CLIMATE CHANGE, FOOD SECURITY, AND SOCIOECONOMIC LIVELIHOOD IN PACIFIC ISLANDS

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ACP	African, Caribbean and Pacific
agGDP	agricultural gross domestic product
ABM	Australian Bureau of Meteorology
ALTA	Agricultural Landlords and Tenants Act (of Fiji)
BMI	body mass index
CBSI	Central Bank of Solomon Islands
CATM	Chinese Agriculture Technical Mission (of Taipei,China)
CAC	Coastal Aquaculture Centre (of Solomon Islands)
CEMA	Commodity Export Marketing Authority (of Solomon Islands)
PRC	People's Republic of China
CO_2	carbon dioxide
CMB	Copra Marketing Board (of Papua New Guinea)
CMIP3	Coupled Model Intercomparison Project
CMFL	Copra Millers Fiji Limited
CNRM	*Centre National de Recherches Météorologiques* (National Center for Meteorological Research [of France])
CRED	Centre for Research on the Epidemiology of Disasters (of Belgium)
CSIRO	Commonwealth Scientific and Industrial Research Organization (of Australia)
DAL	Department of Agriculture and Livestock (of Solomon Islands)
DEVFISH	Development of Tuna Fisheries in the Pacific ACP Countries Project
DOF	Department of Fisheries (of Fiji)
DREAM	Dynamic Research Evaluation for Management
DSSAT	Decision Support System for Agrotechnology Transfer
ECHAM	European Center Hamburg [Germany]
EEZ	exclusive economic zone
EM-DAT	International Disaster Database (of the Centre for Research on the Epidemiology of Disasters)
ENSO	El Niño Southern Oscillation
EU	European Union
FAD	fish aggregating device
FAO	Food and Agriculture Organisation of the United Nations
FMS	Fiji Meteorological Service
FSC	Fiji Sugar Corporation
fte	full-time equivalent
GCM	general circulation model
GDP	gross domestic product
GHG	greenhouse gas

GIFT	genetically improved farmed tilapia
GPPOL	Guadalcanal Plains Palm Oil Ltd. (of Solomon Islands)
HadCM3	Hadley Centre Coupled Model, Version 3 (of the United Kingdom Meteorological Office)
HADC	Highlands Aquaculture Development Center (of Papua New Guinea)
HDR	Human Development Report
HDI	human development index
HPI	human poverty index
ICLARM	International Center for Living Aquatic Resources Management
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
IPCC AR3	Intergovernmental Panel on Climate Change Third Assessment Report
IPCC AR4	Intergovernmental Panel on Climate Change Fourth Assessment Report
LDC	least developed country
KGA	Kastom Gaden Association (Solomon Islands)
LMMA	locally managed marine area
MAL	Ministry of Agriculture and Livestock (of Papua New Guinea)
MAL	Ministry of Agriculture and Livestock (of Solomon Islands)
MFNP	Ministry of Finance and National Planning (of Fiji)
MIROC	Model for Interdisciplinary Research On Climate (of Japan)
NADP	National Agricultural Development Plan (of Papua New Guinea)
NAPA	National Adaptation Program of Action
NARI	National Agricultural Research Institute (of Papua New Guinea)
NBPOL	New Britain Palm Oil Ltd.
NCD	national capital district
NFA	National Fisheries Authority (of Papua New Guinea)
NFD	National Fisheries Development (of Solomon Islands)
NFNC	National Food and Nutrition Center (of Fiji)
NLTB	Native Land Trust Board (of Fiji)
NRRDP	National Rural Rice Development Program (of Solomon Islands)
NZODA	New Zealand Official Development Assistance
OPIC	Oil Palm Industry Corporation
OPRA	Oil Palm Research Association (of Papua New Guinea)
PCCSP	Pacific Climate Change Science Program
PNA	Parties to the Nauru Agreement
PNG	Papua New Guinea
PNGNWS	Papua New Guinea National Weather Service

R&D	research and development
RBD	refined, bleached, and deodorized
ROCAM	Republic of China Agricultural Mission (of Taipei,China)
ROW	rest of the world
SIDHS	Solomon Islands Demographic and Health Survey
SIMS	Solomon Islands Meteorological Services
SIPL	Solomon Islands Plantation Ltd.
SOC	soil organic carbon
SPC	Secretariat of the Pacific Community
SPAM	Spatial Production Allocation Model
SPCZ	South Pacific Convergence Zone
SRI	System of Rice Intensification (of Solomon Islands)
SWAT	soil and water assessment tool
WCPFC	Western and Central Pacific Fisheries Commission
WFC	WorldFish Center

Weights and Measures

°C	degrees Celsius
ha	hectare
kcal	kilocalorie
kg	kilogram
kg/yr	kilograms per year
km	kilometer
km^2	square kilometer
m	million
mt	metric ton
mt/ha	metric tons per hectare
t	ton

Foreword

The Asian Development Bank (ADB) requested the International Food Policy Research Institute (IFPRI) to carry out a research study under the regional technical assistance (RETA) project on "Capacity Strengthening of the Pacific Island Developing Member Countries in Responding to Climate Change." The overall goal of the study was to formulate specific policy recommendations for policy makers in three countries: Fiji, Papua New Guinea, and Solomon Islands. The study is timely given the challenges due to climate change faced by the Pacific Island countries. Agriculture and fisheries will be hard-hit by changes in climate conditions, with negative effects on nutrition and food security, particularly in rural communities. Even without the effects of climate change, rising food prices since mid-2000s have affected rural communities in the developing countries of the Pacific and elsewhere. Adaptation technologies and strategies for agriculture and fisheries sectors need to be practical, available, accessible, and easily applied by the rural farmers and fishers.

This report presents a framework for providing policy makers in the three Pacific island countries with the quantitative and qualitative information required to formulate policies for counterbalancing—or at least minimizing—the negative impacts of climate change on output and efficiency in their agriculture and fisheries sectors and hence minimize the impacts of climate change on food security and economic livelihood.

The policy recommendations on priority adaptation strategies for the agriculture and fisheries sectors are of significant importance for consideration by the governments in Fiji, Papua New Guinea, and Solomon Islands to improve the ability of their agriculture and fisheries sectors to combat the detrimental effects of climate change, thus providing benefits to the rural poor and vulnerable groups, especially farmers and fishers; improving the living conditions of rural communities; and enhancing food security.

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Executive Summary

Pacific Island Countries under Threat

Climate change projections internationally accepted as being reliable indicate that most countries in the Pacific region will suffer large-scale negative impacts from climate change. These impacts are likely to include elevated air and sea-surface temperatures, increasingly unpredictable rainfall patterns, rising sea levels, and intensification of extreme weather events such as tropical cyclones and El Niño-related droughts.

Pacific island countries are particularly vulnerable to such climatic changes, since on average, two-thirds of the region's population depends on agriculture and fisheries for its livelihood and food security. This is certainly true of at least two of the three countries analyzed under the study on which this report is based, the latter including Fiji, Papua New Guinea (PNG), and Solomon Islands.

PNG and Solomon Islands are both vulnerable to the negative impacts of climate change since the percentage share of agriculture in total employment is relatively high in both countries (69% in PNG and 68% in Solomon Islands). Similarly, because of their relatively high percentage share of agriculture in the gross domestic product (GDP) (36% in PNG and 39% in Solomon Islands during 2000–2009), the current capacity of both countries for adapting to climate change is limited.

In relative terms, Fiji fares somewhat better in terms of vulnerability to climate change, since its percentage share of agriculture in GDP is only about 13%, which is less than half that of PNG and Solomon Islands. However, this relatively low share of agriculture in GDP is in part due to a tourism sector of substantial size, as well as the fact that land tenure issues have constrained output in the production of the country's principal crop, sugarcane. Further, this 13% statistic relates solely to agriculture, and thus ignores the substantial contribution of the country's fisheries to GDP.

Despite the relative differences in vulnerability to climate change referred to above, overall, the negative impact of climate change on the agriculture and fisheries sectors in all three study countries is likely to be considerable, simply because from a geographic standpoint, no Pacific island country can escape being impacted by it. For example, annual precipitation levels in all Pacific island countries are projected to change by at least 20% in 2050 as compared with the average precipitation level over the period 1950–2000. Such a shift would no doubt impact crop yields and output levels.

Further, there is now a growing body of evidence that suggests that some of these negative impacts on output in the agriculture and fisheries sectors in the three study countries are already occurring. It is thus vital that all three countries begin building resilience to climate change with all possible speed, regardless of the rate at which climate change ultimately unfolds. However, building resilience to climate change is not a trivial task. This is particularly true since little information exists, for example, about the specific impacts of projected changes in climatic variables on the output of staple crops in these countries, or on the output of their fisheries sectors. Such information is vital if policy makers are to put into place specific policies for mitigating the negative impacts of climate change on food security and economic livelihood in the three study countries.

The overall goal of the study on which this report is based is to develop a framework for providing policy makers in Pacific island countries with the specific (e.g., quantitative and qualitative) information they need to formulate policies for counterbalancing—or at least minimizing—the negative impacts of climate change on output and efficiency in the agriculture and fisheries sectors in the countries they serve, and thence minimizing the negative impacts of climate change on the food security and economic livelihood of the populations of the countries concerned. Thus ultimately, the goal of the study is to formulate specific policy recommendations for policy makers in the three study countries.

More specifically, the purposes of the study are to

(i) assess the likely negative impact of climate change on output and efficiency in the agriculture sector both in volume and value terms, and thence on food security and the economic livelihood of the populace in Fiji, PNG, and Solomon Islands,
(ii) identify operational means of counterbalancing—or at least minimizing—these negative impacts, and evaluate the economic costs and benefits of such means, both in terms of financial value and economic efficiency, and
(iii) identify specific policy recommendations for minimizing the negative impact of climate change on output and efficiency in the agriculture and fisheries sectors, and thence on food security and the economic livelihood of the populace in the three study countries.

Modeling the Problem—and the Solution

The analysis on which this report is based identified potential climate change adaptation mechanisms in the agriculture and fisheries sectors of the three study countries. Due to data limitations, as well as a host of other constraints, the analysis relating to the fisheries sector is of a more heuristic than quantitative nature, whereas that relating to the agriculture sector is quantitatively rigorous.

In particular, the analysis relating to the agriculture sector assessed the likely negative impacts of climate change on crop yields, and thence, agricultural output. As well, it quantitatively assessed a variety of climate adaptation mechanisms (i.e., modifications to crop production practices) that could be employed to counterbalance or minimize the negative impacts of climate change on crop yields. Further, the analysis performed the above assessments for a range of climate profiles projected to occur in the year 2050, this range of future profiles comprising the forecasts of four internationally respected general circulation models (GCMs). The crops included in the analysis comprised the staple crops of the three study countries: cassava, maize, rice, sugarcane, sweet potato, and taro.

The analytical framework used to perform the quantitative work carried out under the study integrated the use of a number of computer-based models and tools as follows:

(i) a crop allocation model (i.e., the *Spatial Production Allocation Model* [SPAM]),

(ii) the soil and water assessment tool (SWAT), the latter originating from the erosion productivity impact calculator model,
(iii) the *Decision Support System for Agrotechnology Transfer* (DSSAT), which was used for purposes of crop modeling,
(iv) the *International Model for Policy Analysis of Agricultural Commodities and Trade* (IMPACT), which was developed by IFPRI for the purpose of projecting food supply, demand, and security to the year 2020 and beyond, and
(v) the *Dynamic Research Evaluation for Management* (DREAM) model, which the study used to help evaluate the financial costs likely to be borne by the agriculture sector due to climate change, as well as the financial benefits of the climate change adaptation mechanisms (i.e., modifications to crop production practices) considered by the study.

