of tuna from west to east with an overall gain within the Pacific. Countries such as Kiribati, Tuvalu, Tokelau and Nauru, which already receive a large proportion of their government revenue from fisheries access fees, may see this income increase up to the medium term. Sustainable management of these resources will therefore be a priority for these countries in adapting to climate change (Bell et al. 2011).

9.4.2 Trade and balance of payments

All of the micro-states face severe trade imbalances. The trade merchandise of Kiribati is typical, where over the period 2003 to 2010 exports averaged only 6% of imports (Table 9.5).

Table 9.5 Kiribati trade and agricultural export statistics, 2003–2010 (AUD '000) (source: Kiribati National Statistics Office).

	2003	2004	2005	2006	2007	2008	2009	2010
Total exports (FOB)	3,545	3,145	2,964	2,674	9,560	6,570	4,378	2,601
Coconut products	2,114	2,677	2,153	1,627	7,702	4,640	2,666	1,967
Marine products	1,431	468	811	1,047	1,858	1,930	1,712	634
Imports (CIF)	72,621	79,308	83,511	79,308	78,758	91,599	77,258	64,394
Food	25,080	26,871	30,712	24,733	26,844	29,626	31,752	28,059
Fuel	10,407	9,926	16,437	20,586	20,849	24,066	15,472	19,719
Trade balance (exports - imports)	-69,076	-76,163	-80,547	-76,634	-69,198	-85,029	-72,880	-61,793
Exports as percentage of imports	5%	4%	4%	3%	12%	7%	6%	4%
Agriculture as percentage of exports	60%	85%	73%	61%	81%	71%	61%	76%

The future global impact of climate change on agriculture will have potentially serious consequences for the balance of payments of these countries. This will occur almost entirely through the expected real price increase in imported grain. Unlike the situation described for the Melanesian countries, and to some extent the Polynesian countries, there are no offsetting benefits from the improved comparative advantage of traditional staples.

9.4.3 Food security

The impact of future climate change on agriculture has serious implications for the food security of the micro-states, given that they are already amongst the most food insecure countries on earth (McGregor et al. 2009). The cropping systems of countries such as Kiribati and Tuvalu, particularly in the outer islands, continue to make a valuable contribution to household self-sufficiency despite the difficult environment in which they operate. However, they fall far short of being able to adequately meet the food needs of the communities in which they operate. Future climate change, through salinisation of groundwater, storm surges, and loss of land due to coastal erosion, will make it even more difficult for these systems to supply food to growing populations. In atoll environments swamp taro, the most important food staple, is often grown in pits, which are highly susceptible to saltwater incursion. In Chapter 4 it was indicated that due to salinisation swamp taro production would decline in importance in the short term (2030) and could disappear entirely in the medium term (2050). However, this decline could at least be slowed through the adoption of adaptation measures such as those being trialled in Palau under the Secretariat of the Pacific Regional Environment Programme, Pacific Adaptation to Climate Change project (McGregor et al. 2012).

More food will need to be imported to meet basic caloric needs and the prices of imports will increase in real terms, placing a huge strain on household incomes. Households will become increasingly food insecure unless supplementary sources of income can be found. The most likely potential sources of this supplementary income are remittances (particularly through increased migration), fishing license fees, income from offshore investment funds and aid. For a few of the micro-states, such as Palau, tourism provides an important source of this income.

9.4.4 Employment and livelihoods

Agricultural exports, with a few small exceptions, make no contribution to household income in the micro-states. The sale of crops for local consumption makes a small contribution. However, the recent HIES for a range of countries indicate that these sales seldom exceed 5% of average household income. Thus climate change's impact on agriculture is unlikely to have significant overall consequences for the cash incomes of households in the micro-states.

Climate change will, however, impact the vulnerability of many people's livelihoods through its impact on their access to forest resources. The forests on Kiribati are littoral forests, agroforests, coconut plantations and mangroves. Key species provide timber for buildings, leaves for mats, fruit, food and juice, as well as shade, protection from storm surges and many other cultural services. The production of copra in particular is a highly government-subsidised activity in Kiribati, in part to provide outer island employment and in the process slow population drift to the already overcrowded Tarawa. In the short term, coconut production in Kiribati is not expected to be affected by climate change but in the medium term, coconut production may drop, due to sea-level rise. In the wetter islands such as Butaritari, breadfruit is suffering from increasing salinity of groundwater. However, apart from salinity, (and as discussed in Chapter 4, some varieties may be more tolerant of salinity than others) breadfruit is expected to be quite tolerant to climate change. Consequently, the impact of climate change on agriculture and its subsequent impact on employment and livelihoods in the micro-states will most likely be felt by an increase in vulnerability in populations resulting from a degradation of forest resources and tree crops.

9.5 Summary and conclusions

This chapter has focused on how the impact of climate change on agriculture and forestry will affect PICTs' economies and communities. It has not looked at the impact of climate change on economies more widely. It is important to emphasise this because of the difference it makes to the conclusions. Throughout this chapter we have emphasised the relatively high impact on Group 1 Melanesian countries because of their high reliance on agriculture for GDP, export earnings and livelihoods. Group 3 countries are much less affected by changes to agriculture and forestry resulting from climate change; however, as densely populated, low-lying coral islands they are more vulnerable to climate change overall.

There are many complications in attempting an analysis of this kind, principally because the relative impact of the Pacific's agriculture sector on growth in the region will be largely determined by changes outside of the Pacific, in the global economy. It is possible that the productivity of a crop in a particular location could decline as a result of climate change but the overall financial viability of the crop could be enhanced (at least for the medium term) by even greater declines in crop production in other growing locations. Climate change is also going to have multiple and interacting impacts on sectors other than agriculture, which will lead to changes in markets, prices and the comparative advantages of economic activities (Stern 2007). For forestry, the largest influence on its contribution to exports will likely be internal approaches to forestry management, with poor management being exacerbated by climate change.

It is particularly difficult to factor in the potential impact of adaptation to climate change. A greater emphasis on some sectors by governments and funding agencies (e.g. domestic staple food production) seeking to reduce their vulnerability to climate change may lead to actual increases in production in the medium or even long term. However, these increases are likely to be lower than they could have been without climate change.

For forestry, increasing intensity of cyclones and rising sea levels will negatively impact the role forests play in supporting the livelihoods of Pacific communities. The ability of communities to integrate more wind- and salt-tolerant varieties and use better land management practices will be crucial in determining the final impact.

Underlying all of the points above is the difficulty of extracting the impact of agriculture and forestry on PICTs' economies from other wider-level trends and changes such as demographic changes or the extraction of non-renewable resources, which could have much greater consequences for growth and development in the long term. Climate change, however, can accentuate the impact of these other factors.

Nevertheless, building on the analysis of climate change's impact on key agricultural sub-sectors in Chapters 4–8, this chapter has explored the impact at the national level in relation to GDP and economic growth; trade and balance of payments; food security; and employment and livelihoods. The following bullet points pull out some of the key messages from the chapter.

9.6 Key messages

9.6.1 Who will be most affected?

- Relatively large Melanesian countries most affected: The Melanesian countries will be most affected by positive and negative impacts of climate change on agriculture due to the high importance that the sector plays in the economies, livelihoods and food security of those countries. The mid-sized countries of Polynesia are likely to be the least negatively affected and might even stand to gain from changing comparative advantages in export markets such as taro from Samoa. The micro-states, as limited agricultural producers, will be largely unaffected by changes in domestic production but are extremely vulnerable to changing prices of food globally that are expected to result from climate change.
- Disproportionate impact on the landless/urban poor: The negative effects of climate change on agriculture are likely to have a disproportionate impact on low income households, particularly those that do not have access to land. Urban dwellers or landless rural dwellers will not be able to compensate for higher import prices by increasing their own food production. They are therefore vulnerable to rising prices of both imports and domestic products. This poses a much larger problem for the urban poor in Melanesia, where the prospect of rising food prices resulting from climate change could have a significant adverse impact on households and communities, with political and economic consequences.
- Negative impact on rural livelihoods: The negative impact of climate change on the production of export commodities has the potential to have a significant negative impact on employment and livelihoods within Melanesia. This would be most severely felt from coffee in PNG, where currently more than 50% of rural households generate an income from coffee.

9.6.2 Food production and food security

- Worsening food security: All three country groupings rely on their agriculture for food security — much more so for Group 1 countries and much less so for the Group 3 countries. The combination of worsening balance of trade, the increasing price of imported grain and the increasing instability of food production will serve to worsen food security in the region. It is feasible that increases in domestic production and consumption of traditional food staples could reduce diet-related NCDs in the Pacific but this is hard to assess.

- Potential boost to domestic staple production: Anticipated price rises in imported grains, particularly rice, are expected to boost demand for domestically grown traditional staples. This could both encourage people to increase their own production (i.e. establish and expand food gardens) and also increase the incomes received by domestic producers through higher prices.
- Changing relative importance of particular staples: Taro and sweet potato are both expected to suffer significant negative production impacts from climate change (depending on location, the effectiveness of adaptive actions taken and emissions scenario over the long term). As discussed in Chapter 4, it is likely that over time, populations reliant on these crops for their daily calories will increasingly substitute more climate-resilient crops such as cassava, cocoyam and breadfruit. These adjustments are likely to occur regardless of any government interventions.
- Uncertain but potentially large negative impacts from pests and diseases: The impact of climate change on pests and diseases is largely unknown. Changing temperatures and rainfall are likely to result in the spread of pests and diseases to higher altitudes. The impact of TLB in Samoa demonstrates the potentially large socio-economic consequences from pests and diseases. Despite the strength of traditional Pacific crops and cropping systems in dealing with the risk of pest/disease incursion, there is an underlying vulnerability due to the narrow genetic base of the region's traditional staples, particularly the aroids. The Samoan TLB experience discussed in Chapter 4 clearly illustrates the high economic returns that can result from public investment in appropriate germplasm development as a climate change adaptation strategy. Vanuatu is now proactively adopting this approach as a 'no regrets' climate change adaptation strategy.

9.6.3 Trade impacts and livelihood implications

- Strains on agricultural exports: Exports of coffee and to a lesser cocoa, coconut products, sugar, and high value horticultural crops, are all expected to face negative production pressure due to climate change. These industries play an important role in the larger Melanesian countries in providing livelihoods and export revenue. Possible increases in global prices for these commodities are unlikely to fully offset production decreases.
- Worsening balance of trade across all groups but especially micro-states: Rising prices of grain imports resulting from climate change will significantly increase the import bill of all PICTs. For Melanesia, agricultural export revenues for most agricultural commodities are expected to decline at least in the medium term. This may be partially offset by gains in palm oil exports for PNG and Solomon Islands but overall the balance of trade in Melanesia is likely to worsen. Population growth and urbanisation in western Melanesia and some of the micro-states will compound this effect. For Melanesian and mid-sized Polynesian countries, a subsequent boost of domestic production of food staples may partially offset the increasing import bill but this will not be possible in the micro-states.

Consequently, the micro-states are expected to suffer the greatest deterioration in the balance of trade.

- Reduced productivity of forest resources: Negative impacts of climate change on the Pacific's forest resources are likely to undermine the sustainability of Pacific livelihoods. The greatest negative impact of climate change on forests is expected to be on coastal forests, including mangroves. Increasing sea-level rise and possible increased intensity of cyclones have the potential to seriously reduce the productivity of coastal forests, which provide not only extractive benefits (such as food, fuel and medicine) but also important ecosystem services such as storm surge protection and watershed management. A reduction in the productivity of these resources will undermine the sustainability of livelihoods particularly for communities on atoll islands.
- Shifting comparative advantage between countries: This possibility was illustrated by the case of taro. Following the outbreak of TLB in Samoa in 1993, Fiji replaced Samoa as the main supplier of taro to New Zealand. Taro is now an important Fijian export industry, but the preferred export variety is genetically vulnerable to TLB. An incursion of TLB into Fiji (and also Vanuatu) is highly likely in the medium term. Samoa has been successful in integrating more TLB-resilient varieties into its domestic production. If Fiji is not able to also incorporate TLB-resilient varieties into its production it is possible that its taro export industry will be devastated, in which case Samoa will be well positioned to regain the market.

9.6.4 Increasing demands on government budgets

- Increasing instability and rehabilitations costs: As discussed in Chapter 2, some climate change models predict that cyclones will increase in intensity in PICTs but reduce in frequency. Most models predict increasing temperatures and rainfall. These eventualities would greatly increase the instability of agriculture, threaten coastal forest resources and increase the costs of rehabilitating the sectors. This will increase the demands on available public funds and reduce the availability of funds to invest in longer-term climate change adaptation. The challenge will be to attract private investment to be part of the adaptation response.

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Photo: Andrew McGregor

Chapter 10

Adapting Pacific agriculture and forestry to climate change: management measures and investments

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Contents

10.1 Introduction

The previous chapters have focused attention on specific crops, livestock and forestry, and attempted to identify the impacts according to projected climate change conditions. Expected economic, livelihood and food security impacts were also discussed. Concrete recommendations for specific sub-sectors and sectors were covered in these chapters. This chapter draws together this information and recommends adaptation approaches to maximise the contribution of agriculture and forestry to economic development, food security and livelihoods in a changing climate.

This chapter also summarises the knowledge gaps that need attention if we are to improve our understanding of the vulnerability of agriculture and forestry to climate change and implement realistic adaptation opportunities. Further, the chapter discusses institutional and coordination issues and changes required for supporting climate change adaptation in the Pacific. Adaptive capacity is also discussed, being an essential element for assessing the likelihood that recommended adaptation options and strategies will be adopted and sustained by farmers and communities. Understanding how communities (men, women, youth and elders) may be affected differently depending on their roles, and how their traditional knowledge, capacities and perspective can help develop and implement adaptations, is part of the process.

