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Chapter 10

Adapting Pacific agriculture and forestry to climate change: management measures and investments

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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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References

1. Aalbersberg B, Dumaru P, Limalevu L and Weir T (2010) Community adaptation in Fiji: some lessons learnt, PACE–SD Occasional Paper 2010/1. University of the South Pacific, Suva, Fiji.
2. Biasutti M and Yuter SE (2013) Observed frequency and intensity of tropical precipitation from instantaneous estimates, *Journal of Geophysical Research: Atmospheres* 118, 9534–9551. doi:10.1002/jgrd.50694.
3. Burton I and Lim B (2005) *Adaptation policy framework for climate change: developing strategies, policies and measures*. Cambridge University Press, Cambridge, United Kingdom.
4. Challinor AJ, Watson J, Lobell DB, Howden SM, Smith DR and Chhetri N (2014) A metaanalysis of crop yield under climate change and adaptation, *Nature Climate Change* 4, 287–291.
5. Easterling WE, Aggarwal PK, Batima P, Brander KM and others (2007) Food, fibre and forest products. In: ML Parry, OF Canziani, JP Palutikof, PJ van der Linden and CE Hanson (eds) *Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom, 273–313.
6. Field CB, Barros VR, Mach KJ, Mastrandrea MD and others (2014) Technical summary. In: CB Field, VR Barros, DJ Dokken, KY Mach and others (eds) *Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, United States of America, 35–94.
7. Hay JE (2009a) Assessment of implementation of the Pacific Islands Framework for Action on Climate Change *(PIFACC)*. Prepared for the Pacific Climate Change Roundtable (PCCR) and the Secretariat of the Pacific Regional Environment Programme (SPREP).
8. Hay JE (2009b) Implementation of the Pacific Adaptation to Climate Change (PACC) project: process, status and assessment. Technical Report. Prepared for the Secretariat of the Pacific Regional Environment Programme (SPREP).
9. Howden SM and Crimp S (2005) Assessing dangerous climate change impacts on Australia's wheat industry. In: A Zerger and RM Argent (eds) MODSIM 2005 *International Congress on Modelling and Simulation.* Modelling and Simulation Society of Australia and New Zealand, December 2005, 170–176.
10. Howden SM, Soussana J-F, Tubiello FN, Chhetri N, Dunlop M and Meinke H (2007) Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences of the United States of America* 104, 19691–19696.
11. Jones RN, Patwardhan A, Cohen SJ, Dessai S and others (2014) Foundations for decision making. In: CB Field, VR Barros, DJ Dokken, KJ Mach and others (eds) *Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, United States of America, 195–228.
12. Kindt R, Lillesø JPB, Mbora A, Muriuki J and others (2006) *Tree seeds for farmers: a toolkit and reference source*. World Agroforestry Centre, Nairobi, Kenya. http://www.worldagroforestry.org/treesandmarkets/tree%20seeds/Documents%20of%20Toolkit/Toolkit.htm
13. Lal PN, Biloko M, Menandu A, Susumu G, Nonga N, Taylor M and Guillaume P-R (2014) *Applying CBA in the context of climate risk management: A Solomon Islands Case Study on Food Security.*

14. Lobell DB and Tebaldi C (2014) Getting caught with our plants down: the risks of a global crop yield slowdown from climate trends in the next two decades. *Environmental Research Letters* 9 (7): 074003

15. Maclellan N (2011) Improving access to climate financing for Pacific Islands. Analysis paper, Lowy Institute for International Policy, Sydney, Australia.

16. McGregor A, Kaoh P, Mariner LT, Lal PN and Taylor M (2011) Assessing the social and economic value of germplasm and crop improvement as a climate change adaptation strategy: Samoa and Vanuatu case studies. A background case study prepared for IUCN's report, Lal PN 2011 *Climate Change Adaptation in the Pacific: Making Informed Choices*, prepared for the Australian Department of Climate Change and Energy Efficiency (DCCEE), IUCN, Suva, Fiji.

17. McGregor A, Tora L and Lebot V (2014) Planting breadfruit orchards as a climate change mitigation strategy for the Pacific Islands. Paper presented at the International Horticulture Conference, Brisbane, Australia.

18. Nelson GC, Rosegrant MW, Koo J, Robertson R and others (2009) *Climate change impact on agriculture and costs of adaptation*. International Food Policy Research Institute, Washington DC, United States of America.

19. Phu Le D, Smith M, Hudler GW and Aitken E (2014) Pythium soft rot of ginger: Detection and identification of the causal pathogens, and their control. *Crop Protection*, 65, 153–167.

20. Porter JR, Xie L, Challinor AJ, Cochrane K and others (2014) Food security and food production systems. In: CB Field, VR Barros, DJ Dokken, KJ Mach and others (eds) *Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, United States of America, 485–533

21. Ramirez-Villegas J, Challinor AJ, Thornton PK and Jarvis A (2013) Implications of regional improvement in global climate models for agricultural impact research. *Environmental Research Letters* 8, 024018.

22. Stice K (2014) Fijian papaya gets a boost. ACIAR Information Sheet (PC/2008/003).

23. Tubiello FN, Soussana J-F and Howden SM (2007). Crop and pasture response to climate change. *Proceedings of the National Academy of Sciences of the United States of America 104,* 19686–19690.

24. van Ittersum MK, Howden SM and Asseng S (2003) Sensitivity of productivity and deep drainage of wheat cropping systems in a Mediterranean environment to changes in CO2 temperature and precipitation. *Agriculture, Ecosystems and Environment* 97, 255–273.

25. World Bank (2012) *World development report 2011: Conflict, security and development.* World Bank, Washington DC, United States of America.