Using three sets of data—some of which included outputs of the SPAM model referred to above as well as soil and water data drawn from other sources—DSSAT was used to estimate the changes in crop yields likely to occur under conditions of climate change. These three sets of data used by DSSAT included:

(a) daily weather data, including maximum and minimum temperature, solar radiation, and precipitation;
(b) a description of the physical and chemical characteristics of the soil in the field; and
(c) crop management data, including the types of crops grown, the specific varieties planted, the planting date for each crop, the amount of physical space between plants, the quantity and types of fertilizer used, and whether or not irrigation was used to provide water.

DSSAT was used to estimate the changes in crop yield due to climate change likely to occur as a result of changes in climate-related parameters such as rainfall patterns and minimum and maximum temperatures. From these estimates of climate change-driven reductions in crop yield, it was then possible to estimate the decline in the annual output of each crop analyzed due to climate change. Price elasticities of demand and supply for each crop analyzed were applied to the estimated change in output for each crop to determine the likely change in market price of the commodities analyzed that would occur because of the decline in crop yield driven by climate change.

Using the results from the above steps, the DREAM model was used to estimate the economic costs of the negative impacts of climate change, as well as the economic benefits likely to arise from modifying crop production practices as a means of minimizing the negative impacts of climate change on crop yields. This analysis, in turn, incorporated the use of IMPACT—the IFPRI's global agricultural supply and demand model. Use of IMPACT in conjunction with the DSSAT and DREAM analyses described above also allowed the following to be assessed: (i) the likely impact of climate change on food security, and (ii) the degree to which agricultural adaptation policies would be likely to improve food security under conditions of climate change. The analysis described above was accomplished by means of incorporating three scenarios simulated by IMPACT, each of which is briefly described below.

(a) A *baseline scenario,* in which no climate change takes place. This scenario assumed that the average values for climate-related parameters prevailing during the period 1950–2000 would remain unchanged to the year 2050.
(b) A *climate change scenario,* in which no adaptation to climate change in the agriculture sector occurs. Under this scenario, the full extent of the reductions in crop yield and agricultural output estimated by DSSAT are assumed to occur, there being no adaptations to climate change to counterbalance these. Crop yields thus fall, and with them, agricultural output and income as per DSSAT and DREAM estimates.
(c) A *climate change scenario under which climate change adaptation occurs.* Under this scenario, the negative impact of climate change on crop yields is counterbalanced by the yield-boosting impact of a range of investments in the agriculture sector. These investments include (1) use of improved crop management techniques (e.g., use of optimal cultivars, spacing between plants, and optimal planting dates), (2) increased fertilizer application rates, and (3) an increase in the extent to which irrigation is used. As such investments all tend to raise crop yields, then to some degree counterbalance the negative impact of climate change on agricultural output.

One of the benefits of using IMPACT to incorporate these scenarios into the overall analysis is that it takes into account the manner in which climate change in *non*-study countries is likely to affect food security in the three study countries through its impact on world commodity prices. In short, the results of the analysis incorporating the three scenarios referred to above indicate that climate change dramatically curtails progress toward food security in the three study countries. More specifically, reductions in calorie availability due to climate change in the year 2050 are estimated at 7% in Fiji, 17% in PNG, and 13% in Solomon Islands as compared to the year 2000. Section on the Impacts of Climate Change and Climate Change Adaptation on Food Security below summarizes the likely path either toward or away from food security in each of the study countries under each of the three scenarios referred to above.

Impact of Climate Change on Crop Yields: Modeling Results

As mentioned above, four GCMs internationally recognized as producing reliable results, were used to generate the range of likely future climate profiles for the Pacific region used in performing the analysis. Using four climate profiles was preferable to relying on a single projected profile for the region, since this allowed results based on the projected climate profiles generated by the four GCMs to be compared, any convergence in the results generated thus increasing the confidence level of the results of the study.

These four GCMs included the following (i) the model developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) [of Australia], (ii) the model developed by *Centre National de Recherches Météorologiques* (the National Center for Meteorological Research [of France] or CNRM), (iii) the Model for Interdisciplinary Research on Climate [of Japan] (MIROC), and (iv) the model developed by the Max Planck Institute for Meteorology at the European Centre Hamburg [Germany] (or ECHAM).

Briefly, the differences in the year-2050 climate profile for the Pacific region forecast by the four GCMs are as follows. The CSIRO model forecasts a relatively modest increase in temperature by 2050, while the CNRM predicts a steeper increase. MIROC predicts a much drier future, while the CSIRO model predicts a slightly wetter future. The ECHAM model forecasts a year-2050 climate profile for the Pacific that falls within the range of the other three models in an intermediate manner.

The significant differences in the climate profiles forecast for the Pacific by these four GCMs reflects uncertainty about the future impacts of climate change. This, in turn, suggests that policies and strategies for adapting the agriculture and fisheries sectors to the negative impacts of climate change must be flexible. (The section below discusses the collective results from the four GCMs as these specifically relate to each of the three study countries.)

The differences in the climate profiles of the Pacific region forecast by the four GCMs notwithstanding, the results of all four models taken together indicate that ultimately, climate change is likely to have a significant negative impact on the output of major crops, and thence on agricultural income and food security in the three study countries. In brief, in the absence of adaptation to climate change, yields for most crops are projected to decline by 10%–20% by the year 2050. This is a significant loss, particularly given the already slow rates of growth in yield and output for these crops overall.

Collectively, producers of the crops under study are projected to experience losses of millions of dollars. For example, in the absence of climate change adaptation measures, Fiji is projected to lose more than 1% of the annual value of its sugarcane output each year during the period 2008–2050. While seemingly small in percentage terms, this 1% equates to about $8 million per year, or approximately $375 million for the 43-year period 2008–2050. Although this is the most dramatic loss in agricultural income for all crops in all countries included under the study, the financial losses for the other crops studied are collectively of sufficient magnitude to warrant immediate attention from policy makers.

On the positive side, the study results project that planting cultivars optimal for the year-2050 climate, planting those cultivars during the optimal month for each crop, and incorporating other yield-boosting crop management measures would significantly mute the losses in crop yield and output caused by climate change described above. Likewise, crop yields and output overall are projected to increase significantly in the face of climate change when rates of fertilizer application are increased, or the use of irrigation is expanded.

While such responses to climate change represent relatively low-cost adaptation strategies, they still require significant levels of investment. This is mainly because identifying cultivars and crop production practices optimal for the year 2050 is likely to be more efficiently achieved through funding of national or regional agricultural research institutions than through trial and error at the farm level, particularly in the case of smallholders.

Results for Fiji

The CSIRO model projects that given moderate temperature and precipitation increases, the yield of rainfed sugarcane would rise in most areas of Fiji. However, the CNRM, ECHAM, and MIROC models all forecast yield decreases for most areas of the country. This convergence suggests that yield decreases for rainfed sugarcane are the most likely outcome.

For cassava, yields are projected to decline by as much as one-third by the year 2050 as compared to their year-2000 levels. Significant yield losses for taro are likewise forecast. However, planting improved cultivars adapted to climate change is projected to significantly cut the losses estimated for cassava, and to a substantial extent, for taro.

For both rice and taro, the negative impact of climate change on yields is more pronounced when higher rates of fertilizer application are used. However, this effect is overwhelmed by yet *further* increasing the rate at which fertilizer is applied. Depending on the region within the country, rice yields in the latter high-fertilizer-use case are projected to exceed those in the low-fertilizer-use case by 50% to more than 100%, the corresponding range for taro yields being 17% to 114%.

The study analyzed the impact of climate change on crop yields in Fiji under both a worst-case and best-case scenario. In nearly all cases for that country—as well as for PNG and Solomon Islands—the results from three of the four GCMs converged around the worst-case scenario. As a result, this scenario provides the best guide to the likely impacts of climate change on yields and output levels for major crops.

Results for Papua New Guinea

For most areas of PNG, the CSIRO model forecasts the smallest declines in yields due to climate change as compared to the other three GCMs. For sugarcane, the decline in yield due to climate change is projected to be relatively small. Nevertheless, planting improved sugarcane varieties is projected to boost yields by 5.5%.

For rainfed taro, yield losses from climate change in 2050 as compared to year-2000 yields are projected to be 13%, and for sweet potatoes under the most likely scenario, 11%. However, adaptation through planting of optimal cultivars cuts these losses by nearly half.

Results for Solomon Islands

For most areas, the CSIRO model forecasts smaller crop-yield losses than the other three models. For rice, sweet potato, and, in most cases, taro, yield losses due to climate change are significant for high levels of fertilizer use. However, further raising the rate at which fertilizer is applied by a substantial amount significantly reduces the magnitude of these losses.

Economic Costs of Climate Change in the Agriculture Sector

For all three study countries, the projected losses from climate change in the agriculture sector are significant. For example, the decline in the financial value of sweet potato output for the period 2008–2050 is $132 million in PNG, and nearly $10 million in Solomon Islands, while the corresponding losses in the value of taro and cassava production in Fiji are about $34 million and $24 million respectively. However, the above losses are dwarfed by the approximately $375 million projected loss in sugarcane production in Fiji referred to earlier.

In Fiji, producers and consumers are each forecast to bear approximately half the financial cost of the climate change-driven loss in output of the crops studied. Producers are forecast to bear half of these losses because of declines in output (and thence revenue from crop sales), and consumers the other half because of increased market prices caused by reductions in supply.

The only *increase* in crop yields due to climate change projected by the study was for rice produced in PNG. However, the total projected increase in financial value for this additional rice production was only $40,000 for the entire period 2008–2050, or less than $1,000 per year for the entire country.

Economic Benefits of Adaptation to Climate Change in the Agriculture Sector

In Fiji, the economic benefits from adaptation to climate change are significant. For example, increasing the rate at which fertilizer is applied as a climate change adaptation strategy results in projected financial gains for rice and taro production of about $70 million and $170 million, respectively, over the period 2008 to 2050. Similarly, increasing the use of irrigation as a climate-change adaptation strategy is projected to produce total financial benefits of $15 million, $30 million, and $70 million, respectively, for rice, taro, and sugarcane production over the same period.

In PNG, the cumulative benefits from increased fertilizer use in the production of rice over the period 2008–2050 are projected to be nearly $3.4 million. Similarly, the projected benefits from the use of optimal cultivars and planting months on the one hand, and irrigation on the other are $0.3 million and $0.8 million respectively. However, the greatest benefits from adaptation occurs in the production of sweet potato, increased fertilizer use leading to a projected $1,400 million in financial benefits over the period, and that from the use of optimal cultivars and planting months an additional $100 million. In all cases, producers and consumers share more or less equally in these benefits.

Similarly, increased fertilizer use in sweet potato production in Solomon Islands is projected to result in benefits of $160 million over the period 2008–2050, and an additional $4 million over the same period from use of optimal cultivars and planting months. For rice production, the cumulative benefits from increased fertilizer use exceed $12 million over the period, whereas increasing the use of irrigation and optimal cultivars and planting month are projected to result in gains of $6 million and $2 million respectively.