The agriculture and forestry sector is of vital importance to the Pacific region. Food production activities (agriculture and fishing) continue to contribute substantially to livelihoods (Chapter 1) and forests and trees are also vital to the lives of Pacific Islanders for socio-economic purposes (Chapter 8). Over the last few decades the economic growth of Melanesian countries, mid-sized Polynesian countries and micro-states has been erratic and sluggish, and in many countries has not kept pace with population growth. Almost all countries have substantial mercantile trade deficits (Chapter 9) with PNG being the exception due to significant foreign income earnings generated from mineral exports. Agriculture and forestry contribute to the GDP of PICTs through both subsistence and commercial activities. Most countries' exports are dominated by agricultural and forestry products while food products dominate imports. Thus the consequences of future climate change on agriculture and forestry will have an important influence on the balance of payments in the Pacific region.

Agricultural productivity is already being adversely affected by a range of factors. These include the tendency to move away from traditional agroforestry and mixed cropping farming practices to cash cropping monocultures. In many cases this has resulted in problems such as declining soil fertility and increased pest and disease outbreaks, which have weakened the resilience of Pacific production systems. Poor agricultural practices have also resulted in land degradation and increased soil erosion. Degraded land and the resulting low soil fertility and structure reduce the resistance of crops to extreme climate events, such as droughts, floods, extreme temperatures, and pest and disease outbreaks, which also could be exacerbated by climate change. Land use practices, such as logging within riparian 'buffer zones', has seriously undermined the ability of forests to provide ecosystem goods and services and protection against extreme weather events. In addition, as extension and research services tend to be under-resourced and poorly focused in the Pacific region, the introduction of new or more resilient practices has been limited to date.

Changes in climate conditions have already been observed. These include increased temperatures, some shifts in rainfall patterns, increased frequency and intensity of some extreme weather events, and rising sea levels (Chapter 2). As preceding chapters have noted, climatic impacts in the past have mainly been felt through extreme events such as tropical cyclones, droughts and floods. The impacts of these events are highly visible and economic assessments of losses can be quantified. Further, their impact is exacerbated by the fact that food production systems and the ecosystems supporting them are already under stress, for example, from rural migration, pests, weeds and diseases and loss of soil fertility (Kindt et al. 2006;). Failure to address the factors responsible for this underlying stress will merely increase the vulnerability of agriculture and forestry to further climate change. With likely increases in extreme weather intensity, and in some cases also frequency, greater pressure will be placed on agriculture and forestry and economic and social costs will increase. We still, however, have low confidence in model projections which suggest that tropical cyclones may become less frequent, but may be more destructive. It is, therefore, pragmatic for those PICTs currently affected by tropical cyclones to maintain and/or enhance disaster risk management strategies for these highly destructive weather events.

It is far more difficult to measure and link changes in productivity to the more subtle long-term slow onset changes, such as the increased rate of warming (from 0.07°C /decade from 1900 to 0.11°C/decade since 1950) (Chapter 2). As noted in previous chapters there are reports of changes in the fruiting patterns of fruit trees, but these are mostly based on anecdotal evidence and have not been rigorously documented. The impact of rising night-time temperatures on the incidence of taro leaf blight was discussed in Chapter 4, highlighting the potential for a changing climate to affect pest and disease outbreaks.

10.2 Future Pacific climate conditions

All North and South Pacific Islands are very likely to warm in all seasons by up to 1.0°C by 2030[1] , regardless of the emission scenario (Chapter 2). By 2050 the extent of warming across the Pacific could be up to 2.0°C and by 2090 may possibly reach 4.0°C. It is important to note that the climate projections start to diverge, according to the emission scenario, at about 2030. Thus, inferences about potential impacts to agriculture and forestry beyond this time are limited in confidence and strongly

1 Changes with respect to 1986–2005 base period.

dependent on the global mitigation strategies put in place to reduce emissions (Chapter 2).

Some model projections also suggest that the wet season will become wetter and the dry season drier (Biasutti and Yuter 2013). Future rainfall projections indicate an increase in average annual rainfall over large parts of the equatorial Pacific in a warmer climate though the confidence in these projected changes is substantially less than for projected temperature changes (Chapter 2; Figure 2.19).

During November–April, relatively large percentage increases in rainfall are projected along the equator, in the northeast near the Republic of the Marshall Islands and in the middle of the South Pacific Convergence Zone (SPCZ), with decreases at the northeastern edge of the SPCZ near the Cook Islands (Chapter 2; Figure 2.19a, left side). During May to October, relatively large percentage increases in rainfall are projected along the equator and the northwest around Palau and the Federated States of Micronesia with small changes in the multi-model mean south of the equator (Chapter 2; Figure 2.19b, right side).

Projected changes to cloud and radiation broadly follow that of rainfall. In most places there is generally a projected increase in cloud cover and decrease in radiation at the surface consistent with the increase in rainfall. However, most of the changes are fairly small. For example, changes in surface radiation are <10% under any scenario by the end of the century (Chapter 2).

A warmer climate is expected to bring a greater incidence of daily extremes of high temperatures and rainfall amount. The future climate projections show that the 1-in-20 year event of extreme daily temperatures is projected to increase in line with average temperature increases. The current 1-in-20 year extreme daily rainfall event is projected to occur once every 7 to 10 years by 2030, and once every 4 to 6 years by 2090 as greenhouse gas concentrations continue to grow. However, there is some variation across the region with a range of results around this model mean value.

Despite the availability of broadscale projected changes in climate, reliable island-scale climate projections are not yet available as many of the global climate models do not have sufficiently fine resolution to represent small islands. For agricultural impacts research, regional- to local-scale projections of climate variables, such as seasonal temperatures, seasonal rainfall, and frequency of both temperature and rainfall extremes are key requirements in understanding the potential impacts on agricultural productivity (Ramirez-Villegas et al. 2013). Thus, our ability to predict what the actual climate change impacts on agriculture and forestry will be at the individual island scale remains somewhat limited, and consequently the projected impacts identified in this report have been based largely on likely changes in response to assumed levels of change in key climatic variables.

10.3 Likely impacts of climate change on Pacific crop production

As discussed in the previous chapters, projections of probable climate change impacts on agriculture and forestry can be made based on current data and observations, taking into account known physiological thresholds and pest and disease responses. For example, projected changes to climatic conditions are likely to have a significant negative impact on the production of Arabica coffee, while the impact on most traditional staple crops is expected to be relatively low. Similarly with livestock, based on existing information, indigenous locally adapted breeds are likely to be more resilient to projected future conditions than introduced temperate latitude breeds. For agroforestry and forestry, knowledge regarding the climatic ranges of species can be used to assess vulnerability. For example, *Bischofia javanica* (Java cedar, koka), an important tree in certain agroforestry systems, is generally considered to have a low vulnerability to predicted climate change, including increased temperatures and altered rainfall regimes (but low rainfall, that is less than about 2000 mm annual rainfall, and/or more than three months of dry season, is not favourable). Strategic use of such information can help in better positioning Pacific agriculture and forestry to minimise the threats posed by climate change and to harness potential opportunities.

10.3.1 Staple food crops

For most staple food crops, extreme weather events are most likely to have the greatest impact in the short- to medium-term timescale (2030–2050), compared with changes in mean temperature where significant impacts are not expected before 2050. The increased probability of extreme rainfall (both frequency and intensity) will greatly test the skills of farmers in those countries where rainfall is already high, especially for crops sensitive to waterlogging, such as sweet potato. Similarly, domesticated yam is also highly susceptible to increased rainfall variability and extreme rainfall events. The climate change response of pests and diseases that affect staple crops is far less certain, with the exception of taro leaf blight, where an increase in minimum temperatures and increased humidity provide the conditions conducive to the spread of the disease. High wind speeds from more intense tropical cyclones would also create significant problems for many crops. However, despite these threats the overall impact on Pacific staple food crop production is expected to be generally low over the next few decades and far less than the impact on imported grain crops from other regions.

Beyond 2050, the negative effects of climate change are expected to become much more pronounced, especially if global emissions continue to track the high emission scenarios (RCP6.0 and RCP8.5). Negative production impacts have been assessed as high for rice, swamp taro, domesticated yams, and moderate to high for sweet potato and taro. By contrast the production impacts on cassava, aibika (bele), breadfruit and banana has been assessed as low to moderate; and low for cocoyam, giant taro, and wild yams.

Apart from the atoll countries and the atoll islands of the larger Melanesian countries, sea-level rise is not a major issue for the region in terms of agricultural production, with the major effects of sea-level rise being felt beyond 2050, especially with the high emission scenarios (RCP6.0 and 8.5). In the short to medium term, storm surges and king tides present significant challenges to these countries, generally resulting in increasing salinisation. The extent of damage caused by these events often depends on whether adequate rainfall occurs immediately after the event to dilute excess salt. As discussed in Chapter 4, increasing salinisation could result in an accelerating decline in swamp taro production in the short term (2030) with production potentially disappearing entirely in the medium term (2050).

An important finding of this report is that the main Pacific staple food crops generally appear to be more resilient to climate change relative to other global staples, particularly grain crops. Further, there is some evidence that elevated levels of CO_2 will have yield benefits for cassava, taro and possibly other aroids. These findings underscore the importance of promoting sustainable cropping systems across the Pacific that maximise the production and use of traditional crops, including the maintenance and strengthening of traditional Pacific agricultural practices. This is critical for future food security in the Pacific and is an important climate change adaptation measure. Linked to this is the urgent need to strengthen research into more varied processing and value-adding techniques so that staple food crops can be more easily used and marketed.

Recent international research indicates that there is a 'medium confidence' that global aggregated production of wheat and maize is expected to fall by mid-century; rice yields are also expected to decline (Porter et al. 2014). As discussed in Chapter 9, these effects on yield could potentially increase the price of internationally traded grains and alter the relative prices of imported versus domestic costs of staple foods in the Pacific, which may improve the economic competiveness of Pacific staples and increase farmer returns if they can be increased or, at least, maintained.

These seemingly positive aspects will, however, need to be balanced against other competing pressures facing many PICTs, especially rapid population growth, socio-cultural changes, and environmental degradation through poor land and waste management practices, which could further undermine the resilience and sustainability of traditional cropping systems.

10.3.2 Export commodities

The projected impacts on the Pacific's major agricultural export commodities (coconut, coffee, cocoa, palm oil and sugar) show considerable variation (Chapter 5). Coffee (Arabica) is the commodity predicted to be the most vulnerable to climate change with yields expected to fall significantly by 2050 in current production areas, mainly due to increased temperature effects, especially in the uplands. Coffee, as a major export commodity for PNG, employs a large number of people, so potential declines in production are likely to have significant adverse implications for livelihoods.

Most cash crops are vulnerable to extreme weather events, accounting for many of the losses that occur in the region. The projected increase in the frequency and intensity of extreme weather events due to climate change poses the greatest risk to cash crop production over the next few decades. High wind speeds are a significant threat to senile (> 60 year) palms, which make up a major proportion of many existing coconut plantings. Extreme rainfall events, increased floods and changes in rainfall patterns are also likely to result in higher potential crop losses for sugar. However, as with the staple food crops, opportunities for increased production exist for some export commodities. For example, as discussed in Chapter 5, increasing average temperatures are likely to favour cocoa production in some countries, such as Vanuatu. Palm oil production is unlikely to suffer adverse impacts in the existing production areas and could experience favourable price trends.

In the period beyond 2050, potential adverse impacts are likely to become more pronounced. Many of the current coffee production areas of PNG are likely to become unsuitable by the second half of this century and vulnerability has therefore been assessed as high. The overall production impact assessment for coconuts is low to moderate but is dependent to some extent on the successful replacement of senile palms with new coconut plantings. The greatest threat to sugar will continue to be from extreme events, such as floods, with a projected moderate negative impact on production. Cocoa production in PNG and Solomon Islands is also expected to be adversely impacted and production vulnerability has been assessed as moderate to high with moderate economic impact. However, as mentioned above, in some countries, where conditions are currently sub-optimal for cocoa production, some potential exists for increased production. Little is known about how climate change will impact on cocoa pests and diseases, though black pod disease could increase in severity. One potential exception to the adverse trend in cash crop production potential is oil palm. Due to its relatively high resilience to increased temperatures and rainfall, and the likelihood of increased oil prices over the medium term (palm oil prices are strongly correlated to crude oil prices) current production areas could see some positive economic benefits. As a result the production impact assessment is neutral or slightly positive over the longer term. The high returns that are being secured from oil palm plantations are creating interest in planting the crop in Vanuatu and Fiji but its high vulnerability to tropical cyclones could limit the potential for production in these countries, especially as tropical cyclone intensity is projected to increase.

10.3.3 High-value horticultural crops

Chapter 6 discussed a range of high-value horticultural crops including fruits, vegetables, spices and stimulants. As with the other crop categories, extreme weather events are the greatest threat in the short to medium term. Of the fruit crops, papaya and mango are considered to be the most vulnerable, with fungal diseases a particular threat for papaya. Fruit set[2] in mango will be adversely affected by the projected increased variability in rainfall and extreme rainfall events. For these two crops, the projected production and economic impact assessment is low to moderate up to 2050. The impact of climate change on citrus and pineapple is likely to be insignificant to low, though some pests and diseases may become more problematic for citrus. Higher rainfall is likely to have a negative impact on both tomato and watermelon production (moderate and low to moderate impact on production respectively), and extreme heat (depending on the timing) can significantly reduce tomato production and yield. For spices, ginger and vanilla, the projected impact is also insignificant to low, with the possibility that changed rainfall patterns could actually increase the areas suitable for ginger production. Similarly for betel nut and kava, the short-to-medium term impact of climate change on production is expected to be insignificant.