Impacts of Climate Change and Climate Change Adaptation on Food Security

Because of the relatively rapid rate of population growth in both PNG and Solomon Islands assumed for the period 2000–2050, the number of people at risk of hunger in both countries increases over the period, even under the baseline scenario that assumes no climate change and thence, no climate change-driven reductions in crop yields.[1, 2] Under the climate change scenario, the situation is considerably worse, as the projected number of people at risk of hunger increases by 21% in PNG and 45% in Solomon Islands over the same period.

1 The rate of population growth assumed by the analysis for all three study countries is consistent with that of scenario A1B of the Hadley Centre Coupled Model, Version 3 of the United Kingdom Meteorological Office (HadCM3). Scenario A1B was used for purposes of the present study since it was the most appropriate overall scenario of those considered by the International Panel on Climate Change in its Fourth Assessment Report.

2 The analysis of the share of the population at risk of hunger, and the share of malnourished children in the total population under 5 years of age excludes Fiji due to unavailability of data.

As for the projected share of malnourished children in the total population aged 5 years and below, the baseline scenario projections for PNG and Solomon Islands indicate reductions of 21% and 33% respectively over the period. However, under the climate change scenario, this progress is reversed, with both the share and number of malnourished children under 5 years of age in 2050 exceeding that in 2000.

For the climate change adaptation scenario, the aggressive agricultural productivity investments undertaken offset the negative impact of climate change, thus restoring the percentage share and number of malnourished children to the year-2050 baseline scenario level. Under the climate change adaptation scenario, calorie consumption increases significantly, and approximately three-fourths of the increase in childhood malnutrition that occurred under the climate change scenario is erased. Nonagricultural and nonfisheries investments in clean water and maternal education also assumed under this scenario further reduce child malnutrition, thus restoring child malnutrition to its baseline-scenario level.

An additional benefit under the climate change adaptation scenario is the substantial increase in consumption of traditional staple crops (taro, sweet potato, and cassava) relative to imported rice and wheat. The increases in productivity of these staple crops that occur in response to the agricultural productivity investments undertaken in this scenario reduce domestic prices of these staple foods, thereby increasing consumption. Conversely, the import prices of rice and wheat remain high due to climate change-driven negative impacts on the production of rice and wheat in countries exporting these commodities

The potential increase of skipjack tuna catch by 24% or 33% under the B1 and A2 scenarios, respectively, in 2100 could lead to improve nutrition and income of rural fishers in Fiji (Bell et al. 2011). In aquaculture, tilapia could be grown in small ponds at higher altitudes than at present in inland PNG and other Pacific countries given the rising temperatures under climate change (Bell et al. 2009). This is a promising economic activity for highland and inland rural communities, but will require proper infrastructure, quality fingerlings, and suitably formulated feed based on local ingredients (Bell, Johnson, and Hobday 2011). However, such aquaculture will need strong or improved infrastructure for protection against cyclones and other natural disasters.

In sum, results from the agriculture and fisheries sectors indicate that climate change adaptation can improve dietary diversity in all three study countries, as well as directly improving calorie availability and food security, and contributing to income and economic stability in the rural areas.

Policy Recommendations for Adaptation to Climate Change in the Agriculture and Fisheries Sectors

Overall, the results of the study suggest that climate change is likely to have a highly negative impact on food security in all three study countries. But, the results also suggest that agricultural and fisheries adaptation measures have the potential to offset many of these negative impacts. In this regard, agricultural adaptation particularly includes improved crop management, increased use of fertilizer and irrigation, and increased investment in agricultural research and extension. Adaptation strategies for the fisheries sector include policies to enhance the inshore national catch and to improve and support aquaculture development, as well as investment in socioeconomic/policy and technical research done by regional and national institutions and promotion of extension services. To be successful, such strategies also require an enabling institutional and policy environment. As a result, the policies identified below as being necessary for adapting to climate change include not only policies for directly promoting climate change adaptation, but also those that facilitate successful implementation of climate adaptation practices.

Overall Recommendations for the Agriculture Sector

In sum, the specific policy recommendations produced by the study for adapting to climate change in the agriculture sector in the three study countries include

(a) reforming land tenure systems and policies to increase the availability of land for agricultural (and aquaculture) production, usage of land under customary ownership in a way that ensures security of traditional land ownership while at the same time tapping its agricultural production potential, and to ensure efficiency in land administration;
(b) increasing fertilizer use through subsidies and vouchers, public investment in soil-fertility enhancement technologies, locally tailored fertilizer recommendations, coordinated service provision and creation of an enabling policy environment for farmers and private-sector fertilizer suppliers;
(c) developing nontraditional agricultural exports and value-adding products and promoting other cash crops so as to diversify agricultural base;
(d) reducing the risk of climate change through development and use of new high-yielding cultivars, including promoting varieties of rice better adapted to local conditions, that are resilient to multiple types of climate shocks; adoption of improved crop production practices; and increased use of irrigation;
(e) upgrading the road and port infrastructure required for the smooth functioning of fertilizer supply and distribution networks as well as to facilitate transport and marketing of rural farm produce to market/urban outlets;
(f) undertaking marketing, technical, and financial prefeasibility appraisals with pilot testing of new technologies and management arrangements prior to scaling-up; and
(g) further developing climate models and projections that focus on crops relevant to the three study countries.

Overall Recommendations for Agricultural Research and Extension

Adaptation to climate change-induced declines in crop yields requires

(a) increased investment in research on resilient seed varieties that are salt, drought, flood, and heat-tolerant; developing improved cultivars and farming system strategies; testing varieties for adaptation to local conditions;
(b) promotion of soil fertility management options designed to both provide nutrients to crops and enhance overall soil fertility;

(c) promotion of the use of appropriate levels of fertilizer with proper crop management;
(d) establishing regional centers of excellence, undertaking cost-benefit analyses of evaluated technologies, building national and regional research capacity, strengthening linkages with international agricultural research centers to facilitate access to broader genetic diversity, advanced bioinformatics, and gene sequencing; and
(e) developing and promoting extension services in order to provide improved market support to farmers, and dissemination of information relating to efficient crop production technologies and agricultural practices.

To address these challenges, the trend toward inadequate and declining public investment in agricultural research needs to be reversed. To achieve this, agricultural research funding should increase in real terms by at least 10% per year in the three study countries to achieve a tripling of agricultural research investment to at least 1.5% of agricultural GDP.

Overall Recommendations for the Fisheries Sector

Coastal and open-ocean fisheries in the three study countries are likely to suffer significant negative impacts from climate change including

(a) changes in the distribution and abundance of tuna,
(b) a decline in the extent of coral reefs and coastal fisheries,
(c) difficulties in developing aquaculture, and
(d) increased operating costs for both aquaculture and fisheries in general.

The most important policy recommendations for adapting to climate change in the fisheries sector are

(a) improving and encouraging a larger inshore national tuna catch, using networks and tools such as low-cost inshore fish-aggregating devices, and developing technologies for small-scale fishers;
(b) negotiating payment of increased access fees both by distant-water fishing nations and local fishing nations, and reorienting government spending of the revenue collected from these fees into indirect support of the domestic market;
(c) expanding and supporting aquaculture management by incorporating local participation and communities into the management of marine resources, introduction of necessary regulations (e.g., prevent downstream pollution from excessive feeding of fish in operations), and improving biosecurity mechanisms to protect biodiversity;
(d) investing both in technical research and in socioeconomic and policy research, given that most research is performed by regional and national institutions primarily focusing on technical evaluation;
(e) improving and promoting extension services that support markets for fishers and fish farmers, building community awareness regarding the importance of environmental protection, and disseminating fishery and aquaculture technologies;
(f) further developing climate models and projections of the negative impacts of climate change and appropriate adaptation responses; and

(g) building an enabling policy environment for aquaculture operations (such as through the provision of incentives, credit, and marketing support), and encouraging rural residents to enter the industry.

Overall Aims of Policy for Adapting to Climate Change

Prioritizing reforms is always difficult. However, the highest ranked adaptation policies based on the study's quantitative results and review of evidence are those identified immediately below. These priorities were likewise reflected during the presentation and feedback mechanisms adopted during the regional consultation and workshop with representatives from the national governments of Fiji, PNG, and Solomon Islands, nongovernment organizations, regional research offices, and donor communities in Asia and the Pacific.

1. Rationalizing land tenure policy in a way that retains indigenous ownership of land, but that allows commercial use rights to be put into in place, such as by creation of land banks and incorporated land groups.
2. Increasing investment in agricultural research and harmonizing agricultural and fisheries research at the regional level by establishing centers of excellence that link national research institutions and access services from international agricultural and fisheries research centers.
3. Revitalizing extension systems in a way that incorporates local participation and effective coordination of public- and private-sector providers including nongovernmental organizations in order to support adaptive crop and fisheries management.
4. Increasing investment in rural infrastructure that directly links to market development.
5. Promoting aquaculture and coastal fisheries by providing technological, institutional, and management support at the local and community levels, as well as promoting adoption of, and adherence to best aquaculture and fishing management practices.
6. Developing and implementing integrated data management, monitoring, and evaluation systems for the agriculture and fisheries sectors at all levels from the community level to the national level.

I. Introduction

Overview

Agriculture is an important sector in Pacific island countries, particularly in terms of its contribution to the livelihood of the populace, gross domestic product (GDP), and food security. Overall, approximately 67% of the region's population depends on agriculture for its livelihood (FAO 2011). More especially, for the three countries included under the present study, agriculture accounted for 15% of GDP in Fiji, 37% in Papua New Guinea (PNG), and 36% in Solomon Islands during the period 2000–2009 (World Bank 2011). Coastal resources likewise play an important role in the subsistence and cash economies of the Pacific region, fish providing an important source of protein and income for most coastal communities.

In light of the above, climate change poses a significant threat to output in both the agriculture and fisheries sectors in Pacific island countries, this threat being acknowledged by The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) (Mimura et al. 2007). In short, climate change is projected to result in large-scale impacts in the region that include elevated air and sea-surface temperatures, unpredictable rainfall patterns, rising sea levels, changes in regional climate systems, and increasing intensity and frequency of extreme weather events including tropical cyclones, depressions, and droughts (Barnett 2007; FAO 2009; Simpson et al. 2009; Barnett and Campbell 2010). Such alterations in the climate profile of the Pacific region pose significant risks to its fragile ecosystems, thus threatening the food security of millions of its inhabitants.

Climate change is projected to increase air temperatures in the southern Pacific by 0.99°C–3.11°C by 2099 (Ruosteenoja et al. 2003). This projection may well be conservative, given decadal increases in annual temperatures of 0.3°C–0.5°C in the Pacific region since the 1970s (Barnett and Campbell 2010). Moreover, climate change is expected to increase sea-surface temperatures, thereby causing coral bleaching, which may have severe consequences for the coral reef systems that are important breeding and feeding sites for a variety of fish species.

Similarly, rainfall events in the Pacific will likely be more intense and possibly less frequent due to climate change (Jones et al. 1999; World Bank 2000). Projections for the region show an increase in rainfall of about 0.3% by the 2050s and 0.7% by the 2080s (Nurse et al. 2001). The projections of weather forecast models also indicate fewer rainy days per year, and an increase in precipitation intensity (Lal et al. 2002; Lal 2004). This, in turn, suggests drought and flooding events of greater intensity, increased drought occurrence being of particular concern to food security as agriculture in the region relies more heavily on rainfall than irrigation.