Beyond 2050 the impacts are less certain but the increased intensity of extreme weather events is expected to pose the greatest challenge. High wind speeds associated with tropical cyclones could potentially be a significant threat to mango and papaya production (moderate and moderate to high impact respectively), and more intense rainfall leading to waterlogging and flooding will affect most crops. For tomato, the impact on production is projected as moderate to high and for watermelon, low to moderate. For citrus and betel nut the production and economic impact assessment is low, and for vanilla, ginger and kava, low to moderate.

10.3.4 Livestock

The impacts on livestock are variable. Existing data highlight the resilience of indigenous, locally adapted breeds and conversely the vulnerability of introduced temperate-latitude breeds. Existing breeds may be able to cope with temperature projections for 2030–2050, but beyond this time, breed and species substitution may become necessary. Considerable uncertainty exists in relation to expected impacts beyond 2050 but, in general, projected climate change is likely to have an overall negative impact on livestock production. *Bos taurus* dairy breeds and poultry are particularly vulnerable to projected temperature shifts. Livestock managed in traditional systems will be at risk from heatwaves and flooding; commercial systems, on the other hand, have the capacity to adjust to projected climate conditions, such as increased temperature, but at a cost.

More intense droughts will reduce the quality and availability of stock drinking water and potentially intensify competition between the various water users, especially in those countries where animals are kept in highly populated areas. Extended drought periods are likely to have an impact on the availability of local feed. If feed is produced locally using imported grains the impact of climate change on the global production of grain crops is likely to affect the stability and cost of supply. Pigs and poultry are more efficient at converting concentrated feed to livestock products, such as meat. Thus, any impact on feed quality and supply could encourage increased use

2 Fruit set is defined as the transition of a quiescent ovary to a rapidly growing young fruit, which is an important process in the sexual reproduction of flowering plants.

of these livestock species, and therefore require more investment into determining optimum formulations for local animal feeds.

The impact of climate change on pasture quality in the medium to long term could be of significance for those countries involved in ruminant production, for example, Vanuatu. A decline in feed quality is projected as a result of the shift from C_3 to C_4 grass species, the increased lignification of plant tissues and the expansion of generalist species into areas previously dominated by locally adapted species.

Of the three native bee species found at different elevations, the lower elevation species is likely to be able to adapt to increasing temperatures. However, higher elevation species, which are already comprised of very small populations with lower genetic diversity, are likely to be adversely impacted by a warmer climate. Their current restriction to very high elevations raises the possibility that with increasing mean temperatures, they may be unable to persist by retreating to even higher habitats. As important pollinators, this has broader implications for the plant species they interact with.

For livestock, pests and diseases, changes in their geographical extent, population, life cycle and transmission characteristics are expected. For example, larger populations of pathogens may arise with higher temperatures and humidity, especially for those pathogens that spend some of their life cycle outside the animal host.

10.3.5 Forestry

Overall the major commercial production forests, including most timber plantations, are not particularly vulnerable to climate change until later this century, though littoral and atoll forests are considered the most vulnerable, especially to extreme weather events such as tropical cyclone-related storm surges and waves. Major tropical cyclones already result in significant damage to both trees (outside forests) and forests and this will remain a significant problem for the future. Effective management after such events is required to prevent the incursion of exotic invasive weeds. The increase in native forest-smothering vines, notably *Merremia peltata*, and exotic trees such as African tulip (*Spathodea campanulata*) is of particular concern.

Extreme rainfall events are likely to result in increased damage to trees from flooding, waterlogging and landslips. Conversely, the predicted decrease in the average incidence of drought in countries near the equator, such as Kiribati and Nauru, will be generally beneficial to tree survival and growth; this is significant because trees in these locations make important contributions to soil enhancement. However, more intense El Niño events, coupled with higher temperatures, could increase the risk of severe droughts and wildfires for some countries. This could have a significant impact on forest biodiversity. For example, unique forest ecosystems and tree species, especially endemic conifers in New Caledonia, are considered to be potentially vulnerable.

Any adverse impacts of higher temperatures and extreme heat events on tree growth will likely be at least partly counterbalanced by increases in CO_2 levels, especially for the drier forest types. Planted forests more at risk from climate change are monocultures, including *Pinus caribaea* in Fiji (tropical cyclones, fire and landslides), *Eucalyptus deglupta* in Solomon Islands (tropical cyclones) and *Swietenia macrophylla* in Fiji (tropical cyclones, especially if *Hypsipyla* shoot borer were to reach Fiji and cause a multi-stemmed growth habit).

10.3.6 Summary/discussion

Overall the potential impacts of climate change in the short to medium term (up to 2050) are generally low to moderate for most of the crops discussed in this book, with the probable exception of coffee. Generally, extreme weather events are likely to be the greatest threat relative to fundamental changes in the underlying average climate variables, such as temperature. For those countries with currently high rainfall conditions, the projections for further extreme rainfall events are a key concern, especially for crops particularly susceptible to waterlogging and flooding. Extreme events, such as cyclones and flooding, pose a particular threat to commercial production systems. Thus putting in place or enhancing disaster risk reduction measures, such as those outlined in the proposed regional Strategy for Climate and Disaster Resilient Development in the Pacific (SRDP 2014)[3], will be a vital adaptation response for these systems.

Similarly, extreme events pose the greatest threat in the short to medium term to the forestry sector. As an example, the Fiji Pine plantations in the west of Viti Levu have already suffered from an increased incidence of extreme weather events in recent times including unseasonal flooding and associated landslips, intense tropical cyclones, droughts and associated wildfires.

For the livestock sector, projected increases in temperature may require species/breed substitution in extensive production systems, as existing types are pushed beyond their upper temperature thresholds. Both extensive and intensive systems will require greater investment in shade provision and other cooling technologies to counter incremental gains in temperature and the frequency and intensity of heatwaves. Rising sea levels will lead to increased stock densities and closer human/animal contact with increased risk of disease transfer, especially on smaller atolls.

Beyond 2050 the impacts of climate change become much more difficult to predict as considerable uncertainty exists in relation to the extent of climate change that actually eventuates and the effectiveness of the response measures put in place to accommodate any future changes. However, assuming emission scenarios follow an RCP6.0 or higher trajectory, then adverse impacts will become more pronounced for

3 The draft Strategy for Climate and Disaster Resilient Development in the Pacific builds on two current regional policy frameworks, namely the Pacific Disaster Risk Reduction and Disaster Management Framework for Action (2005–2015) (RFA) and the PIFACC (2006–2015), creating a single framework to guide future response actions to build resilience to climate change and natural disasters. It was considered by Pacific leaders at the Pacific Islands Forum, 2015.

both agriculture and forestry. For example, an average 1.5°C rise in mean temperature, projected for 2050 under RCP8.5, may have unforeseen impacts on Pacific Island tree species.

How pests, diseases and invasive species will be affected in both the short- to-medium and long term will clearly play an important role in determining the resilience of crops and livestock, and, to some extent, forests and trees, to climate change. Insufficient data are available with which to make any accurate projection of the impacts on known pests, diseases and invasive species and, therefore, considerably greater research effort is required in this area.

In terms of the economic implications of the projected climate change-induced impacts on agricultural production, these are likely to be relatively small for most countries in the next 30–40 years, especially if appropriate adaptation measures are put in place. There will, however, be significant adverse economic impacts arising from the expected increase in the real price of imported food. In the latter half of the century the potential production losses for all crops are expected to increase considerably and this will have subsequent economic flow-on effects. However, there may be some offsetting export price benefits for agriculture and forestry products which could temper future GDP and balance of payment losses. The overall extent of these future economic costs and any offsetting benefits will depend on the pre-emptive measures and actions taken by farmers and industry organisations, together with the policy and funding support provided by governments and donor agencies.

10.4 Adaptation

Despite the inherent resilience of Pacific agriculture and forestry to climate change in the short to medium term, it is important that the two sectors implement adaptation strategies to minimise the risks in the short to medium term so as to strengthen resilience to threats from more long-term changes. Successful implementation of adaptation strategies not only relies on the identification of suitable adaptation responses but also requires increased research and investment in adaptation planning to understand the factors that affect the adoption of new approaches.

Climate change is not the only influence on the agriculture and forestry sectors. Other factors have to be considered, with population growth and urbanisation of particular significance, especially in Melanesia. Adaptation strategies have to take these other drivers into account. A further consideration is that agriculture is supported by multifunctional landscapes, which provide a range of ecological goods and services to the agricultural sector, of which land is one component. The sustainable use of land and other goods and services, therefore, goes beyond the agriculture sector (Chapter 1).

Chapter 4 highlighted the importance of building on the resilience of traditional farming practices, paying attention, for example, to soil health and diversity (both inter- and intra-specific diversity). These components of traditional farming systems indicate some of the ways in which resilience can be strengthened to offset projected adverse impacts, as well as to position agriculture to meet the demands of other drivers. Traditional knowledge is often held by certain groups or households at the local level. It is vital that adaptation planning creates the enabling environment to ensure that all community members — men, women, youth and elders — can contribute their skills and knowledge to the identification and implementation of suitable adaptation responses. This requires the use of participatory approaches and investment in the meaningful participation of all members of society in supporting adaptation.

Chapter 1 discussed the IPCC distinction between autonomous adaptation and planned adaptation. A distinction can also be made between tactical, systemic and transformational adaptation. Tactical adaptation options can be seen as modifications of current practices to offset risk associated with climate variability, such as timing of planting, changing crop types or varieties and changing practices related to soil health (Howden et al. 2007). These options have been identified as relatively short-term approaches, associated with 2030 climate change conditions identified as part of the RCP2.6 and 4.5 scenarios (Howden and Crimp 2005), and, accordingly, there are limits with regards to their effectiveness under more significant climate changes associated with RCP6.0 and 8.5 emission scenarios (van Ittersum et al. 2003; Easterling et al. 2007). However, they can make a significant contribution to enhancing the resilience of a production system. Many of these measures make sense in their own right with or without climate change (especially taking into account the other challenges faced by agriculture), but importantly, they build climate resilience into production systems.

Other adaptation approaches exist — namely systemic and transformational — moving from the single, incremental approach of tactical adaptation through to a more complex joint implementation of options. The extent to which tactical-level adaptation options will be effective is difficult to predict. Large climate changes are likely to need transformational change/adaptation.

10.4.1 Tactical adaptation options

As indicated above, tactical adaptation options often involve modification of current practices to offset risk associated with climate variability and promote enhanced productivity. They are characterised by short-term farm level management interventions that are 'no regrets' strategies[4] to respond to changing and less predictable seasonal conditions. These short-term adaptation options can be accomplished by farmers taking into account local climate conditions and trends if

4 Strategies that generate direct or indirect benefits that are large enough to offset the costs of implementing the options regardless of future climate change outcomes.

there is a strong correspondence between these trends and projected climate changes (Tubiello et al. 2007). A significant benefit from adaptation research is the knowledge of how short-term response strategies can link to long-term options to ensure that, at a minimum, management decisions do not undermine the ability to cope with potentially larger impacts later in the century. For example, shifts from small-scale diversified crop rotations to larger-scale individual crop rotations may provide short-term economic gains but will undermine longer-term resilience as the variability of the production environment changes (Tubiello et al. 2007). A number of tactical options are already in use in the Pacific; for example, the introduction and adoption of climate-resilient crops and varieties.

10.4.2 Systemic adaptation options

Systemic adaptation options refer to the effective packaging of multiple incremental changes in ways that deliver benefits across the social, economic and environmental domains. Examples of such options, though not necessarily in response to climate change, already exist across the Pacific — for example, the development of breadfruit orchard systems incorporating mixed cropping (McGregor et al. 2014). Mixed tree and crop production systems serve to spread risk around seasonal conditions and are an effective way of both generating income and supplying food, but need scaling up to have a significant overall impact. They do, however, represent effective options to provide resilience to more extensive climate change in excess of 1.5°C (Howden and Crimp 2005; Challinor et al. 2014). However, if the Pacific, by 2050, does see climate change associated with the RCP6.0 or 8.5 scenarios then the effectiveness of these options may also be limited, and more transformational adaptation will be required for many crops across the region.

10.4.3 Transformational adaptation options

The IPCC 5AR Report defines transformational adaptation as 'adaptation that changes the fundamental attributes of a system in response to climate and its effects' (Field et al. 2014). This could include adaptation at a greater spatial scale or magnitude, the introduction of new technologies or practices, the formation of new structures or systems of governance, or shifts in the location of activities (Jones et al. 2014). Inherently these types of adaptation options are difficult to identify and differentiate from the systemic options, but can require considerable investment and are likely to occur on a much longer timescale than either tactical or systemic adaptation options. This is not always the case, as in the example below, but is generally the norm.

The Pacific Community's Centre for Pacific Crops and Trees (SPC CePaCT) has an important emerging role in contributing to the resilience of Pacific agriculture to climate change. Despite the strength of traditional Pacific crops and cropping systems in dealing with risk and disasters, there is an underlying vulnerability due to the narrow genetic base of several crops, particularly the aroids, as is well illustrated by the decimation of the Samoan taro industry by taro leaf blight (Chapter 4). Increasing the genetic base of taro resulted in the large-scale cultivation of taro and the resumption of exports. The use of local and exotic staple varieties (provided by SPC CePaCT) in different climate and environmental regimes across the Pacific will ensure that as the climate changes, genetic materials can be selected that will most effectively grow under those changing conditions. The availability of this material may not just mean selection of different varieties, but also crops, and therefore may allow other types of agricultural production to be established. For this reason the CePaCT programme can be seen as supporting both tactical and transformative change.