Sea-level rise likewise poses a significant threat to Pacific island countries. Global projections suggest that the sea will have risen on average by 0.58 meters (m) by 2090–2099, as compared to a rise of 0.19 m during the period 1980–1999 (Meehl et al. 2007). Because sea-level rise encroaches on a country's total land area, it often reduces the amount of arable land which is already in short supply in the region, that could ultimately make Pacific island countries more dependent on food imports than at present. Sea-level rise also exacerbates coastal inundation, soil salinization, seawater intrusion into freshwater ecosystems, and erosion, thereby affecting the sustainability of coastal agriculture. Moreover, sea-level rise will likely affect the landward and longshore migration of the remnants of mangrove forests, which provide protection for coastal areas and backshore infrastructure (Nurse et al. 2001). Projections of a rise in sea level of 0.09–0.88 m between 1990 and 2100 would lead to about a 50% loss in the mangrove area of American Samoa, and approximately a 12% reduction in the mangrove area of 15 other Pacific island countries (Gilman et al. 2006). Further, increases in temperature and water depth, together with changes in sediment load, would have a negative impact on the productivity and physiological functions of sea grasses, such alterations resulting in a harmful effect on the fish populations that feed on these plant communities (Nurse et al. 2001).

Changes in regional climate systems are also anticipated as a consequence of climate change. Of particular concern in the Pacific is the El Niño Southern Oscillation (ENSO). El Niño, which is the warm phase of the oscillation, could bring drought to most of the region, as occurred during the 1997–1998 El Niño event which caused widespread drought and food shortages in the Pacific. During this period, Tonga's squash exports shrank by more than half, and PNG required emergency food aid in its isolated highlands and low-lying islands, where about 260,000 people faced life-threatening conditions due to depleted food supplies (WMO 1999; Simpson et al. 2009). In Fiji, about two-thirds of the sugarcane crop was destroyed, total agricultural losses amounting to $65 million. Finally, changing ENSO conditions have been found to also impact catch rates per unit of effort for fisheries across the South Pacific (SPC 2006).

Since the 1970s, the impact on climate change of the ENSO phenomenon has been indeterminant, though more frequent and intense El Niño events have occurred (Barnett 2007). Droughts of increased intensity during El Niño years could lead to a 9% average reduction (from the 1983–1998 average level) in sugarcane production in Viti Levu, Fiji by 2050, with losses averaging $13.7 million per year (in 1998 US dollars) (World Bank 2000). Moreover, yields of traditional crops such as cassava, taro, and yam could be reduced by 11%–15%. In the absence of climate change adaptation, the resulting economic costs to Fiji economy would be about $23–$52 million per year by 2050, or the equivalent of 2%–3% of the country's GDP in 1998 (World Bank 2000).

Climate change may also cause the intensity of tropical cyclones to increase. Maximum tropical cyclone wind intensities are likely to increase by 5%–10% by 2050, with increases in peak precipitation rates of up to 25%, which, in turn, would cause higher storm surges (Mimura et al. 2007). The occurrence of severe tropical cyclones (categories 4 and 5) more than doubled in the southwest Pacific between the two periods 1975–1989 and 1990–2004 (Webster et al. 2005). As it is, the region is susceptible to cyclones, which have been a cause of widespread crop damage. In 2010, Cyclone Ului damaged about 70%–90% of the food gardens in several Solomon Islands provinces

(IFRC 2010). During the same year, Cyclone Tomas resulted in $25.4 million in crop and livestock damage in Fiji (OCHA 2010). In 2007, about 58,000 people in Oro Province, PNG needed food relief and assistance due to tropical Cyclone Guba, which necessitated establishment of 15 food distribution centers (IFRC 2009). Cyclones also increase the risk of flooding in river catchments, thereby threatening food production. In April 2004, heavy flooding of the Wainibuka and Rewa rivers in Fiji damaged 50%–70% of crops (Government of Fiji Islands 2004). Reduced agricultural output could lead to lower earnings from agricultural exports and reductions in domestic food availability in some Pacific island countries. More intense cyclones could also affect food availability by reducing fish supply, as such extreme weather events make fishing trips dangerous and less productive, thereby depriving fishers of this important source of both protein and income (FAO 2009).

The present study had two overall goals. The first was to investigate issues relating to the nexus between climate change and output in the agriculture and fisheries sectors in three Pacific island countries: Fiji, PNG, and Solomon Islands. Second, the study offered policy recommendations for minimizing the impact of climate change on food security in the region.

More specifically, the study aimed to: (i) assess the impacts of climate change on food security, availability, and accessibility, and determine how these changes will impact the livelihoods of Pacific island communities; (ii) identify the potential adaptation mechanisms and coping strategies that would ensure food security and enhance the livelihoods of rural communities in the three study countries; and (iii) offer food security policy options for the agriculture and fisheries sectors for strengthening existing technical and financial support from national governments and regional and national organizations for rural communities facing climate change.

The remainder of this section outlines the conceptual framework and analytical procedures used in assessing the impact of adoption of climate change adaptation technologies on food security in the three study countries.

Analytical Framework

The study assessed agricultural technologies in order to identify potential climate change adaptation mechanisms appropriate to the agriculture sectors of Fiji, PNG, and Solomon Islands. The criteria used in selecting these three study countries included: (i) the share of the agriculture and fisheries sectors in national GDP, (ii) the GDP growth rate for the country concerned, and (iii) the range of likely climate change outcomes that would impact output in the agriculture and fisheries sectors.

The study assessed the likely impact of alternative macroeconomic policies and institutions and climate adaptation strategies on food security with respect to a range of climate and socioeconomic futures. In particular, the study employed a variant of the modeling approach used by an earlier ADB/IFPRI (2009) study (Figure 1.1). This approach integrated both macroeconomic and microeconomic components with processes driven by both economic and biophysical variables.

From the perspective of analytical procedure, this approach integrated the use of four separate models in producing the study results. The first of these is the *Spatial Production Allocation Model* (SPAM), which is a crop allocation model. The second is the *Decision Support System for Agrotechnology Transfer* (DSSAT). The third is the *International Model for Policy Analysis of Agricultural Commodities and Trade* (IMPACT), while the fourth is the *Dynamic Research Evaluation for Management* (DREAM) model, the first and these latter two models being developed by the International Food Policy Research Institute (IFPRI).

The crop allocation data derived from the SPAM model used by the study included data regarding the existing geographic distribution of crops and the spatial pattern of crop yields, both of these being reported at the highly disaggregated 5 arc-minute pixel level. Because of the highly disaggregated level at which these data are reported, they were particularly useful in constructing the baseline spatial distribution of crops used in performing the analysis (Figure 1.1).

The second model used in performing the analysis under the present study was the *Decision Support System for Agrotechnology Transfer* (DSSAT). DSSAT is a software package that combines data regarding the impacts on crop yields of soil, crop type, weather, and management decisions, with crop, soil, and weather databases. By combining these data into standard formats, DSSAT makes such data accessible by other crop models and application programs.

DSSAT is capable of simulating multiyear crop yields that would result from the use of alternative crop management techniques. Further, DSSAT can perform such simulations for a relatively wide range of crops grown in any location in the world. This is because DSSAT incorporates models of 27 different crops with tools that facilitate creation and management of experimental, soil, and weather data files. Finally, DSSAT includes application programs that allow seasonal and sequence analyses for assessing the economic risks and environmental impacts associated with irrigation, fertilizer use, nutrient management, climate change and variability, soil carbon sequestration, and precision management.

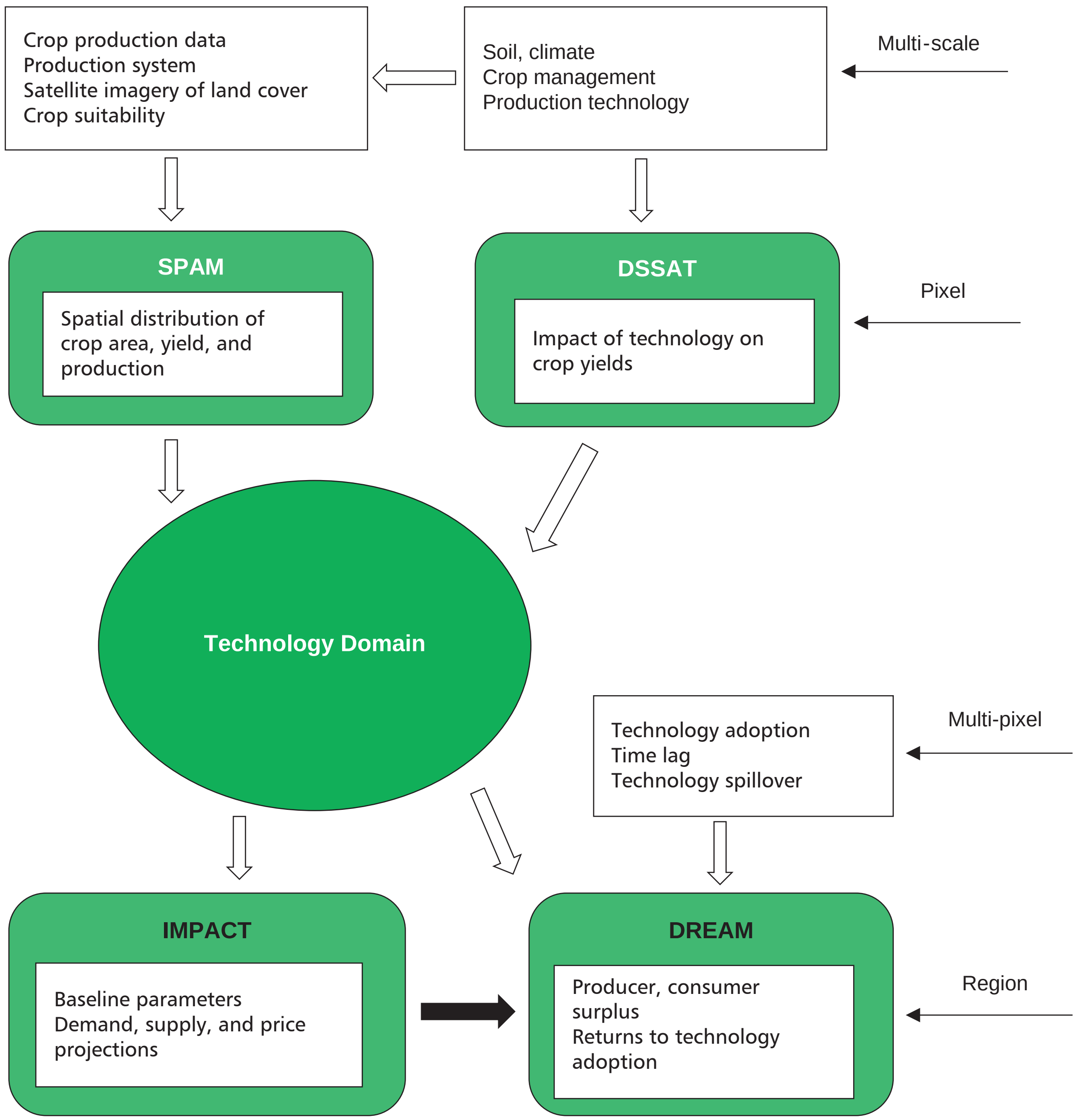
The study used the DSSAT software to produce three different sets of simulations. In the first simulation, climate data available in DSSAT for crops currently grown in the three study countries were used to estimate baseline yields for the year 2000. Yields for these same crops were then reestimated under the climate profile projected to exist in the year 2050. Four general circulation models (GCMs) and three alternative climate scenarios were used to generate the projected climate profile for the year 2050.[1] In short, in this first simulation, climate variables were altered to reflect the climate profile likely to exist in the year 2050, all other parameters of the crop production system being held constant. The resulting differences in estimated yields for the years 2000 and 2050 were then taken to reflect losses or gains in crop yields due to climate change alone.

The second DSSAT simulation altered crop production technology parameters such as cultivars, planting dates, and fertilizer use in order to assess the impact on crop yields of changes in these parameters.

The third DSSAT simulation altered the composition of crops grown by simulating introduction of crops not currently cultivated in the study countries. The purpose of this simulation was to determine whether under conditions of climate change, introducing crops not currently grown in the

1 Note, however, that this study focuses on the A1B scenario only.

Figure 1.1 Analytical Framework for Assessing the Impact of Adoption of Climate Change Adaptation Technologies



DREAM = Dynamic Research Evaluation for Management, DSSAT = Decision Support System for Agrotechnology Transfer, IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade, SPAM = Spatial Production Allocation Model.

Note: Technology spillover is the beneficial effects of new technological knowledge on the productivity and innovative ability of other (non-targeted) regions and countries.

Specifically, SPAM allocates crop production spatially from large reporting units (usually administrative level 0 or 1) to a raster grid. The allocation model infers likely production locations from multiple indicators, including subnational crop production statistics, satellite data relating to land cover, maps of irrigated areas, biophysical crop suitability assessments, population density, secondary data on irrigated and rainfed production systems, cropping intensities, and crop prices. The model employs a cross-entropy approach (i.e., a statistical estimation procedure designed to make the most of the informational content of specific data) to manage inputs with alternative levels of likelihood in indicating the specific locations of various crop types (You and Wood 2006; You et al. 2006; You et al. 2009).

Source: Modified from Figure 1.1, ADB and International Food Policy Research Institute (IFPRI). 2009. *Building Climate Resilience in the Agriculture Sector*. Manila, Philippines.

study countries would produce yields sufficiently large to make their adoption financially feasible.

Use of the DSSAT software package to perform the above simulations had a particular advantage in that DSSAT incorporates the use of three types of data. The first of these are daily weather data (maximum and minimum temperature, solar radiation, and precipitation). Second, DSSAT accommodates data relating to the physical and chemical characteristics of the soil in which crops are planted. Third, DSSAT accommodates crop management data such as crop composition, varieties each of crop planted, the date of planting, the spacing between plants, and specific types of inputs such as fertilizer and irrigation techniques. Because it can accommodate such detailed data, DSSAT is able to simulate relatively reliable projections of changes in yields that would result from change in a wide range of crop production parameters.

Further, DSSAT can simulate changes in yields at particular points in space (sometimes referred to as "pixels" or "grid cells") that would result from the use of particular production technologies. It can thus accommodate spatial variations in both soil and weather conditions. Because DSSAT performs analysis at the pixel level, the software is capable of producing maps that show geographic variations in the major results generated.

Upon completing the DSSAT yield simulations described above, the results were aggregated and inputted into IFPRI's IMPACT model. This multi-commodity, multimarket projection model, projects global food supply, food demand, and food security to the year 2020 and beyond for 32 crop and livestock commodities for 281 regions of the world. These 281 regions together cover the earth's entire land surface with the exception of Antarctica.

The IMPACT model was particularly useful to the study in that it is able to simulate growth in the output of particular crops on the basis of crop and input prices, externally determined rates of growth in crop productivity and area expansion, investment in irrigation, and availability of water. Further, the model simulates changes in demand for four categories of commodities (food, feed, biofuel, and others) that would result from changes in prices, income, and population growth. Finally, the 2009 version of IMPACT incorporates a hydrology model and links to DSSAT (Rosegrant et al. 2008; Nelson et al. 2009).

Under the present study, international prices derived from IMPACT projections were used in the analyses for Fiji and Solomon Islands. For PNG, IMPACT simulations were used to estimate the domestic prices of the commodities included under the study .

The fourth model used in performing the analysis under the study was the DREAM software package. The major use of DREAM is evaluation of the economic impacts of agricultural research and development (R&D. In particular, DREAM estimates the financial returns to commodity-oriented research, given that the crop production improvements resulting from such research are put into use. Because DREAM assumes that the home country is an open economy, it can estimate how changes in prices and technologies in the country in which a particular type of R&D originates impacts changes in prices and technologies in the home country (Alston, Norton, and Pardey 1998).

The DREAM software uses a flexible, multimarket, partial equilibrium model to simulate scenarios that incorporate a wide range of parameters.

These include changes in markets, the degree or pace of adoption of particular technologies or application of new research findings, and even changes in trade policy. Despite these advantages, DREAM can be run for only one commodity at a time. This means that the model is not capable of capturing any cross-commodity effects that result from changes in the parameters that DREAM accommodates. To compensate for this constraint, DREAM calculations use parameters generated by IMPACT such as baseline prices, elasticities, and price, demand, and supply projections to simulate the type and extent of cross-commodity effects.

DREAM outputs include estimates of the benefits accruing to producers and consumers alike of changes in particular parameters such as adoption of new technologies. If relevant cost data are available, DREAM can also estimate the cost–benefit ratios relevant to adoption of new crop production technologies. Thus under the present study, DREAM was used to estimate the likely gains from adoption of agricultural technologies developed for the purpose of adapting to climate change.

Despite all of the technical advantages of the four models referred to above, accuracy of the estimates generated ultimately depend greatly on availability of reliable data for the study country concerned.

Appendix 1 presents a detailed discussion of each of the models referred to above.

Vulnerability of Pacific Island Countries to Climate Change

As mentioned briefly in the opening paragraphs of this section, the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) confirmed that Pacific island countries are vulnerable to the negative impacts of climate change. This vulnerability arises from a range of factors particularly relevant to Pacific island countries. These include physical and topographical characteristics such as the region's fragile ecosystems and susceptibility to natural hazards and external shocks. However, certain social, institutional, and economic characteristics of Pacific island countries likewise exacerbate their vulnerability to the negative impacts of climate change. These latter characteristics include their (i) relatively small geographic size, (ii) degree of food and water insecurity, (iii) limited opportunities for reaping the advantages of scale economies in production, (iv) geographic remoteness from markets of significant size, (v) limited financial, technical, and institutional capacities, (vi) dependence on food imports, (vii) relative degree of poverty, and (viii) relatively rapid rates of urbanization (Mimura et al. 2007; Simpson et al. 2009).

While even the casual reader would agree that all of the above characteristics exacerbate the vulnerability of Pacific island countries to the negative impacts of climate change, such agreement begs the question of what exactly constitutes "vulnerability"?

IPCC (2007) sees vulnerability to the negative impacts of climate change as being a function of the character, magnitude, and rate of climate variation to which a system is exposed, as well as its sensitivity, and adaptive capacity. The notion of "vulnerability" thus comprises three components: exposure, sensitivity, and adaptive capacity.

Exposure is defined as the biophysical impacts of climate change on agroecological systems. Exposure thus relates to the spatial and temporal dimensions of climate variability, such as droughts and heavy rains, the magnitude and duration of weather events, and long-term change in the mean values of climate-related parameters such as temperature and precipitation levels.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change (IPCC 2007). Thus, a relatively low degree of sensitivity would indicate ability on the part of an agroecological system to withstand the negative impacts of climate variability in the absence of overt or deliberate efforts to adapt to climate variability.

Finally, adaptive capacity is defined as the ability of institutions and individuals to avoid potential damage, to take advantage of opportunities for avoiding such damage, or to cope with the consequences of climate change or variability.

The definition of "vulnerability" to the negative impacts of climate change referred to above thus depends not only on exposure to climate-related events, but also on the physical, environmental, socioeconomic, and political characteristics of a particular country insofar as these affect that country's sensitivity to the impacts of climate variability, as well as its ability to cope with and adapt to such impacts.

This section applies the notion of vulnerability to the negative impacts of climate change as outlined above to Fiji, PNG, and Solomon Islands. It thus particularly focuses on the degree of exposure, sensitivity, and capacity for adapting to climate change relevant to these three study countries.

Exposure

Table 1.1 shows that based on historical disaster frequencies for the period 1900–2011, Fiji, PNG, and Solomon Islands are vulnerable to rising sea levels, floods, and storms. Based on the list of top 10 disasters and data sourced from the International Disaster Database of the Centre for Research on the Epidemiology of Disasters (EM-DAT) (2011), Solomon Islands does not appear to be as vulnerable to drought as do Fiji and PNG. However, when the two devastating floods that occurred on 29 January 2009 and 21 January 2010 are taken into account, floods are among the top 10 disasters impacting Solomon Islands.

ADB/IFPRI (2009) constructed an overall indicator of vulnerability to the negative impacts of climate change for Asia and the Pacific. This indicator combines the three components of vulnerability as identified in IPCC AR4

Table 1.1 Vulnerability to Rising Sea Levels and Extreme Weather Events

Country	Sea Level Rise	Floods	Droughts	Storms
Fiji	X	X	X	X
Papua New Guinea	X	X	X	X
Solomon Islands	X	X		X

Note: The results reported in Table 1.1 represent the top 10 natural disasters in terms of number of persons affected or killed, and the costs of economic damage incurred during the period 1900–2011. An "X" indicates vulnerability to the relevant climate event on the part of the country concerned.
Source: Table 1.3 in ADB/IFPRI (2009) updated using data from EM-DAT (2011); ADB and IFPRI. 2009. *Building Climate Resilience in the Agriculture Sector*. Manila, Philippines.

referred to above: exposure to climate change, sensitivity to climate change, and capacity for adapting to climate change. Construction of such an overall indicator required quantification of each of these three components of vulnerability.

The differences between the projected temperature and annual precipitation levels for the year 2050 and their historical averages for the period 1950–2000 were used as a quantitative measure of exposure. The projections of temperature and annual precipitation levels for the year 2050 were estimated by the authors using the United Kingdom Meteorological Office's Hadley Centre Coupled Model, Version 3 (HadCM3), using the A2A Scenario drawn from the IPCC's Third Assessment Report. Since the annual precipitation levels of all three countries are projected to change by more than 20% as compared to their historical average levels for the period 1950–2000, the degree of exposure to climate change of all three study countries is rated as high (Table 1.2).[2]

Table 1.2 Indicators of Climate Change Exposure, Sensitivity, and Adaptive Capacity: Fiji, Papua New Guinea, and Solomon Islands

Indicators	Fiji	Papua New Guinea (PNG)	Solomon Islands
Climate change exposure			
Mean precipitation (millimeters per year)[a]			
Current level	2,196.90	2,548.80	2,729.00
Projected level for 2050 (Hadley A2A scenario)	2,934.70	3,469.80	3,623.60
Percentage change	33.58	36.13	32.78
Mean temperature (°C)[a]			
Current level	23.9	23.7	25.5
Projected level for 2050 (Hadley A2A scenario)	24.9	24.9	26.5
Unit change	1.00	1.20	1.00
Climate change sensitivity for the agriculture sector			
Percentage share of agricultural employment in total employment, 2010[b]	35.9	69.4	67.7
Rural population density (persons per square kilometer of arable land), 2005[c]	203	2,210	2,178
Adaptive capacity to climate change			
Percentage share of agriculture in GDP, 2009[c]	13	36	39
Overall vulnerability to climate change			
Exposure	High	High	High
Sensitivity	*	High	High
Adaptive capacity	Medium	Low	Low

Note: Current levels are the average levels for the period 1950–2000.
* Fiji has relatively strong performance on these indicators so data on people at risk not maintained in the standard UN-FAO database.
Sources:
[a] ADB and IFPRI. 2009. *Building Climate Resilience in the Agriculture Sector.* Manila.
[b] FAO (Food and Agriculture Organization of the United Nations). 2011. FAOSTAT.
[c] World Bank. 2011. *World Development Indicators.* Washington, DC: World Bank.
[d] Authors' assessment.