10.5 Options for adaptation

In the short term (to 2030), there is low vulnerability to climate change for staple food crop production, based on current knowledge of physiological thresholds and expert opinion. However, the implications of changes to the pest and disease spectrum, and extreme weather events, such as cyclones, heatwaves and droughts, have to be recognised. In the medium term (2030–2050) the extent to which the vulnerability of staple food crops will be threatened depends on which emission scenario is realised, but in general it is expected that these impacts will be low to moderate and most likely could be accommodated by a range of adaptation measures.

Identifying adaptation approaches and strategies should not be based simply on the availability of the technology and projected future responses of the resources underpinning agriculture and forestry, but should consider the barriers to the uptake of the various strategies when evaluating the likely success of proposed adaptations (see Section 10.6).

Further, prospective adaptations should be assessed using cost–benefit analysis (CBA) based on the best available information. In the absence of readily available empirical data an informed 'expert-based' 'with and without' analysis may be the most cost effective, particularly in the case of many small-scale interventions and in the presence of resource and capacity constraints. Some empirical data required for CBA could be easily collected during the standard vulnerability and adaptation (V&A) assessment without requiring sophisticated survey designs. Detailed CBA may not always be suitable, particularly where it is not feasible to quantify and assess monetary values, due to poor data or the costs of conducting such an assessment. Instead, as a minimum, the CBA framework could be applied to identify and assess all the costs and benefits associated with climatic and non-climatic risks of adaptation options. These can then be compared qualitatively to make informed choices (Lal et al. 2014). Similarly, gender and social analysis, which assesses how climate change impacts may be differently felt by men, women, elders and youth, is important for supporting effective adaptation that draws on the skills, knowledge and abilities of all members of society. A promising adaptation strategy from a technical perspective will not be effective if social norms prevent its adoption.

The preceding chapters in this book have identified a number of broad adaptation options that, if affectively applied, could serve to enhance the resilience of Pacific agriculture and forestry to climate change and other drivers. These include:

Improved soils: Soils in the Pacific have, to a large extent, been neglected. Land degradation and declining soil fertility are one of the key development concerns in the Pacific. Improved soil health management, including the use of cover crops, legumes, composting and agroforestry systems, as well as efforts to curb land clearing and encourage sustainable levels of land-use intensification, will serve to improve productivity and build resilience to climate change.

Enhanced pest, disease and weed controls: Pest, weeds and diseases are likely to become an increasing problem under projected future climatic conditions. Improved quarantine capabilities, sentinel monitoring programmes and commitment to identification and management of pests, weeds and disease threats will raise productivity and will represent important management interventions under future climate conditions. The recent development of plant health clinics and the release of an app for Pacific Pests and Pathogens[5] are illustrative of the approaches that should be supported and promoted to assist farmers manage the potential impact of pests and pathogens.

Improved water-use efficiency: Introduction of cost-effective technologies and management practices to reduce pressure on water resources will improve agricultural productivity. More appropriate application of fertiliser and pesticides, and careful management of agricultural wastes such as piggery waste, can dramatically reduce pollutant loads to aquifers, rivers and coastal waters. Water conservation approaches such as eco-sanitation can also have direct benefits for agriculture, as demonstrated by the use of composting toilets in atoll environments, saving precious drinking water while also providing a valuable source of organic material for community gardens.

Improved integration of traditional and modern farming practices: Farming practices should better reflect traditional farming systems and the carrying capacity of the land. Reduced fallow periods or repeated cropping of high-value crops on the same land, often without rotations or sufficient replenishment of soil nutrients, have resulted in a 'rolling crisis' in industries such as ginger and taro exports from Fiji. Efforts to adopt more balanced farming practices will improve long-term productivity, and should include more research on agroforestry systems. More attention should be paid to collecting, sharing and disseminating, in culturally appropriate ways, traditional knowledge that can support adaptation.

5 https://itunes.apple.com/au/app/pacific-pests-and-pathogens/id903244644?mt=8

Improved processing and storage of staples: Significant productivity gains could be realised through improved processing and storage. These potential gains may more than offset production losses due to climate change, at least in the short to medium term. Processing is a vital component of any strategy to increase consumption of locally grown staple food crops, and can open up export opportunities through exploiting the chemotype[6] potential of root crops and breadfruit. Improved interaction between donors, researchers, farmers and agribusiness is necessary to improve the efficiency of processing and storage.

Improved research, development and training: Agricultural and forestry research capacity must be considerably strengthened if adaptation needs are to be identified and met. If the needs of all farmers are to be addressed, and climate change impacts minimised, there must be an appropriate balance between the work undertaken at centralised research stations and participatory research carried out in farmers' fields. The extent, and in some cases the complexity, of the research highlights the importance of establishing mechanisms for prioritisation, and for effective coordination, monitoring, evaluation and dissemination. Understanding the barriers to the uptake of new approaches based on research results also deserves more attention.

Model development and application: Development of modelling systems to understand the production implications of climate change on Pacific crops, livestock and trees is essential as few currently exist. At present the region is overly reliant on international research for data on climate change sensitivities of crops and livestock. Current models are often not relevant to Pacific crops, livestock and trees grown in archipelago environments. Improving the capabilities of existing crop, agroforestry, forest and livestock models in such situations, and linking climate, management and natural resources together, represents an opportunity to examine the likely impacts of climate change and to investigate the effectiveness of a range of alternative management options.

Protect existing ecosystem assets: Protection of existing mangroves and littoral forests, and in suitable locations, replanting, re-establishing or enriching existing mangrove and coastal forest and scrub communities, can contribute to building reliance in coastal farming systems and to maintaining coastal forest integrity. For forest ecosystems better surveillance, monitoring and control of exotic forest pests and diseases and environmentally invasive weeds is urgently needed as this will build forest resilience.

Improved land use planning: Governments working with land owners, farmers and communities in landscape approaches (also referred to as whole-of-catchment or ridge-to-reef approaches) can best identify those areas most susceptible and contributing to soil erosion. These areas should preferably be either reforested and/

6 Plants of the same species with genetically defined phytochemical characteristic, such as organic acids, flavonols,anthocyanins, and carotenes.

or placed under an appropriate agroforestry/arboricultural system. Investment in strengthened governance arrangements that support integrated land use planning is a critical component of this.

Maintain and enhance crop diversity: Enhancing current efforts to use the resilience that can be gained from crop, tree and livestock diversity represents an effective tactical and transformative adaptation option. This should include improved assessment of diversity in the region, as well as strengthening linkages and mechanisms for access to diversity from outside the region, and enhancing national germplasm and planting material networks. More extensive multi-locational evaluation of diversity combined with simulation modelling would ensure that appropriate provision of planting material is achieved. It is vital that farmers grow a diversity of crops, rather than just one or a few that are recommended to be the best adapted to future climate conditions and the market, or have the highest gross margin. Understanding the barriers to the adoption of new varieties and identifying champions at the national and local level for diversification can support wider uptake of new varieties. Diversity of crop production is a vital climate change adaptation strategy as it helps mitigate the impact on households of gluts and shortages that result in large price fluctuations.

Crop, tree and livestock improvement: Crops, trees and livestock that are more tolerant of climatic and environmental extremes should be developed, and where possible, breeding programmes should address known pest and disease risks. For crops, breeding programmes should take into account nutrition and taste preferences so they are more readily taken up by farmers and consumers. Breeding initiatives aimed at increased processing efficiency should focus on ease of harvest of the underground organs (short neck for cassava, compact tubers for yams) and on dry matter content which is highly correlated with starch content. Effective linkages and collaboration between national and regional agencies, and relevant international organisations, will be necessary to ensure the sharing of breeding programme developments, such as improved methodology and useful breeding lines such as those demonstrated by the International Network for Edible Aroids (INEA).

Increased use of protected cultivation and nursery systems: Extreme heat, drought and rain events are often limiting factors for the production of many horticultural crops. Protected cultivation (polythene and netting tunnels) can be used to extend 'off-season' planting of vegetables, and with irrigation could support year-round cropping. Use of irrigation pumps and drip irrigation would enable production to be moved away from vulnerable river banks and the risk of flooding.

10.6 Adaptive capacity

Increasing attention is being given to 'building adaptive capacity' in PICT communities by governments, donors and their implementing agencies in the region

(Aalbersberg et al. 2010). Adaptive capacity considers the farmers, growers and communities involved in agriculture and forestry; it is a product of natural, human, physical, social and financial capital, and is the means by which we can understand how environmental change will impact on households and communities and how different members of society contribute to successful adaptation. Adaptive capacity can explain why some communities may be less at risk than modelling studies might suggest (Chapter 1). Several approaches can be used for assessing and measuring adaptive capacity. For example, the Pacific Adaptive Capacity Analysis Framework (PACAF) was developed as part of the Australian-funded Pacific Adaptation Strategy Assistance Programme (PASAP), to enable the rapid assessment and measurement of Pacific-specific adaptive capacity at the community level. Social capital was identified as a critical adaptive capacity determinant of communities through the application of this framework across a number of Pacific Island countries. The identified indicators were community diversity, leadership, collective action, support services and networks and governance (Hay 2009a; 2009b). Of these, leadership, collective action and the ability of communities to engage effectively with external agents were most important. Investing in leadership, including women's leadership, has also been recognised as an important factor in encouraging innovation and driving changes in approaches.

Communities' ability to engage effectively with external agents in sourcing and using adaptation resources (such as finance and technology) in a way that responds to their own immediate and future needs is considered critical given the influx of adaptation investment in the Pacific (World Bank 2012). This ability may vary between and within communities, with more marginalised community members finding access to external support more difficult. Enhancing their ability to access these services is crucial in ensuring that adaptation support and finance are reaching the most vulnerable members of society. Supporting their increased engagement in decision-making processes ensures that the skills and knowledge of all community members are being used to support effective adaptation. Financial capital was identified as the most limiting capital during Community Based Vulnerability Assessments conducted in Fiji, Kiribati, Samoa, Solomon Islands, Tonga and Vanuatu (Chapter 1) by the Pacific Community (Halavatau pers. comm.).

The Integrated Vulnerability and Adaptation Assessment Framework (IVAF)[7] is a generic guide for planning, implementing and reporting an integrated vulnerability assessment. The IVAF, which incorporates experience, scope and lessons from previous Pacific Vulnerability Assessment (VA) approaches and methods, intends to provide a set of core vulnerability indicators that might be used as a common reference point, as well as avoid the duplication of climate vulnerability and adaptation work in the region. Although it can be sector and context based, the IVAF is designed for use across sectors, scales, disciplines and space. Based on the premise that reducing vulnerability is the ultimate aim of adaptation projects, the IVAF is an

7 SPC, SPREP & GIZ, 2015, Integrated Vulnerability Assessment (IVA) Framework for Atoll Islands: A Multiple Agency Approach, based on lessons learned from the Secretariat of the Pacific Community (SPC), the Secretariat of the Pacific Regional Environment Programme (SPREP) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

important tool to support the planning, implementation, monitoring and evaluation of adaptation processes and measures in the immediate and long term. The IVAF takes into account resource-based adaptive capacity, which includes asset- or capital-based adaptive capacity (natural, physical, financial and human) and institutional structures and processes.

In adopting community-focused approaches, the fact that implementation of agricultural innovations in PICTs primarily occurs at the individual farmer/farm household level should not be forgotten. Increasing the productivity of farmers operating within traditional farming systems will require a substantial and ongoing extension, training and applied research effort. Such an effort needs to be undertaken with an understanding of the local context, including gender-differentiated roles and responsibilities, and, accordingly, how innovations can be introduced and sustained. Existing and emerging farm organisations have been identified as having an important role to play in this respect (Stice 2014), and for this reason, efforts to increase the knowledge and capacities of such organisations, along with the strengthening of networks and alliances to support, document and share lessons on farmer-led innovation, are needed.

10.7 Positioning to respond to climate change

Actions to improve the resilience of Pacific farmers, tree growers and communities to climate change, and the decisions about which adaptation measures to adopt, are not made in isolation, but in the context of the wider society and political economy (Burton and Lim 2005). The choices are thus shaped by public policy, which can either support, or act as a barrier or disincentive to adaptation (e.g. government subsidies for production of certain commodities and inputs). The most successful actions and/or policies to respond to future climate change involve building resilience to existing climate variability and meeting short-to-medium term needs. It is the short-term priorities and meeting today's needs that should drive adaptation responses which will build resilience, thereby ensuring the sustainability of Pacific agriculture and forestry.

Adaptation options and their supporting policies need to be integrated into government programmes in the agriculture and forestry sectors and implemented by institutions in direct contact with farmers, tree growers and communities. For example, adaptation responses, such as changing planting dates, varieties and tillage practices, will be implemented by farmers but might be facilitated and supported by the provision of technical services from local extension agents, farmer organisations and through regional agencies. These organisations are responsible for demonstrating both why changes in agricultural practices are required and how these changes will deliver increased resilience in the future despite not necessarily delivering immediate production gains in any one year, such as demonstrating that drought-tolerant crop and tree varieties may under-perform in good growing conditions but may out-perform other varieties in dry conditions.

A project implemented by the Vanuatu Agricultural and Technical Centre (VARTC) and the Farm Support Association (FSA), discussed in Chapter 4, provides a good example of what can be done now so that rural households can better manage climate change, and also highlights the importance of effective message delivery. The project broadened genetic diversity in village farmers' fields with crops and varieties (taro, yams, sweet potato and cassava) that included some with key resistant characteristics. By enriching the diversity in farmers' fields, some protection is provided against future epidemics and biological disasters that are expected to increase with climate change. The sustainability of this approach relies very much on the interest and enthusiasm of the farmers, the perceived benefits of adopting such measures and also their understanding of the importance of diversity — hence the importance of effective message delivery. A social and economic assessment of this 'no regrets' strategy of establishing 'reservoirs' of genetic diversity in farmers' fields is difficult, as much of the benefit would occur during future pest and disease outbreaks and/or climate-related disasters. Scaling up such schemes involves potentially significant upfront costs but assuming new varieties are maintained, the benefits can be measured in terms of reduced grain imports if there were to be a catastrophic loss of a subsistence crop. Even quite small decreases in the resulting grain imports make this investment worthwhile if it can be successfully implemented (McGregor et al. 2011).

The Australian Centre for International Agricultural Research (ACIAR)-funded Pacific Breadfruit Project is another example of a programme that aims to assist farmers to better manage climate change impacts. One of its key objectives is to establish breadfruit as a commercial smallholder-based orchard crop, with a planting target of 20,000 trees by the end of 2015. By 2021 these trees will conservatively produce around 3300 tonnes of marketable fruit, which could supply the food energy equivalence of 11,000 tonnes of boiled rice. As breadfruit is a crop with relatively high climate change resilience (Chapter 4), this project provides a potentially viable adaptation option. If proven to be commercially viable on a cross-Pacific scale, extending this activity to other PICTs could enhance food and nutritional security in the coming decades.

Improved coordination within and between countries, and between donor organisations, is vital to ensure that adaptation programmes are effectively and efficiently resourced. A key observation drawn from a review of a range of such programmes is that more resources (i.e. financial, institutional and informational) need to be devoted to farmer and community level initiatives in addition to national programmes (Maclellan 2011).

Targeted research and the implementation of appropriate response measures can help to address existing problems associated with productivity and processing of many crops. For example, in Fiji, the introduction of clean planting material grown elsewhere, and the adoption of appropriate crop rotations, have been shown to reduce problems with burrowing nematode in ginger and thus improve productivity, and in turn, build climate resilience, while improved soil drainage has also been shown to help reduce the incidence of rot caused by *Pythium* spp. for a range of staple crops (Phu Le et al. 2014). The effectiveness of such measures will determine how farmers and communities perceive future recommended adaptation approaches, highlighting the importance of prioritised and targeted research, the implementation of appropriate, relevant response measures, and coherent communication.

10.8 Key knowledge and research gaps

Each of the previous chapters has highlighted specific gaps in the knowledge domains discussed. The purpose of this section is to identify important cross-cutting knowledge gaps that exist in terms of climate change impacts on Pacific agriculture and forestry, and thereby help guide future research investments into the areas of highest priority.

Maintaining and enhancing high-quality weather and ocean observations throughout the region is vital. Accurate and continuous records of current climate conditions support assessments of climate vulnerability and sensitivity in natural and managed ecosystems such as agriculture and forestry. Such records also allow for the identification of recent climate trends and when such trends exceed the natural sources of inter-annual and decadal climate variability. National and international commitment is also needed to rescue and digitise additional long-term weather observations, which exist in paper format in various NMS and international archives. Similarly the decline in recent decades in the number of missed observations and reporting stations must be reversed, which will require national commitment and international assistance.

Better use of seasonal climate outlooks by farmers and tree growers can assist in reducing climate-related losses and improving productivity. If the forecasts were made more readily available, farmers could begin to make more informed decisions regarding crop type, scale of production, planting time and other farm management decisions better suited to the projected climate conditions. A demonstration of the reliability of these outlooks is also necessary as it is important to build confidence and awareness in seasonal climate forecasts and the valuable contribution they can make to increasing productivity and profitability. Systems have been established at the regional and national level to support the delivery of seasonal climate outlooks, but ensuring that farmers and tree growers provide input into the design of these outlooks so that they are relevant and useful for their decision-making processes remains a challenge. How can the information be best packaged and disseminated so that it can be used directly by the farmers, growers and advisory services? In addition, data sets in agriculture and forestry are also needed so that a better understanding of climate change impacts on the two sectors can be acquired. Merging these data with meteorological data would allow for more targeted advice to be provided to farmers and smallholder tree growers.

Strategies for the implementation and monitoring of information will be required to ensure adaptation activities are effective. Delivery of information should take into account the varied ways that information is accessed and used. Information should also include the results of regular monitoring of pests, diseases, and other environmental factors that could affect production as part of seasonal climate forecast products. Strengthened research and systems analysis, enhanced extension services and developing regional exchange networks that provide this information can all make an important contribution to building climate resilience. More innovative methods, such as the Pacific Pests and Pathogen App (Section 4.0) are also worth considering.

Technical and other options necessary to respond to short-term climate variability and extreme weather events, as well as longer-term mean changes, need to be available. In some cases, a greater interplay of both traditional knowledge and so called 'new' management approaches must also be considered, for example, in the development of advanced agroforestry systems. Through appropriate combinations of both traditional and non-traditional management practices, existing approaches can be extended or modified to respond to new climate challenges outside those previously experienced, but allow more rapid assimilation across communities.

Over time, as climate change becomes more pronounced, as predicted under an RCP6.0 or RCP8.5 emission scenario later this century, more transformational approaches are likely to be needed. While these may not be required for some time, effective forward planning is essential and will depend on strong support from science, industry and government, as well as a clear willingness by farmers to adopt new and more transformational approaches.

Improved understanding of the climate vulnerability of the entire agricultural value chain, and the adaptation options that are available to reduce these vulnerabilities, is essential for effective climate risk management. Many gaps currently exist in our understanding of the climate sensitivity of agricultural value chains (from farmer to consumer) across the Pacific and these gaps will need to be addressed to achieve effective adaptation responses. Similarly, better understanding of management of ecosystem processes on a larger scale is vital to ensure improved decisions are made regarding land use.

A number of key knowledge gaps exist that are currently barriers to effective adaptation for PICTs' agriculture and forestry. These include, but are not limited to, the following:

- Island-scale climate projection information needs to be enhanced, as many of the global climate models do not have sufficiently fine resolution to accurately represent small islands. For agricultural impacts research, regional- to local-scale projections of climate variables are important prerequisites to improved understanding of the potential impacts on agricultural productivity. The draft outcome document from the Third International Conference on Small Island Developing States (September 2014) called for support 'To improve the baseline monitoring of island systems and the downscaling of climate model projections to enable better projections of the future impacts on small islands'[8] .
- More extensive assessment and understanding of the physiological responses of crops, forestry and livestock to expected climate change (including elevated CO_2 concentrations) as well as the interactions of pests, weeds and diseases with these changes.
- Improved understanding of how climate change will affect pests and diseases — in particular, those currently considered a significant threat — as well as research into strategies for monitoring populations and disseminating information.
- Broader assessment of the current value of adopting climate risk management or production enhancement activities in terms of enhancing resilience to future climate change.
- Examination of a broader set of 'no regrets' options for climate change adaptation.
- Major increases in yield have been attributed to agroforestry and intercropping systems but the optimum combination of species, arrangements and spacing has to be determined. Compatible mixtures of tree species for plantation systems with consideration given to systems which will cope with the projected climate change conditions over their production life cycle also need to be assessed.
- Evaluation and identification of the best approaches to improving soil and at the same time, increasing crop yield and quality. Maximising farmer uptake of recommended adaptation measures is also needed. Therefore, research focusing on the technical value of soil amendments must be closely linked with farmer participatory research.
- Knowledge of cost-effective and optimal feed types to counter the likelihood of the price of imported feed and/or feed components being affected by climate change.
- Assessment of protected cultivation and irrigation systems — research is needed to determine the most appropriate protected cultivation and irrigation systems to use. Commercial enterprises must be climate-proofed — any enterprise needs to

8 http://www.sids2014.org/index.php?menu=1537

have in place strategies to manage extreme weather events and therefore, research is needed to assess the effectiveness of various disaster risk reduction approaches.

- Economic, social and gender analysis is vital in ensuring that the incentives for adopting new measures are well understood. Climate change will affect men, women, elders, and youth differently depending on their respective roles and responsibilities. Without understanding these differences, attempts to provide information, advice and support can be misplaced. Increased research in this area is necessary to demonstrate the importance of investing in community engagement, strengthened governance and decision-making and leadership.

Much of the expenditure on climate change science research in the Pacific conducted over recent years has been focused on modelling future climate change to derive better projections of how key climate variables may change. While this work has substantially improved our understanding of potential changes across the Pacific, and further work needs to be done, a greater proportion of available funding should be focused on improving the knowledge base on which adaptation measures will be based. That is, how will crops, trees, livestock, pollinators, pests and diseases respond to specified changes in key environmental variables? Such knowledge is critical to determining the type and timing of adaptation measures.

10.9 Institutional and coordination issues

The potential impacts of climate change on PICTs will vary significantly across the region. While response measures must be tailored to the specific needs and priorities of individual PICTs, a range of common actions should be implemented at the national and regional levels to help establish an appropriate enabling environment that can facilitate the uptake and maintenance of efficient, timely, and cost effective responses.

Important elements of creating an effective enabling environment include the following:

10.9.1 Integrating climate change into sector policies and programmes

Over the past decade considerable attention has been focused on integrating ('mainstreaming') climate change into plans and policies at the national level. Strategies, action plans and policy statements on climate change have been prepared by most countries, including national adaptation plans of action (NAPAs and NAPs), and climate change policy statements, among others. PICTs also developed and endorsed a regional framework — the Pacific Islands Framework for Action on Climate Change (PIFACC) — to help guide climate change responses. While these are important to provide an overall framework for climate change response action, most of the substantive climate change response action will occur at the sector level and as a result, sector plans and programmes need to better reflect emerging climate change issues and be supported by consistent policies.

Although some countries have commenced the process of integrating climate change into agriculture and forestry sector plans, in general it remains at a preliminary level in most countries. This is in part due to existing uncertainties and lack of knowledge surrounding the magnitude and timing of specific impacts on different sectors, but also due to the lack of climate change-related institutional capacity and understanding within relevant departments and ministries. This book highlights a range of emerging issues and response strategies that could reduce climate change-related risks to the agriculture and forestry sector and that can be used to inform and guide efforts to better integrate climate change into existing plans and sector programmes.

More climate-aware sector approaches must adopt a holistic cross-sector approach that recognises the important synergies and interdependence with policies and plans adopted in other sectors. For example, forestry sector policies need to reflect the impact of management decisions on watershed quality and yield, flood mitigation, sediment loads and soil loss. The links between agriculture, nutrition, non-communicable diseases and food import dependence is another example of the multi-sector nature of decision-making in building climate resilience. It is important that a broader cross-sector focus on climate change adaptation is considered. Recent initiatives such as the whole-of-island or ridge-to-reef approaches being adopted in Choiseul Province, Solomon Islands, and Abaiang, Kiribati, are good examples of integrated multi-sector responses that recognise the interdependence across sectors. Any changes to policies and plans to better accommodate emerging climate change issues in the agriculture and/or forestry sector must take into account potential repercussions for other sectors.

Whole-of-island or ridge-to-reef approaches can help to bring about necessary changes in land use patterns which will require changes in priorities and processes at the government level, and an understanding at the farmer and community level of the importance of managing ecosystem processes on a larger scale. At the government level, more proactive steps may be needed to protect vulnerable habitats and provide appropriate incentives to reverse land degradation. Some learning and decision-making tools are available to support this process, including models that help to show how investments in ecosystem services can provide multiple benefits, as well as exploring trade-offs implicit in such investments (Nelson et al. 2009). However, also needed are case studies of successful experiences that will provide governments and other stakeholders with the information required to make the decisions to invest at an adequate scale in the measures that are so urgently needed.

10.9.2 Building stronger capacity to identify and manage adaptation measures at the sub-national, national and regional levels:

Greater efforts are needed to strengthen institutional capacity to understand the impact of climate change, adjust policies and programmes to build climate resilience, and to implement and maintain climate change adaptation initiatives across the agriculture and forestry sectors. Effective engagement mechanisms must be in place so that capacity building is linked to the needs of farmers, tree growers, communities and commercial enterprises, and also to build acceptance of new policies and measures. Demonstrating that these measures will have a direct positive impact on incomes and livelihoods now or in the near future, rather than being directed at impacts that may occur in the long term, will improve their successful adoption.

Investment is also needed in building capacity through participatory research, involving farmers at the local level. By using their practical knowledge to fill key knowledge gaps, a more comprehensive range of adaptation options can be developed that will enable a more realistic assessment of the costs and benefits associated with different management responses. An increased focus on building strong farmer networks, which provide the mechanism for sharing knowledge and skills, such as farmer-to-farmer exchange and testing adaptation options, would be beneficial in this regard. The newly formed Pacific Island Farmer Organisation Network (PIFON) is starting to initiate such exchanges.

The type and extent of capacity building that should be undertaken at the national and sub-national levels is another important consideration. Developing and sustaining the types of specialist skills and expertise required to identify and implement effective and appropriate response measures is not always possible or realistic at the national level, especially for the smaller countries. Regional organisations have an important role to play in supplementing and supporting national capacities, and sufficient attention must be devoted to strengthening and maintaining regional support capabilities. It is not an either/or decision in terms of national versus regional capacity — it requires both. A balanced and targeted approach to capacity building is required to ensure that appropriate skills and expertise are developed at both the national and regional levels.

In many PICTs, staff working in agriculture and forestry are struggling under increasingly heavy workloads. The number of donor-funded climate change projects often adds an extra burden to this significant workload. Further, staff can be asked to implement activities for which they do not have the knowledge or the skill, which can be a significant constraint to the progress of the project and affect the value of the outputs. In the 1990s, projects often engaged research scientists from overseas to help in the implementation of project activities, and at the same time, mentor and train national staff. Regional agencies also established links with overseas universities, (for example, the University of the South Pacific, Alafua Campus, had a link with the University of Reading, UK), which facilitated the exchange of scientists and students, who contributed to the research activities and importantly, documentation of research outputs. In Vanuatu, CIRAD has been effectively linked to universities to the extent that French graduate students have been successfully undertaking in-country research for nearly 50 years. Establishing such links could be of significant value in supplementing the region's research and documentation capacity. To ensure that adaptations are based on sound assessments, science-based research is essential. The region therefore has to explore a variety of options for supplementing existing capacity.