2 A country's exposure to climate change is rated as high if the projected temperature increase for the year 2050 exceeds the historical average level for the period 1950–2000 by at least 2°C, or if the corresponding change in projected annual precipitation level is 20% or greater (ADB/IFPRI 2009).

Sensitivity

Sensitivity describes the human–environmental conditions that can exacerbate the negative impacts of a hazardous event, ameliorate the hazard, or trigger an impact from that hazard. Thus, a wide variety of variables could be used to assess the sensitivity of a particular country's agriculture sector to the negative impacts of climate change. These include (i) rural population density, (ii) extent of irrigated land, (iii) the percentage share of small-scale farmers in the total farm population, (iv) the degree to which fertilizer is used in crop production, and (v) total employment in the agriculture sector.

Of these, the present study used the measure adopted by ADB/IFPRI (2009): the percentage share of agricultural employment in total employment. It likewise adopted the 40% threshold level of this indicator used in ADB/IFPRI (2009) to indicate a high degree of sensitivity to the negative impacts of climate change.[3] Since the percentage share of agricultural employment in total employment significantly exceeds 40% for both PNG and Solomon Islands, both study countries are deemed highly sensitive to climate change (Table 1.2). Note the substantial difference between the 36% level of this indicator for Fiji (thus indicating a medium level of sensitivity to the negative impacts of climate change) as compared to the approximately 68% level for PNG and Solomon Islands.

Rural populations are generally more exposed to the risk of negative impacts of climate change than are urban populations. Because of this, countries with relatively high rural population densities often need greater amounts of humanitarian assistance following adverse climate-related events. Further, because customary land ownership systems limit the extent of habitable land, such systems similarly limit the amount of land available to migrants, as well as opportunities for backyard farming or paid farm employment. Thus, rural population density can also serve as an index of sensitivity to the negative impacts of climate change. Because their rural population densities exceed 2,100 persons per square kilometer (km^2), which in turn exceeds the overall average for Asia and Pacific of 546.9 people per km^2, PNG and Solomon Islands are deemed to be more sensitive to the negative impacts of climate change than Fiji.

Adaptive Capacity

A number of indicators can be used to measure adaptive capacity. These include poverty incidence, access to credit, the average level of farm income, and agricultural GDP (agGDP). ADB/IFPRI (2009) used poverty incidence to measure adaptive capacity. More specifically, using the internationally accepted threshold level of income for extreme poverty of $1.25 a day, ADB/IFPRI (2009) determined that with a poverty level of 29.7% in 2005, PNG has medium adaptive capacity to climate change. Since no data regarding poverty incidence were available for Fiji or Solomon Islands, the adaptive capacities of these countries were not evaluated under the present study.

Combining the indicator values representing adaptive capacity (poverty incidence), exposure (change in temperature and precipitation levels), and sensitivity (share of labor force employed in agriculture), ADB/IFPRI (2009)

3 Countries with a percentage share of agricultural employment in total employment exceeding 40% were deemed by the study to be highly sensitive to the negative impacts of climate change.

concluded that PNG has significant vulnerability to climate change because of its significant outcomes in the exposure and sensitivity dimensions of vulnerability. Since Fiji and Solomon Islands lacked reliable data relating to poverty incidence at the time of the study, their overall vulnerability to climate change was not assessed. While ADB/IFPRI (2009) could have used other indicators as proxies for adaptive capacity, relevant data for some of the Pacific island countries included under the study were scarce (see Table 1.4 of ADB/IFPRI 2009). Because agGDP data are now available from World Bank (2011), the percentage share of agGDP in total GDP can be used as an indicator of adaptive capacity, a percentage share above 20% indicating a low level of adaptive capacity, and a level falling between 10% and 20% indicating a medium level of adaptive capacity.

As shown in Table 1.2, agriculture accounts for a substantial share of GDP in PNG (36%) and Solomon Islands (39%). These countries are thus deemed to have a low level of adaptive capacity, making them relatively vulnerable to climate change, since a significant percentage share of agriculture in total GDP indicates a relatively low level of economic diversification and thence greater susceptibility to the negative impacts of climate-related events (Gbetibouo and Ringler 2009).

Finally, since a relatively low level of per capita national income indicates a correspondingly limited capacity for preparing for and coping with environmental risks, the lower the level of this indicator, the weaker the adaptive capacity of the country concerned. For example, with an annual per capita gross national income of less than $750, Solomon Islands ranks among the lowest 20% of countries in the world in terms of per capita income (GFDRR/World Bank/SOPAC 2009), thus indicating a limited capacity for adapting to climate change.

Using the three individual indicators of vulnerability including exposure (as measured by projected change in temperature and precipitation levels), sensitivity (as measured by the percentage share of agricultural employment in total employment), and adaptive capacity (as measured by the percentage share of agGDP in total national GDP), PNG and Solomon Islands are deemed to be vulnerable to the negative impacts of climate change due to their relatively poor outcomes across all three indicators (Table 1.2). Because at least one of its indicators falls within the critical range, Fiji is likewise deemed to be vulnerable. As noted in ADB/IFPRI (2009), the indicators used for measuring vulnerability do not take account of climate extremes or rising sea levels, which are particularly relevant to climate change-related events in the Pacific region. If rising sea levels were likewise taken into account, the relative level of vulnerability of Fiji might well be different than that indicated in Table 1.2.

Limitations of the Study

Two major issues encountered in performing the analysis under this study were data availability and accessibility. Official crop and fisheries production data—particularly at` the subnational level—were not available for all three study countries. Since a centralized agriculture data collection system for PNG or Solomon Islands did not exist at the time of the study, agricultural censuses had not been conducted in these countries. Although provincial-level data for some commodities were available for PNG, these were spread across the respective research agencies relating to specific crops such as the Cocoa and Coconut Research Institute, the Coffee Research Institute, and the Oil Palm Research Association.

The fact that these research institutes are widely dispersed geographically complicated collection of these data. In cases in which recent data sourced from these institutes were unavailable, data published by them were used. In instances in which official national data for the study countries were not accessible, data from FAO's online statistical databases were used. Such data included production, consumption, import, and export data.

Lack of technology adoption profiles for the three study countries also complicated creation of a complete data set. Ultimately, adoption of new technologies is a complex and lengthy process. As a result, country-specific technology adoption profiles for Pacific island countries are extremely limited. Given lack of subnational data relating to crop production, prices, and the degree to which new technologies had been adopted, the DREAM simulation was limited to the national level. Sub-national analyses would have greatly enriched the study, as all three countries comprise islands that are widely dispersed geographically, the latter resulting in a relatively high degree of spatial heterogeneity in terms of adoption of new technologies.

For the portion of the analysis for which the DSSAT software was used, the study analyzed the impact of climate change on yields for eight crops, these including crops currently planted and those that might be successfully introduced. For each of these crops, use of the DSSAT software allowed selection of the optimum month for planting by analyzing data from the entire baseline period 1951–2000. Similarly, the best cultivar for each crop from those available in DSSAT was selected for the climate profile relevant to the baseline period. However, selection of the best cultivar for each crop was constrained by the range of cultivars available in DSSAT for each crop. Thus, the optimum cultivar for maize was selected from 142 cultivars, for rice, from 51 cultivars, but for wheat, from only the two tropical wheat varieties available in DSSAT.

Once the yields from the optimum cultivar and planting month for each of the eight crops under study were determined for the period 1951–2000, the analysis was then rerun for the year 2050, the climate profiles being used for this re-run being those projected for the year 2050. These climate profiles projected for the year 2050 were derived from runs of four general circulation models (GCMs) under the A1B scenario.

From the runs for the baseline period (1951–2000) and for the year 2050 referred to above, the differences in yield between the two time periods were then calculated for each of the eight crops under study, all other crop production parameters including the optimum planting month and cultivar for each crop being held constant. This allowed changes in crop yield due solely to climate change to be estimated.

A second run for the year 2050 was then undertaken, with all of the crop production parameters being changed to their projected optimal values for the relevant year-2050 climate profile. The crop yield results from this latter run were then compared to the crop yield results from the previous run for the year 2050, any differences in crop yield results being attributed to the switch to crop production parameters more appropriate to the climate profile relevant to the year 2050.

Subsequent re-runs of the analysis for the year 2050 with projected optimal values for the year-2050 climate profile were then undertaken to explore the impact on crop yields of possible introduction of the drought-, flood-, and salt-resistant crop varieties available in DSSAT. However, these latter runs that explored the drought-, flood-, and salt-resistant crop varieties available in DSSAT did not include hypothetical yet-to-be-introduced varieties that might have improved a particular cultivar's ability to tolerate droughts, floods, salt, heat, or cold.

Further, for each type of crop analyzed under the study, yields resulting from both rainfed and irrigated production techniques were calculated to ascertain the potential improvement in yield, had irrigated instead of rainfed production techniques been used. However, because relevant field data were unavailable, the difference in crop yield resulting from the use of efficient vs. inefficient irrigation techniques was not analyzed.

Similarly, crop yields resulting from alternative levels of fertilizer use were analyzed in order to provide the study with a relatively reliable estimate of how crop yields would respond to an increase in fertilizer use. In particular, yield estimates from alternative levels of nitrogen use were analyzed for both the climate profile prevailing during the baseline period and for that projected for the year 2050. Because it was not possible to use DSSAT to estimate the impact on crop yields resulting from introduction of genetically modified crops, the estimated increases in yield that might result from the use of such varieties were drawn from secondary data sources relevant to the varieties in question.

Finally, for the portion of the analysis that used the DREAM software, the quantitative tools necessary for evaluating the impact on crop yields of introduction of climate change adaptation technologies were limited. While the DREAM software could theoretically be used to evaluate the impact on crop yields of any number of climate change adaptation technologies, the range of these technologies that could actually be analyzed depended on availability of appropriate results from runs of the DSSAT software. For purposes of the present study, the DSSAT model was only capable of evaluating three of the most important crops grown in the study countries (sugarcane, taro, rice), and only fertilizer and irrigation production technology scenarios. On the other hand, the present study was able to use the crop simulation module of the Soil and Water Assessment Tool (SWAT) (Neitsch et al. 2005) (originating from the Erosion Productivity Impact Calculator model) to analyze the impacts of climate change on crop yields for sweet potato and cassava.

II. Agriculture, Fisheries, and Food Security: Key Trends and Current Status

Agriculture and fisheries play a vital role in the subsistence and cash economies of the Pacific region. Thus, anything that undermines their growth and development poses a threat to both the livelihood of these communities and food security. Conversely, any improvements in the output of the agriculture and fisheries sectors benefit many Pacific islanders by increasing their physical and economic access to food, thence improving their ability to meet their dietary needs. Consequently, examining the performance of the agriculture and fisheries sectors in the Pacific region is an important aspect of addressing impediments to their progress.

This section provides an overview of the environment and climatic conditions, socio-demographic profile of, and food production, consumption, and agricultural trade situations in Fiji, Papua New Guinea (PNG), and Solomon Islands. For each country, it examines the key trends and current status of, as well as the factors affecting the level of agricultural gross domestic product (agGDP). It likewise examines the production, consumption, and trade of the three major crops produced, as well as the commodities produced by the fisheries sector. Finally, all of the above parameters are discussed within the context of climate change. In short, this section provides the context in which the impacts of climate change on agriculture, fisheries, and food security in each country were examined by the study.