10.9.3 Improving awareness and understanding of the severity and timing of impacts for each country through appropriately targeted research and information dissemination:

While sufficient information is available to give a reasonable idea of the impending impacts on different crops, livestock and trees, much of this is based on extrapolation from international research work undertaken elsewhere and expert opinion. There is, therefore, an urgent need for enhanced and well-targeted applied research to improve our knowledge base and fill existing knowledge gaps. Without the availability of such knowledge to inform and guide decision-making, the risks of maladaptation are increased, as is the risk of wasting precious financial resources on measures that do not adequately address the underlying problem. Urgent action is therefore needed to establish mechanisms that will facilitate better articulation and prioritisation of research priorities and the funding of these priorities.

At present the mechanisms for prioritisation and coordination of research efforts across the Pacific, and for tapping into the international applied climate change research, are weak. Regional organisations, active in agriculture and forestry, need to strengthen their efforts in prioritising and coordinating research and, importantly, documenting and disseminating information. Joint multi-country research and multi-agency efforts targeting common issues, similar to the AusAID-funded Taro Genetic Resources, Conservation and Utilization (TaroGen) project which addressed the taro leaf blight outbreak, is one option for improving the use of available research financial resources. Donors supporting research in the Pacific should be encouraged to increase the allocation of resources to urgent applied research tasks in agriculture and forestry and also better coordinate their investments to ensure maximum benefit. Establishing a specific agriculture and climate change research task force, as part of the regional agricultural officials meetings (and also in the forestry sector), is one potential option for ensuring a clearly documented and prioritised research agenda is articulated for the Pacific. Other options have been suggested in previous chapters.

10.9.4 Strengthening coordination between governments, regional technical organisations and key donors to ensure the effectiveness of investments:

Adaptation projects, supported by national governments, regional and multilateral organisations, NGOs, and donors across the region, are often ad-hoc stand-alone activities. Although this support can be of direct benefit to the recipient community, it has resulted in the duplication of work, and at times, provided different recommendations on appropriate adaptation response efforts. The project-by-project approach also significantly increases the administrative and reporting burden on government officials who are already stretched thinly across a range of tasks.

A range of options exists to improve the coordination and efficiency of climate change adaptation at the national and regional level. A more programmatic approach of supporting sector-wide climate change agricultural and forestry adaptation initiatives in line with national climate change policy objectives and supported with potential inputs from a range of sources (donors, NGOs and government) under a single coordinated framework, is one potential option. Increased emphasis on joint programming between national and regional entities is also important to ensure that sufficient technical support is available to implement and maintain activities, and to ensure that the knowledge gained and lessons learnt can be effectively disseminated to other countries and territories across the Pacific. Linking climate change responses for the agriculture and forestry sectors with other sectors through integrated multi-sector ridge to reef and whole of island approaches also offers considerable potential to deliver more sustainable and cost effective outcomes.

10.9.5 Financing response measures:

Ensuring sufficient resources are available to identify, implement and sustain measures that build climate resilience is always a difficult challenge in the Pacific due to the limited financial and human resource base of most PICTs. Some of the measures for increasing the resilience of the agriculture and forestry sectors to climate change recommended in previous chapters are 'no-regret' in nature (those that would make sense with or without climate change). They usually entail a relatively modest cost, which can be recouped in a relatively short time due to their contribution to increasing productivity and resilience to climate variability. In the medium to longer term however, adaptation measures are likely to involve more substantive change and investments, such as changing the crop types and livelihoods of communities. For commercial operations such as coffee, palm oil and other export cash crop producers, more proactive investments are likely to be necessary to increase the climate resilience of their industries.

Although governments, communities and commercial producers should be able to contribute their own resources to identifying and implementing low cost 'no-regret' management measures, external sources of finance to supplement local and national resources, especially for more substantive adaptation investments, are likely to be required. Efforts to access additional resources should focus on working with traditional development partners that provide support for the agriculture and forestry sectors to identify opportunities for redirecting and prioritising funding flows to building climate resilience, including investments in strengthening institutional capacities to effectively monitor and manage climate change impacts. Private sector investment in climate change projects is another option. Significant climate change finance is also being provided to PICTs through a range of bilateral development partners and multilateral institutions to fund adaptation responses, though only a relatively small amount is presently directed to the agriculture and forestry sectors. Finance can also be accessed through several international climate change financing facilities such as the Adaptation Fund[9] and the emerging Green Climate Fund[10].

Even though significant climate change funds are available, PICTs have faced a range of constraints in terms of effectively accessing and using these funds, especially in the agriculture sector. A major effort is needed to develop good quality project and programme support proposals that make a strong case for adaptation investments, supported by sound empirical evidence that justifies such investments. Building institutional capacity in climate change-related areas in agriculture and forestry may help to address this issue, but additional input and support from technical experts in regional and international organisations and locally based consultancy companies to develop quality proposals is likely to be required. Human resource constraints at the national level can limit the ability to absorb increased flows of climate change finance. Therefore, as previously discussed, moving to more integrated programmatic approaches, such as sector-wide strategies that encompass a range of activities and engagement points under a single management framework, and supported by a range of donors, is one option. Such an approach could help countries absorb increased climate change finance flows, and is an area that warrants increased attention from PICTs.

10.10 Conclusions and next steps

This book has endeavoured to provide a detailed assessment of the potential impacts of climate change on agriculture and forestry in the PICTs. The assessment has been based on the most recent projections of climate change for the Pacific, for the short (to 2030), medium (to 2050) and long term (2090). There is a higher level of confidence in the short-to-medium term projections but some uncertainty surrounds long-term projections as they are largely dependent on the greenhouse gas mitigation efforts put in place by the international community over the next few decades. Nonetheless, based on what we presently know, there are a number of general conclusions that can be drawn from the assessments for different countries, crops, livestock and forests.

9 https://www.adaptation-fund.org/
10 http://unfccc.int/cooperation_and_support/financial_mechanism/green_climate_fund/items/5869.php

These include:

- Climate change will impact on both the agriculture and forestry sectors; these impacts are likely to increase in severity over time and are likely to adversely affect food security and the livelihoods of a large number of people.
- The most significant effects are likely to stem from the impacts of extreme weather events (floods, droughts, tropical cyclones, high wind speeds and storm surges) due to the projected increase in the frequency and intensity of these events, while the impacts of changes in average temperature and precipitation regimes are likely to be more long-term in nature.
- Pacific staple crops and cropping practices appear to be somewhat more resilient to projected climate change compared with other staples produced in other regions. As such the overall impact of climate change on agricultural production is rated as low for the short term and low to moderate until mid-century.
- Although climate-related risks to forestry exist, in general the projected impacts for Pacific forests are considered to be low for the foreseeable future if sound forest management practices are adhered to. Also, in some areas, opportunities exist for more productive systems, although some coastal forests and higher montane forest systems are at risk of damage including, in some cases, loss of trees and associated dependent species, especially insects.
- The inherent resilience of Pacific staples and traditional agriculture practices highlights the need to increase their role in meeting domestic food demand. Strengthening production and processing of these staples will be an important element of adaptation efforts. The projected impact of climate change on global staple food production, especially for grains such as wheat and rice, could also create a favourable trend in the relative prices of domestic versus imported food costs.
- Climate change may have a positive impact on some crops and efforts need to be made so that these opportunities are maximised where possible.
- Poor management practices resulting in soil loss and reduced soil fertility, combined with the pressures from population growth, are likely to have a greater impact on terrestrial food production than climate change, at least in the short to medium term, and warrant increased attention from PICTs to address these issues.
- A wide range of potential adaptation options are available to increase the resilience of the agriculture and forestry sectors to climate change, many of which are 'no-regret' options associated with increasing crop diversity and improved governance regimes that make sense with or without climate change. A range of more substantive adaptation measures are needed to address climate change impacts, especially in the medium to long term.

- Many knowledge gaps exist in terms of the impacts of climate change on agriculture and forestry, and significantly more effort and resources need to be devoted to applied research in a range of areas. Filling these knowledge gaps and increasing the awareness and understanding of potential impacts across ministries dealing with agriculture and forestry, and at the farmer/producer level, is essential to identifying appropriate cost-effective response measures, and particularly the timing of investments to address emerging issues.
- Improving our knowledge base of how climate change will impact on agriculture and forestry will need greater efforts in prioritising and coordinating research, and strengthening capacity to implement research activities and document the outcomes of that research. Achieving this will require a more innovative approach to enhancing research capacity in the region and more attention to generating and documenting sound, scientific data from that research.
- A key constraint faced by most countries in the region is a general lack of institutional capacity and understanding of climate change and its impact at the national and sub-national level, combined with limited financial resources. These are important constraints to address in the short to medium term. In particular, greater effort needs to be devoted to effectively integrating climate change considerations into sector policy and plans, adopting a more strategic programmatic and sector-wide approach that moves away from the project by project approach. Increasing the level of coordination and joint programming among donors and regional organisations will help countries manage and administer their response efforts and increase their ability to absorb and utilise climate change finance.

A range of potential actions and adaptation response measures have been identified throughout this book that could be used to build climate change resilience in the agriculture and forestry sectors. Given that the impacts are not likely to be significant in the short term, PICTs have some time to put effective response strategies and measures in place. Nonetheless, if the climate-related risks to production and economic livelihoods are to be minimised over the coming decades, PICTs need to commence the necessary work now to build an appropriate and well-informed enabling environment. The assessments contained in this book can help guide and inform efforts, but more work is required at the national level to meet specific challenges and issues.

The threat to countries from an over-reliance on imported food must be recognised. As discussed in previous chapters and reinforced by the IPCC Fifth Assessment Synthesis Report[11], climate change will have a negative impact on the production of major staples, such as wheat and rice, and linked with an increasing demand for food because of a growing global population, can only lead to less secure and more costly supplies of these products. Recently Lobell and Tebaldi (2014) highlighted that,

11 For wheat, rice, and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2°C or more above late-20th century levels, although individual locations may benefit (medium confidence).

even though there are likely to be significant impacts on agriculture associated with climate change, the effects of population growth in the next two decades on the food supply could be as consequential as the larger scale climate change impacts in the future.

The Pacific region produces a range of staple food crops which, according to the assessments made in this book, are likely to be more resilient to the extremes of climate change than other crops. Strengthening the sustainable production of these crops, acknowledging the importance of soil health and fertility, diversity and climate-resilient agroforestry systems, are important means of addressing climate-related risk. With appropriate changes to governance regimes, combined with targeted investments, productivity improvements can be achieved. These need to be accompanied by private sector investments in improved food processing and storage and related public investment in infrastructure (roads, ports and marketing facilities), to ensure that PICTs increase their resilience to climate change. Attention must also be given to raising awareness of the benefits of increasing the consumption of locally produced staple food crops, and thereby changing dietary patterns — combining the messages from the different sectors to strengthen a country's climate resilience and improve the health of its people.

Previous chapters have highlighted where the priorities are for investments for the agriculture and forestry sectors. These have been made based on the data available but as discussed in Section 10.9, key knowledge and research gaps exist. These must be addressed and, importantly, mechanisms established to ensure that research is prioritised and targeted and results documented and disseminated. National and regional reporting systems should be harmonised, where applicable, to increase synergies and coherence. Research prioritisation must be multi-stakeholder based, and planning and implementation must be coordinated.

Adopting more integrated cross-sectoral and strategic programmatic approaches to addressing climate resilience at the national and regional level will be essential. This will require a careful blending of national and regional efforts that acknowledge the specialist skills and knowledge required to address emerging issues. A key message emerging from this publication is that a balanced mix of national and regional efforts is required to build a better understanding of issues and constraints posed by climate change, fill key knowledge gaps, and implement and sustain appropriate adaptation measures. Improved coordination between national and regional efforts, combined with better targeted and aligned donor support to the agriculture and forestry sectors is also needed to ensure that maximum value is gained from the resources available to the region.

As highlighted numerous times throughout this book, linkages and partnerships are crucial if PICTs are to address the many challenges they face — not only the pressures and uncertainties regarding climate change, but also non-communicable diseases, poor governance regimes and population growth. As stated in the draft outcome document from the Third International Conference on Small Island Developing States (September 2014) 'there is an urgent need to strengthen cooperation and enable strong, genuine and durable partnerships at the sub-national, national, sub-regional, regional and international levels to enhance international cooperation and action to address the unique and particular vulnerabilities of small island developing states so as to ensure their sustainable development'.

While it is evident that the impacts on agriculture and forestry in the short to medium term are likely to be quite modest, there is a clear need to commence climate resilience building efforts now to ensure that the productivity and sustainability of the agriculture and forestry sectors are increased and that the costs of adjustment are minimised. This is essential to improving food security, contributing to sustainable development and improving the livelihoods of those dependent on agriculture and forestry.

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Glossary

Adaptive capacity: the capacity of a system to adapt, if the environment where the system exists is changing. As applied to human social systems, adaptive capacity is determined by the ability of individuals, institutions and networks to learn, and store knowledge and experience; creative flexibility in decision making and problem solving; the existence of power structures that are responsive and consider the needs of all stakeholders.

Agroforestry: the deliberate growing of woody perennials on the same unit of land as agricultural crops and/or animals, in some form of spatial mixture or sequence; and involving significant ecological and/or economical interactions between the woody and non-woody components of the system.