More detailed country-by-country discussions are presented in Appendixes 2, 3, and 4 for Fiji, PNG, and Solomon Islands respectively.

General Environment and Development Conditions in the Study Countries

There are about 500 inhabited Pacific islands among 7,500 islands scattered across 30 million square kilometers (km^2) of the tropical Pacific Ocean. These islands comprise 14 independent countries, and 6 French and United States territories. Culturally, the countries are divided into Melanesian (with Timor-Leste including other Austronesian groups), Micronesian, and Polynesian groups. Geologically, there are six mountainous ("high") volcanic countries and nine low coral atoll countries. The high countries are the largest, and are mostly located in Melanesia in the western portion of the Pacific (ADB 2011a). The three study countries—Fiji, PNG, and Solomon Islands—are all "high" countries, and the three largest Pacific countries in terms of land area (Table 2.1).

Table 2.1 Cultural Group, Land Area, Sea Area, and Population of Pacific Island Countries

Rank in Terms of Land Area	High (H)/ Low (L)	Cultural Group, Country	Land Area (km²)	Sea Area ('000 km²)	Population (mid-2010)
		Melanesia:			
1	H	Papua New Guinea	462,840	3,120	6,744,955
2	H	Solomon Islands	30,407	1,340	549,574
3	H	Fiji	18,273	1,290	847,793
4	H	Timor-Leste	14,874		1,131,612
5	H	Vanuatu	12,281	680	245,036
		Polynesia:			
6	H	Samoa	2,785	120	183,123
8	L	Federated States of Micronesia	701	2,978	111,364
9	L	Tonga	650	700	103,365
11	L	Cook Islands	237	1,830	15,708
13	L	Tuvalu	26	900	11,149
		Micronesia:			
7	L	Kiribati	811	3,550	100,835
10	L	Palau	444	629	20,518
12	L	Marshall Islands	181	2,131	54,439
14	L	Nauru	21	320	9,976
		Total Population			**10,130,000**

Source: Reprinted from ADB. 2011. Food Security and Climate Change: Rethinking the Options. *Pacific Studies Series*. Manila. Table 1.

Table 2.2 presents current environment and development conditions in the three study countries. These conditions pose challenges to the country's attainment of the Millennium Development Goals (MDGs), which include poverty alleviation and food and nutritional security. In PNG, for example, only 7% of the country's land area is of high or very high quality for agricultural production, an estimated 20% being of moderate quality. Most food production thus takes place on land of moderate to low quality.

The three study countries are also prone to El Niño events and tropical cyclones. For example, on average, 10–12 cyclones per decade affect parts of Fiji, and 2–3 of these cyclones can be severe. In PNG, an intense El Niño Southern Oscillation (ENSO) event in 1997 caused prolonged drought that seriously disrupted food production nationwide, and led to nearly 1 million people eating poor quality garden food, and in reduced quantities (Allen and Bourke 2009). In Solomon Islands, cyclone incidence averages one to two per year, and a typical El Niño event impacts the country every 4–7 years.

The latest available population and human development indicators show that for all three study countries, at least 50% of the population lives in rural areas, the adult literacy rate is high, and nearly all urban inhabitants have access to improved, safe water sources (Table 2.2). These indicators suggest that human development in the three study countries is considered to be in the low and medium categories. A "medium human development" category

Table 2.2 Environment and Development Conditions in Fiji, Papua New Guinea, and Solomon Islands

	Fiji	Papua New Guinea	Solomon Islands
General Topography[a]	Large mountainous and small volcanic islands, low-lying atolls and elevated reefs; diverse terrestrial ecosystems including extensive indigenous forest areas; coastal ecosystems that include mangroves; algae and seagrass beds in shallow reef and lagoon areas; various types of reefs (barrier, fringing platform, and atoll or patch reefs); only 16% of landmass is suitable for farming	Environments range from mountain glaciers to humid tropical rainforests, swampy wetlands, and pristine coral reefs; 52% of total land area comprises mountains and hills, 19% plains or plateaus, 18% floodplains; only about 25% of total land area is suited and used for agriculture, of which 63% is on mountains and hills and 12% on volcanic landforms	Mainly mountainous, heavily forested, volcanic islands and a few low-lying coral atolls; only 23% of land is classified as agricultural and only 0.62% is arable
General Climate Conditions[b]	Annual mean temperature of 28°C; temperatures lower in the dry season (May to October) and higher in the rainy season (November to April); mean rainfall usually increases between December and April, and is deficient from May to October; ENSO events can be expected from June to August, and tropical cyclones during the wet season	High rainfall, humidity, and temperatures that are generally uniform throughout the year; lowland and coastal areas are hot (24°C–35°C) and more humid; highlands are cooler and less humid; one of world's wettest countries, regularly receiving 2,000–4,000 mm of rain per year; highest rainfall between January and April, with least rainfall between May and August; annual rainfall is highly variable	Humid and warm climate, with high and rather uniform temperature; rainfall at 3,000–5,000 mm per year, not uniformly distributed across the country; wet season during November to April, and dry season the rest of the year; cyclones pose serious threat during December to February; also vulnerable to unusually long dry spells associated with the warm phase of the ENSO
Population and Human Development Status			
Population (mid-2010)[c]	847,793	6,744,955	549,574
Estimated population (mid-2050)	1,060,706	13,271,057	1,245,774
Estimated rural population (%)[d]	50.0 (2007 estimate)	>80.0 (2009 estimate)	~80.0 (2009 estimate)
Health (proportion of children under 5 years old who are under-weight)[e]	11 (2004 national survey)	45 (1982–1983 national nutrition survey)	11.8 (2006–2007 survey)
Education (literacy rate of adults above 15 years old; %)[f]	99 (2000–2004)	60 (as of 2009)	77 (as of 1999)
Living standards[g]	96% of urban communities has access to safe water supply; 79% use flush toilets (as of 2002)	87% of urban population and 33% of rural population have access to a source of improved water (as of 2008)	94% of urban population and 82% of rural population have access to improved water sources (as of 2007)
Proportion (%) of population below the national poverty line[h]	31.0 (as of 2009)	39.6 (as of 2002)	22.7 (as of 2007)
2010 Human Development Index (HDI) ranking among 169 countries[i]	86th (Medium Human Development)	137th (Low Human Development)	123rd (Medium Human Development)

Sources:

[a] The Fiji Islands: Government of the Fiji Islands. 2005. Fiji Today 2004/2005. Ministry of Information, Communications and Media Relations; PNG: Allen, M. and R.M. Bourke. 2009. People and the Environment. In R.M. Bourke and T. Harwood, eds. (2009). *Food and Agriculture in Papua New Guine*a. T. ANU E Press,

continued on next page

Table 2.2 *continued*

Canberra: The Australian National University; Solomon Islands: World Bank. 2007. *Solomon Islands Agriculture and Rural Development Strategy—Building Local Foundations for Rural Development*. Washington, DC: The World Bank.

[b] The Fiji Islands: Government of the Fiji Islands. 2005. Fiji Today 2004/2005. Ministry of Information, Communications and Media Relations; PNG: Allen, M. and R.M. Bourke. 2009. People and the Environment. In R.M. Bourke and T. Harwood, eds. (2009). *Food and Agriculture in Papua New Guinea*. T. ANU E Press, Canberra: The Australian National University; Solomon Islands: Solomon Islands Coastal Marine Resources Consultancy Services (SICFCS). 2002. Synopsis of Issues, Activities, Needs, and Constraints: Sustainable Development 1992–2002. Solomon Islands. Prepared by SICFCS in close collaboration with the National Steering Committee, World Summit for Sustainable Development (WSSD Working Group). Solomon Islands National Assessment World Summit on Sustainable Development. Johannesburg, June 2002; GEF/UNDP/SPREP. undated. Pacific Adaptation to Climate Change Solomon Islands Report of In-Country Consultations.

[c] ADB. 2011. Food Security and Climate Change: Rethinking the Options. *Pacific Studies Series*. Manila.Table 1.

[d] The Fiji Islands: Fiji Islands Bureau of Statistics (FIBS). 2011. Fiji Islands Facts and Figures as of 1st July 2010. Fiji Islands Bureau of Statistics, Suva, Fiji Islands; PNG: Allen, M. and R.M. Bourke. 2009. People and the Environment. In R.M. Bourke and T. Harwood, eds. (2009). *Food and Agriculture in Papua New Guinea*. T. ANU E Press, Canberra: The Australian National University; Solomon Islands: Government of Solomon Islands (GSI) 2010. National Food Security, Food Safety and Nutrition Policy, 2010–2015; World Bank. 2011. *World Development Indicators*. Washington, DC: The World Bank. http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

[e] The Fiji Islands: National Food and Nutrition Center (NFNC). 2007. 2004 Fiji National Nutrition Survey. Main Report. Suva, Fiji: National Food and Nutrition Center; PNG: Saweri, W. 2004. Papua New Guinea: Nutrition Overview. http://www.wpro.who.int/internet/resources.ashx/NUT/png.pdf; Solomon Islands: Government of Solomon Islands (GSI) 2010. National Food Security, Food Safety and Nutrition Policy, 2010–2015.

[f] The Fiji Islands: ILO 2010. Literacy rate for 15–24 years old. PNG: World Bank. 2011. *World Development Indicators*. Washington, DC: The World Bank. http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS; Solomon Islands: World Bank. 2011. *World Development Indicators*. Washington, DC: The World Bank. http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

[g] The Fiji Islands: Ministry of Finance and National Planning (MFNP). 2004. Strategic Development Plan 2007–2011. Millenium Development Goals, Fiji National Report. The Fiji Islands: National Planning Office, Ministry of Finance and National Planning; PNG: World Bank. 2011. *World Development Report.* Citizen Security, Conflict, and Jobs, Washington, DC, US, http://wdr2011.worldbank.org/; Solomon Islands: Secretariat of the Pacific Community (SPC). 2007. Solomon Islands 2007 Demographic and Health Survey. http://www.spc.int/prism/country/sb/stats/Publication/DHS07/factsheet/SOL-DHS_2-fertility.pdf

[h] ADB. 2011. Table 7, page 13. Refers to percentage of population below the basic needs poverty line. This reference includes not only food, but also a basket of other essential non-food items (goods and services) that each household or individual needs to maintain a basic standard of living.

[i] The Fiji Islands: World Development Report (WDR) 2010. Development and Climate Change. The World Bank, Washington, DC, US. http://www.worldbank.org/wdr; PNG: UN Human Development Report (HDR) 2010. The Real Wealth of Nations: Pathways to Development. United Nations Development Programme (UNDP), New York, US. http://www.hdr.undp.org; Solomon Islands: UN Human Development Report (HDR) 2010. The Real Wealth of Nations: Pathways to Development. United Nations Development Programme (UNDP), New York, US. http://www.hdr.undp.org

suggests improved progress in health, education, and living standards, as well as in other parameters including quality of life, access to basic resources, freedom, dignity, and self-respect (UNDP 1997).

In addition to the above, differences among the three study countries likewise influence their food production potential and food security status. The larger, high islands tend to have a greater potential for agricultural production, as well as highland populations that live far away from the other main food source—coastal fisheries. In contrast, the low-lying countries have generally limited agricultural potential and cultures more attuned to obtaining food from the sea. Unsurprisingly, populations in the latter countries are among the largest fish consumers in the world (ADB 2011b).