Animal husbandry: the management and care of farm animals by humans for profit.

Anthropogenic: Caused or influenced by humans. Anthropogenic carbon dioxide is that portion of carbon dioxide in the atmosphere that is produced directly by human activities, such as the burning of fossil fuels, rather than by such processes as respiration and decay.

Agricultural Production Systems sIMulator (APSIM): a farming systems computer model that simulates the effects of environmental variables and management decisions on production (crops, pasture, trees, livestock), profits and the environmental variables (e.g. soil erosion).

Balance of payments: the difference in total value between a country's payments and its receipts over a period (usually a year).

Balance of trade: the difference between the value of a country's exports and its imports over a period (usually a year).

Carotenoids: a widely distributed group of naturally occurring pigments, usually red, orange or yellow in colour. They are known to be essential for plant growth and photosynthesis, and are a main dietary source of vitamin A in humans. They are thought to be associated with reduced risk of several chronic health disorders including some forms of cancer, heart disease and eye degeneration.

Climate: average weather (including variability and extremes) at a particular location and time of year based on many years (typically at least 30) of weather observations.

Climate change: a significant change (in the average and/or variability and extremes) in what we expect the weather to be like at a particular location and time of year. Such changes in climate can occur due to natural internal and external forcings of the climate system but are currently dominated by the response of the climate system to anthropogenic increases in greenhouse gases (see climate variability).

Climate model: numerical model, based on the laws of physics, constructed to understand and predict the dynamics of Earth's climate through the simulation of key variables such as air and sea surface temperature, precipitation and wind fields (see Global Climate Model).

Climate variability: variations in the mean state and other statistics of climate (such as occurrence of extremes) on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes in the climate system or to variations in natural or anthropogenic external forcing (see climate change).

CO_2 –equivalent: a metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential.

Comparative advantage: occurs when one country can produce a good or service at a lower opportunity cost than another. This means a country can produce a good relatively cheaper than other countries.

Coriolis Force: results from the movement of air and water masses relative to the moving latitude/longitude co-ordinates which rotate with the earth. As a result, in the Northern Hemisphere air and water masses are deflected to the right of their line of motion and in the Southern Hemisphere to the left. The amount of deflection depends on both the speed of motion and latitude. The Coriolis Force is zero at the equator and increases in effect towards the poles.

Cost benefit analysis: compares the benefits with the costs of a particular intervention measured in dollar terms - usually expressed as a ratio of the benefits divided by the cost.

Coupled Model Intercomparison Project (CMIP): an international framework for standardising and comparing GCM simulations of present and future climates (used in IPCC assessment reports). Many groups around the world have developed GCMs and, although all are based on the same physical principles, each has its own strengths and weaknesses due to the complex problem of understanding and modelling the global climate systems. CMIP 3 outputs were included in the IPCC-AR4 report published in 2007 and CMIP 5 generation models are included in the IPCC-AR5 report. (There were no CMIP 4 models to keep the naming consistent with IPCC-AR5).

Crop wild relatives (CWR): a wild plant taxon that has an indirect use derived from its relatively close genetic relationship to a crop; this relationship is defined in terms of the CWR belonging to genepools 1 or 2, or taxon groups 1 to 4 of the crop.

Cross price elasticity of demand: a measure of the responsiveness in the quantity demand of one good when a change in price takes place in another good.

Currency devaluation: an official lowering of the exchange value of a country's currency relative to other currencies.

C_3 and C_4: C_3 photosynthesis is the major of the three metabolic pathways for carbon fixation by plants. The C_4 photosynthetic carbon cycle is an elaborated addition to the C_3 photosynthetic pathway. It evolved as an adaptation to high light intensities, high temperatures, and dryness. Therefore, C_4 plants dominate grassland floras and biomass production in the warmer climates of the tropical and subtropical regions.

Downscaling: involves the use of techniques that take outputs from coarser resolution Global Climate Models (GCMs), to provide information at scales smaller than GCM grid spacing.

Ecosystem services: the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as air quality regulation, pollination and disease control; cultural services such as spiritual, recreational, and cultural benefits (taking account of landscape values); and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth.

El Niño: the 'warm' phase of ENSO characterised by unusually warm sea surface temperatures in the eastern equatorial Pacific associated with a weakening of the Walker Circulation and Trade Winds. The centre of maximum tropical convection shifts eastward towards the dateline resulting in the western Pacific experiencing unusually dry conditions, while the central and eastern Pacific have unusually wet conditions. Changes also occur in the main location of tropical cyclone activity and the SPCZ.

El Niño-Southern Oscillation (ENSO): the major source of inter-annual tropical climate variability characterised by periodic variations evolving over 12-18 months in the coupled ocean-atmosphere system of the tropical Pacific. These variations result in distinct and different surface climates (temperature, rainfall, tropical cyclone activity) during ENSO's two phases, El Niño and La Niña.

Evapotranspiration: the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.

Enteric fermentation: a natural part of the digestive process for many ruminant animals where anaerobic microbes decompose and ferment food present in the digestive tract producing compounds that are then absorbed by the host animal. A resulting by-product of this process is methane (CH_4), which has a global warming potential (GWP) 25 times that of carbon dioxide (CO_2).

Exposure: the nature and degree to which a system is subjected to significant climate variation (average climate change and extreme climate variability).

Expressed sequence tags (ESTs): single-pass reads of approximately 200-800 base pairs generated from randomly selected cDNA clones. Since they represent the expressed portion of the genome, ESTs have proven to be extremely useful for gene identification and verification of gene predictions.

Financial capital: the capital base (cash, credit/debt, savings, and other economic assets, including basic infrastructure and production equipment and technologies) that is essential for the pursuit of any livelihood strategy.

Food security: a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. From this definition the four main dimensions of food security can be identified as: food availability, economic and physical access to food, food utilisation and stability of the availability, access and utilisation.

Framework for Action on Food Security in the Pacific: formulated in response to a call for action on food security from Pacific Leaders at the 39th Pacific Islands Forum (2008). The aim of the Framework is to support Pacific countries to move towards ensuring that all their people, at all times, have physical, social and economic access to sufficient, safe and nutritious food. It brings the vision of 'Healthy Islands' closer and was endorsed at The Pacific Food Summit, Vanuatu, in 2010.

Free-air carbon dioxide enrichment (FACE): developed as a means to grow plants in the field at a controlled elevation of CO_2. FACE studies are fully open air and have many benefits over controlled environment and open-top chamber (OTC) experiments. FACE allows the investigation of an undisturbed ecosystem and does not modify the vegetation's interaction with light, temperature, wind, precipitation, pathogens and insects.

Free on board (FOB): a trade term requiring the exporter to deliver goods on board the vessel or aircraft that will carry the goods to the importer. The FOB prices include all costs up to that point, with the importer responsible for all costs after that point (including shipping, insurance and customs clearance).

Gross domestic product (GDP): the measure of value of economic output; the monetary value of all the finished goods and services produced by a country in a specific time period, usually calculated on an annual basis.

Global Climate Model: numerical representation of the global climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. Such models use complex mathematical equations that represent our current understanding of the climate system and are based primarily on the laws of physics (e.g. conservation of energy and momentum) as well as empirically-derived equations describing processes that are too small for models to explicitly resolve (termed 'parameterisation'; e.g. clouds).

Global warming: increase in the average air and sea surface temperatures of the Earth since the late 19th century, attributed to the accumulation of atmospheric greenhouse gases, including carbon dioxide, as a result of human activities such as the burning of fossil fuels and changes in land use.

Glycaemic index: a rating system for foods containing carbohydrates. It shows how quickly each food affects the blood sugar (glucose) level when that food is eaten on its own.

Greenhouse gases: atmospheric gases which absorb and emit thermal radiation and contribute to the 'greenhouse effect'. Naturally occurring greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide and ozone) trap energy in the climate system and maintain Earth's temperature.

Hadley Circulation: main meridional (north-south) atmospheric circulation of the tropics, characterised by rising moist air near the equator and upper level poleward air flow that sinks in the subtropical high pressure cells and returns to the equator as the surface Trade Winds.

Human capital: the skills, knowledge, ability to labour and good health that together enable people to pursue different livelihood strategies and achieve their livelihood objectives. At a household level human capital is a factor of the amount and quality of labour available; this varies according to household size, skill levels, leadership potential, health status, etc.

Intergovernmental Panel on Climate Change (IPCC): intergovernmental body established by the United Nations Environment Program and World Meteorological Organization in 1988 to review and assess the most recent scientific, technical and socio-economic evidence relating to anthropogenic climate change, its impacts and potential for adaptation and mitigation.

Intertropical Convergence Zone (ITCZ): near-equatorial region where surface Trade Winds from the two hemispheres converge and air rises, resulting in a distinctive cloud band and enhanced rainfall which forms the ascending branch of the Hadley Circulation.

Integrated Vulnerability and Adaptation Assessment Framework (IVAF): a generic guide for planning, implementing and reporting vulnerability assessments in an integrated way (across sectors and governance levels) and via a livelihoods-based approach.

Konzo: an upper motor neuron disease caused by cyanide, manifested principally as spastic paraplegia, seen in Africa. The disease is associated with prolonged high dietary cyanogen consumption from insufficiently processed roots of bitter cassava combined with a protein-deficient diet.

Landscape approach: tools and concepts for allocating and managing land to achieve social, economic, and environmental objectives in areas where agriculture, mining, and other productive land uses compete with environmental and biodiversity goals. A more unified landscape approach can better measure trade-offs between issues such as food security, energy needs, income generation, and the preservation of natural resources, such as forests, water supplies, and biodiversity. It can help better identify and implement climate change mitigation efforts so that agriculture, forest management, and land use are not only part of the problem, but also part of the solution.

La Niña: the 'cool' phase of ENSO characterised by unusually cold sea surface temperatures in the eastern equatorial Pacific associated with a strengthened Walker Circulation and Trade Winds. The centre of maximum tropical convection shifts westward resulting in the eastern Pacific experiencing unusually dry conditions, with unusually wet conditions in the western Pacific. Changes also occur in the main location of tropical cyclone activity and the SPCZ.

Lauric oils: coconut oil and palm kernel oil are often referred to as the lauric oils, defined by a lauric acid content of close to 50%. This characteristic affords particular advantages in food and industrial uses compared with other oils. The main edible uses for lauric oils are in ice cream, margarine, chocolate and confectionery products and the main non-edible uses are in detergents and soaps.

Linamarin: a cyanogenic glucoside found in cassava.

Livelihoods: in the context of this book 'livelihoods' refers to the capabilities, assets (including both social and material resources) and activities required for a means of living.

Madden-Julian Oscillation (MJO): source of intraseasonal (30-90 day) variability in the near-equatorial tropical atmosphere that travels eastwards from the Indian to Pacific Oceans. Its passage is usually associated with bursts of convective activity and rainfall.

Mitigation: IPCC defines mitigation as 'technological change and substitution that reduce resource inputs and emissions per unit of output with respect to climate change. Mitigation means implementing policies to reduce GHG emissions and enhance sinks'.

Natural capital: the natural resource stocks (soil, water, air, genetic resources, etc.) and environmental services (hydrological cycle, pollution sinks, etc.) from which resource flows and services useful for livelihoods are derived. There is a wide variation in the resources that make up natural capital, from intangible public goods such as the atmosphere and biodiversity to divisible assets used directly for production (trees, land, etc.).

No regrets: strategies that generate direct or indirect benefits that are large enough to offset the costs of implementing the options regardless of future climate change outcomes.

Opportunity cost: defined as the value of a foregone activity or alternative when another item or activity is chosen.

Pacific Adaptation Strategy Assistance Programme (PASAP): PASAP, funded by the Australian government from 2008–2011, assisted 15 partner countries to assess their vulnerability to climate change and incorporate adaptive measures addressing this vulnerability into planning and development.

Pacific Decadal Oscillation (PDO, Interdecadal Pacific Oscillation (IPO): Pacific basin-wide pattern of sea surface temperature anomalies (associated with distinctive patterns of atmospheric circulation variability), which operates on decadal and longer timescales. It persists in either a warm or cool phase for several decades and these phases modulate the inter-annual variability associated with ENSO events.

Pacific Disaster Risk Reduction and Disaster Management Framework for Action 2005 – 2015 (RFA): the regional adaptation of the global disaster reduction framework, the Hyogo Framework for Action.

Pacific Islands Framework for Action on Climate Change 2006-2015 (PIFACC): endorsed by Pacific Leaders in 2005. The Framework's vision is 'Pacific island people, their livelihoods and the environment resilient to the risks and impacts of climate change'.

Pacific Island Farmers Organisation Network (PIFON): is intended to serve as an umbrella organisation for national Farmer Organisations (FOs), to coordinate capacity building, share success stories and the lessons learnt, support regional exchanges of expertise between FOs and their associated private sector and donor agency partners.

Palm kernel oil: is a valuable by-product derived from oil palm kernels. For every tonne of palm oil produced around 130 kg of palm kernel oil is obtained. This high lauric acid product is almost technically identical to coconut oil and enters the same marketing channels and commands approximately the same price.

Percentile: identified thresholds in frequency distributions of a variable. For example, for daily temperatures, the 90th percentile defines the temperature exceeded by 10% of the values and the 10th percentile defines the temperature below which 10% of all values occur.

Physical capital: comprises the basic infrastructure and producer goods needed to support livelihoods. Infrastructure consists of changes to the physical environment that help people to meet their basic needs and to be more productive. Producer goods are the tools and equipment that people use to function more productively. Physical capital includes infrastructure (buildings and roads), production equipment and technologies.

Physiological thresholds (PT): changes in the physical environment affect physiological processes in plants and animals, such as respiration, photosynthesis, metabolic rate and water use efficiency. All organisms are able to cope with some degree of variability in their environment, and to maintain homeostasis and reproduction within the bounds of that variability. Beyond some physiological threshold, however, responses can change dramatically. Climate change can breach the PT of plants and animals impacting on growth and development. Distribution changes that are caused by climate change are often related to species-specific physiological tolerances of temperature and precipitation tolerance.

Price elasticity of demand: a measure of the responsiveness between the change in the quantity demanded of a particular good and a change in the price of that good.

Radiative forcing: difference between the amount of incoming solar radiation and the amount of energy radiated back to space. The amount of radiative forcing can alter due to variations in the amount of incoming solar radiation and changes in atmospheric composition (e.g. greenhouse gases) which affect the amount of outgoing long-wave radiation.

Real GDP: the measure of the value of economic output adjusted for price changes (i.e., inflation or deflation).

Real price: the actual price (nominal price) adjusted for inflation (or deflation).

Representative Concentration Pathways (RCPs): a range of possible futures (scenarios) for the main drivers of current climate change (greenhouse gas and air pollutant emissions and land use) including mitigation strategies, used as input for GCMs within CMIP5. The pathways describe four possible climate futures, all of which are considered possible depending on the total emissions of greenhouse gases in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (i.e. 2.6, 4.5, 6.0, and 8.5 W/m^2, respectively).

Resilience: ability of a system to absorb shocks and to bounce back, for which certain conditions are necessary, namely the ability to self-organise, to buffer disturbance and have the capacity for learning and adapting.

Ridge to Reef: grounded in the ecosystem approach, which is defined by the Convention on Biological Diversity (CBD) as "a strategy for the integrated management of land, water and living resources that provides sustainable delivery of ecosystem services in an equitable way". This concept requires a holistic, cross-sectoral and multidisciplinary approach to any island ecosystem, recognizing the inter-linkages between terrestrial and coastal and marine biodiversity.

Rossby waves: low-frequency oscillations in the ocean's surface and thermocline operating over 100s–1000s km with periods of tens of days and which move from east to west.

Sea-level rise: an observed consequence of the current warming climate in which the height of the ocean has increased due to changes in its volume. These changes are due to thermal expansion and addition of melting land-ice and glaciers.

Sea-level pressure (SLP, atmospheric pressure): pressure exerted at the Earth's surface due to the weight of the overlying air. Horizontal variations in SLP drive winds, storms and other atmospheric circulation processes.

Sensitivity: the degree to which a system is affected, either adversely or beneficially, by exposure to the direct and indirect effects of climate change.

Social capital: the social resources (networks, social claims, social relations, affiliations, associations) upon which people draw when pursuing different livelihood strategies requiring co-ordinated actions.

Soil organic carbon (SOC): comprises organic carbon in mineral soils to a specific depth chosen, also including live and dead fine roots within the soil (as defined by IPCC). The amount of SOC depends on soil texture, climate, vegetation and historical and current land use/management.

Strategy for Climate and Disaster Resilient Development in the Pacific (SRDP): strategy proposed to succeed the existing Pacific Disaster Risk Reduction and Disaster Management Framework for Action 2005 – 2015 (RFA) and the Pacific Islands Framework for Action on Climate Change 2006 – 2015 (PIFACC). The strategy aims to ensure a systematic and integrated approach to the implementation of both disaster risk management and climate change adaptation activities across the Pacific.

Southern Oscillation Index (SOI): an index of the strength of ENSO activity based on the difference in sea-level pressure between Darwin, Australia (representing the ascending branch of the Walker Circulation) and Tahiti, French Polynesia (representing the sinking branch of the Walker Circulation). Sustained positive values characterise La Niña events and sustained negative values characterise El Niño events.

South Pacific Convergence Zone (SPCZ): an extension of the Intertropical Convergence Zone extending from the Western Pacific Warm Pool south-eastwards towards French Polynesia, characterised by surface wind convergence and ascent resulting in a distinctive cloud band and enhanced rainfall.

Sustainable land management: the use of renewable land resources (soils, water, plants, and animals) for production and services while protecting the long-term productive potential of these resources.

Trade winds: easterly surface winds of the tropical Northern (northeast trades) and Southern (southeast trades) Hemispheres originating in the sinking air of the subtropical high pressure belt of each hemisphere as a result of the Hadley Circulation. Trade winds are characterised by the constancy of their speed and direction.

Transboundary disease: highly contagious epidemic diseases that can spread extremely rapidly, irrespective of national borders.

Tropical cyclone: non-frontal, rotating low pressure system formed over warm waters with organized convection and wind speeds > 115.km.hr. Tropical cyclones (also known as hurricanes and typhoons) are the most destructive weather systems affecting the tropics. They are particularly destructive when making landfall, bringing strong winds, high rainfall, storm waves and storm surges. They rarely form within 5-10^{o} of the equator.

Value added: value added measures the contribution to an economy of an individual producer, industry, sector or region. It is the difference value of the output and the cost of the inputs used.

Vulnerability: degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of character, magnitude, rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.

Walker Circulation: zonal (east-west) atmospheric circulation of the tropical Pacific operating within ~20° of the equator and closely linked to ENSO. It is characterised by rising moist air over Indonesia, which travels eastward aloft and then sinks and dries in the region of French Polynesia.

Weather: instantaneous state of the atmosphere described from day to day by measurable variables such as temperature, humidity, wind speed and direction, cloud cover and rainfall.

Western Pacific Monsoon (WPM): is the eastern part of the larger Australasian monsoon system that moves from the Northern Hemisphere across the equator to the tropical regions of the Southern Hemisphere in austral summer months giving rise to marked seasonal changes in rainfall.

Western Pacific Warm Pool (WPWP): warmest part of the tropical oceans in the tropical western Pacific. Characterised by low sea surface salinity and high sea surface temperatures, >28°C throughout the year.

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Abbreviations

ACIAR:	Australian Centre for International Agricultural Research
ADB:	Asian Development Bank
APSIM:	Agricultural Production Systems Simulator
AusAID:	Australian Agency for International Development
AVRDC:	World Vegetable Centre
BBTV:	Banana bunchy top virus
BCS:	Bogia coconut syndrome
BFI:	Breadfruit Institute
BLSD:	Black leaf streak disease
BOM:	Australian Bureau of Meteorology
BSR:	Basal Stem Rot
C_3:	Carbon fixation pathway in photosynthesis
C_4:	Carbon fixation pathway in photosynthesis.
CBA:	Cost benefit analysis
CBB:	Coffee Berry Borer
CBDV:	Colocasia bobone disease virus
CBVA:	Community Based Vulnerability Assessment
CCI:	Cocoa and Coconut Institute, PNG
CCRIL:	Cocoa and Coconut Research Institute Ltd, PNG
CePaCT:	Centre for Pacific Crops and Trees
CFDD:	*Coconut foliar decay disease*
CFDV:	Coconut foliar decay virus
CGIAR:	Consultative Group on International Agricultural Research
CIAT:	International Centre for Tropical Agriculture
CIFOR:	Centre for International Forestry Research
CIMMYT:	International Maize and Wheat Improvement Centre
CIP:	International Potato Centre
CIRAD:	Centre de coopération Internationale en Recherche Agronomique pour le Développement
CliDE:	Climate Data for the Environment
CLR:	Coffee leaf rust
CRI:	Coffee Research Institute
CMIP3:	Climate Model Intercomparison Project 3
CMIP5:	Climate Model Intercomparison Project 5
CNMI:	Commonwealth of the Northern Mariana Islands
CO_2:	Carbon dioxide
CMV:	*Cucumber mosaic virus*
CPI:	Consumer price index
CRP:	CGIAR Research Programmes
CSA:	Climate-smart agriculture

CTV: *Citrus tristeza virus*
CWR: Crop Wild Relatives
CSIRO: Commonwealth Scientific and Industrial Research Organisation (Australia)
DNA: Deoxyribonucleic acid
DSAP: Developing Sustainable Agriculture in the Pacific
DsMV: *Dasheen mosaic virus*
DSSAT: Decision Support System for Agrotechnology Transfer
eCO_2: Elevated CO_2
EEZ: Exclusive Economic Zone
ENSO: El Niño Southern Oscillation
ESTs: Expressed Sequenced Tags
EU: European Union
FACT: Facilitating Agricultural Commodity Trade
FAO: Food and Agriculture Organisation of the United Nations
FD: Fiji Disease
FDMT: Foliar decay (coconut) transmitted by *Myndus taffini*
FJD: Fijian dollars
FICI: Food Import Capability Index
FOB: Free on board
FSA: Farm Support Association, Vanuatu
FSM: Federated States of Micronesia
GCM: Global Climate Model
GDP: Gross domestic product
GHG: Greenhouse gas
GLEAM: Global Livestock Environmental Assessment Model
GxE: Genotype x Environment
HDI: Human Development Index
HIES: Household income and expenditure survey
HLPE: High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security
HOAFS: Heads of Agriculture and Forestry Services
IAASTD: International Assessment of Agricultural Knowledge, Science and Technology for Development
ICARDA: International Centre for Agricultural Research in the Dry Area
ICCAI: International Climate Change Adaptation Initiative
ICCO: International Cocoa Organization
ICM: Integrated Crop Management
ICRAF: World Agroforestry Centre
ICRISAT: International Crops Research Institute for the Semi-Arid-Tropics
IEA: International Energy Agency
IFPRI: International Food Policy Research Institute
ILRI: International Livestock Research Institute

INEA: International Network of Edible Aroids
IPCC: Intergovernmental Panel on Climate Change
IPCC-AR4: 4th Assessment Report of the Intergovernmental Panel on Climate Change
IPCC-AR5: 5th Assessment Report of the Intergovernmental Panel on Climate Change
IPM: Integrated Pest Management
IPDM: Integrated Pest and Disease Management
IPO: Inter-decadal Pacific Oscillation
IRCA: Institut de Recherches sur Le Caoutchouc (Rubber research and development institute CIRAD)
IRCC: Institut de Recherches sur Le Café et Le Cacao (Coffee and cocoa research and development, CIRAD)
IRHO: Institut de Recherches pour Les Huiles et Oléagineux
ITCZ: Intertropical Convergence Zone
IUCN: International Union for Conservation of Nature
IVAF: Integrated Vulnerability and Adaptation Assessment Framework
IWMI: International Water Management Institute
KGA: Kastom Gaden Association
LRD: Land Resources Division
MJO: Madden-Julian Oscillation
MOU: Memorandum of Understanding
MPI: Ministry of Primary Industries
NAP: National Adaptation Programme
NAPA: National Adaptation Plan of Action
NCDs: Non-communicable diseases
NGO: Non-Government Organisation
NMS: National Weather Monitoring Stations
NIWA: National Institute of Water and Atmospheric Research
NMDI: National Minimum Development Indicators
NMS: National Meteorological Services
NOAA: National Oceanographic and Atmospheric Agency (US)
OECD: Organisation for Economic Co-operation and Development
OLS: Ordinary Least Squares
OrNV: *Oryctes rhinoceros nudivirus*
PACAF: Pacific Adaptive Capacity Analysis Framework
PACC: Pacific Adaptation to Climate Change
PACCSAP: Pacific-Australia Climate Change Science and Adaptation Planning Program
PASAP: Pacific Adaptation Strategy Assistance Programme
PCCSP: Pacific Climate Change Science Program
PDO: Pacific Decadal Oscillation

PICTs:	Pacific Island countries and territories
PIFACC:	Pacific Islands Framework for Action on Climate Change
PIFON:	Pacific Island Farmer Organization Network
PNG:	Papua New Guinea
RMI:	Republic of the Marshall Islands
RCP:	Representative Concentration Pathway
REDD:	Reducing emissions from deforestation and forest degradation
SIDS:	Small Island Developing States
SLM:	Sustainable Land Management
SOC:	Soil organic carbon
SPC:	Secretariat of the Pacific Community
SPCZ:	South Pacific Convergence Zone
SPREP:	Secretariat of the Pacific Regional Environment Programme
SRDP:	Strategy for Climate and Disaster Resilient Development in the Pacific
SRES:	Special Report on Emissions Scenarios
SRI:	System of Rice Intensification
SST:	Sea surface temperature
SPI:	Standardised Precipitation Index
TAB:	Technical Advisory Board
TAG:	Technical Advisory Group
TaBV:	*Taro bacilliform virus*
TaroGen:	Taro Genetic Resources, Conservation and Utilization
TC/TS:	Tonnes Cane/Tonnes Sugar
TLB:	Taro leaf blight
TCZ:	Thermal Comfort Zone
UNDP:	United Nations Development Programme
UNFCC:	UN Framework Convention on Climate Change
USAID:	United States Agency for International Development
USDA:	United States Department of Agriculture
USEPA:	United States Environmental Protection Agency
USP:	University of the South Pacific
VARTC:	Vanuatu Agricultural Research and Technical Centre
VOCGA:	Vanuatu Organic Cocoa Growers Association
VUV :	Vanuatu vatu
WHO:	World Health Organization
WOSED:	Women's Social and Economic Development Programme
WPM:	Western Pacific Monsoon
WPWP:	Western Pacific Warm Pool
WTO:	World Trade Organisation

Notes

This book, which is the second in a series of climate impact assessments by the Pacific Community, follows the 2011 publication, *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*. Similar to the findings of the 2011 fisheries assessment, it is evident that climate change will, overall, have a negative impact on the productivity of the agriculture and forestry sectors across the Pacific over coming decades. However, this research also highlights the underlying resilience of Pacific agriculture to climate change, particularly for many of the region's staple food crops, and indicates there is some breathing space to enable appropriate measures to be put in place to accommodate the expected changes.