Current Agriculture and Food Security Context

Share of Agriculture in Gross Domestic Product

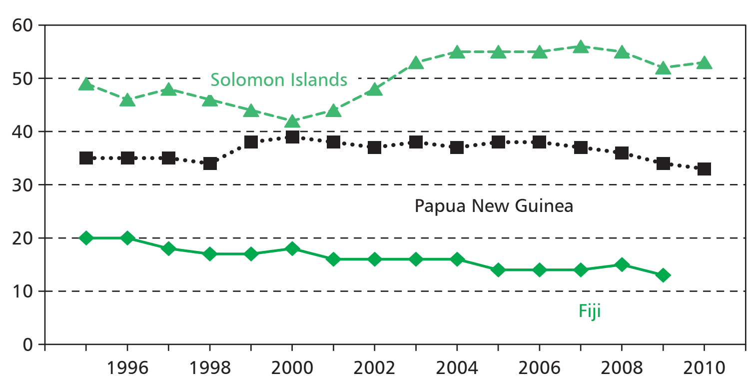
In all three study countries, agriculture remains an important sector in that it provides food and nutrition security, employment, income, and livelihood to a significant portion of the populace.[4] Activities in the agriculture and fisheries sectors also contribute to national income through export markets and licensing or access fees, particularly in the tuna fishing industry. These sectors also support environmental preservation. Backyard and smallholder farmers practice organic farming because of poor access to, or limited supply of synthetic agro-inputs.

4 In this report, "agriculture" in the broadest sense refers to cultivation of crops, production of livestock, as well as economic activities in fishing, forestry, and hunting.

In 2010, 36% of Fiji's economically active population was involved in agriculture (FAO 2010), the corresponding figures for PNG and Solomon Islands being 70% and 68% respectively (FAO 2011). However, in Fiji, the percentage share of agriculture in GDP has fallen from 20% in 1995 to 13% in 2009, mainly due to rapid growth in the non-agriculture sector (Figure 2.1). The economic performance of rural enterprises has also suffered from declining prices for key commodities and disruption in land tenure arrangements for sugarcane growers, these disruptions contributing to a decline in sugarcane production in the previous decade (Hone et al. 2008). In addition, the decline in the country's percentage share of agriculture in GDP has occurred because of vulnerability to natural disasters, minimal private investment in agriculture, inadequate infrastructure, marketing deficiencies, and soaring input costs. Lack of private investment in agriculture is due to a weak business climate, the source of which is structural issues relating to land leases and uncertainty regarding Fiji's regulatory and legal environments (IMF 2011). Political instability has also contributed to sluggish private investment.

In PNG, agriculture's percentage share in GDP was stable at around 36% on average during the period 1995–2010, this declining from 35% to 33% over the period (Figure 2.1). Factors that constrain agricultural development in PNG include: (i) domestic markets geographically distant from production areas, and lack of market information; (ii) poor transport and road infrastructure, and high costs of transport; (iii) a complicated land tenure system (lands are mostly under customary ownership and unregistered); (iv) weak research-extension-farmer linkages, exacerbated by limited political support and budgets for agriculture at the national and provincial levels; and (v) vulnerability to natural disasters, including tsunamis, droughts, frost, and volcanic eruptions. These factors create disincentives for farmers, often discouraging them from investing in their farms, which leads to poor agricultural production, and in some cases, a complete move out of agriculture.

Figure 2.1 Percentage Share of Agriculture in Gross Domestic Product in Fiji, Papua New Guinea, and Solomon Islands, 1995–2010[a]



Note:
[a] Based on agriculture GDP as a percentage of real GDP at factor cost.
Source: ADB. 2011. Food Security and Climate Change: Rethinking the Options. *Pacific Studies Series*. Manila.

Particularly in rural areas, the majority of Solomon Islanders derive their livelihoods from a combination of subsistence agriculture and small-scale, income-generating activities, export cash crop production, and fresh produce marketing. However, the percentage share of agriculture in GDP generally declined over the period 1995–2002 (Figure 2.1). This was mainly due to civil unrest caused by ethnic tensions, which badly affected output of primary export commodities such as copra, coconut oil, palm oil, palm kernel, and cocoa. During this period, plantations were closed, offices and mills were destroyed, agricultural marketing channels were disrupted, and agricultural research stations were either destroyed or abandoned and looted (Bourke et al. 2006).

However, the agriculture sector began recovering in 2003, its percentage share in GDP rising above 50% in that year (Figure 2.1). This resurgence was due to favorable macroeconomic conditions such as strong international commodity prices fueled by demand from the global recovery, and low rates of inflation among Solomon Islands' trading partners (CBSI 2010). However, this resurgence of agriculture was accompanied by slow growth in other sectors. In all, the sector remains plagued by a number of technical and economic concerns (Evans 2006; IMF 2004; MAL 2008, 2009a). These include: (i) production areas geographically isolated from major urban market centers; (ii) poor and inadequate domestic transport and communications infrastructure; (iii) lack of improved production technologies, incentives, agricultural credit, and input/output price and market information; (iv) limited access to world markets (or other market opportunities) due to low quality and inadequate quarantine standards; (v) lack of private- and public-sector investment; and (vi) inadequate agricultural extension services due to limited allocations from the government budget. In addition, the agriculture sector is highly vulnerable to adverse weather conditions such as tropical cyclones and drought. Ultimately, all three study countries suffer from similar production constraints.

Food Production, Consumption, and Trade

Food Production

Traditional and subsistence agriculture, which has long provided the bulk of food in Pacific islanders' diets, is based on tree crops (e.g., coconut) and taro or other root crops, which are staple foods. However, crop composition varies widely in response to differences in topography, rainfall patterns, and markets (ADB 2011a). Based on 2008–2010 average values, sugarcane, which is Fiji's major export crop, accounted for almost 87% of total production of major crops, or about 2.1 million metric tons (mt) (Table 2.3). In PNG, banana led the production of major food crops at about 27% over the same period, followed by coconut, and then sweet potato. In Solomon Islands, coconut accounted for 63% of total production of major crops, followed by sweet potato, and palm oil. Rice is also cultivated in all three study countries, but only minimally (less than 1% of total agricultural output).

Cassava and sweet potato can tolerate low and declining soil fertility in most Pacific countries, which is often caused by short fallow periods between production seasons. In addition, their short production period is an important advantage over *pana* and yams, which are harvested at 8–14 months.

Table 2.3 Output of Major Crops in Fiji, Papua New Guinea, and Solomon Islands
(2008–2010 average values)

Fiji			Papua New Guinea			Solomon Islands		
Major Crop	Output (mt)	Share in Total Output of Major Crops (%)	Major Crop	Output (mt)	Share in Total Output of Major Crops (%)	Major Crop	Output (mt)	Share in Total Output of Major Crops (%)
Sugarcane	2,053,667	87.07	Banana	1,149,486	26.97	Coconuts	412,800	63.16
Coconuts	156,700	6.64	Coconuts	992,667	23.29	Sweet potatoes	87,134	13.33
Taro (cocoyam)	68,052	2.89	Sweet potatoes	531,755	12.47	Taro (cocoyam)	48,086	7.36
Cassava	49,932	2.12	Palm oil	481,000	11.28	Palm oil	40,333	6.17
Rice, paddy	10,305	0.44	Yams	650,985	8.23	Yams	36,215	5.54
Bananas	4,978	0.21	Taro (cocoyam)	302,515	7.10	Palm kernels	10,000	1.53
Papayas	4,855	0.21	Maize, green	226,152	5.31	Vegetables	6,510	1.00
Yams	4,031	0.17	Palm kernels	112,000	2.63	Cocoa beans	4,712	0.72
Pineapple	3,490	0.15	Coffee, green	63,040	1.48	Pulses	4,000	0.61
Ginger	2,609	0.11	Cocoa beans	53,100	1.25	Rice, paddy	3,819	0.58
Total	**2,358,619**	**100.00**		4,262,700	100.00		653,610	100.00

mt = metric tons.
Source: FAO. 2012. FAO Statistical Database.

Consumption

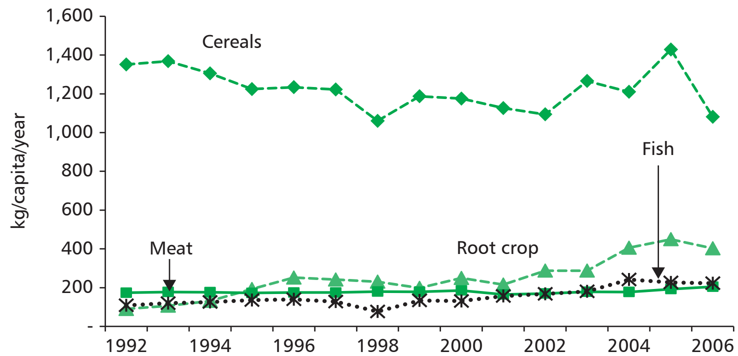
Figures 2.2a and 2.2b show the consumption of major food commodities in Fiji and Solomon Islands respectively. In Fiji, annual per capita cereal consumption in 1992 was 1,351 kg, though by 2006, this had fallen to 1,081 kg, representing an annual decline of 1% on average. However, over the same period, annual per capita consumption of root crops grew by 13% on average, rising from 90 kg in 1992 to 403 kg in 2006.

In Solomon Islands, this trend was reversed. Over the period 1990–2007, annual per capita consumption of starchy root crops decreased by 0.17% annually, while that of cereal consumption increased by nearly 4% per year. Despite this, average annual per capita consumption of starchy root crops for the period was about 330 kg, while that of cereals was only 81 kg. These trends indicate significant substitution of root crops for cereals for the *iTaukeians*,[5] and the reverse for Solomon Islanders. (Time series data regarding staple food consumption in PNG was unavailable at the time the study was undertaken.)

Similarly, a trend of substituting meat for fish as the preferred protein food likewise occurred over the period referred to above. In Fiji, consumption

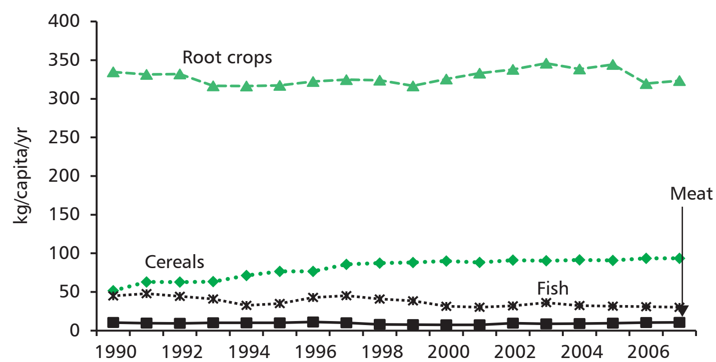
5 Based on Fijian Affairs Amendment Decree of 2010, the term "*iTaukei*" replaces the terms "Fijian", "Indigenous", or "Indigenous Fijian" (see www.fijianaffairs.gov.fj/iTaukei.html).

Figure 2.2a Annual Per Capita Consumption of Major Food Commodity Categories in Fiji, 1992–2006 (kg)



Source: Fiji Islands Bureau of Statistics (FIBS). 2011. *Fiji Islands Facts and Figures as of 1st July 2010*. Fiji Islands Bureau of Statistics, Suva, Fiji.

Figure 2.2b Annual Per Capita Consumption of Major Food Commodity Categories in Solomon Islands, 1990–2007 (kg)



Source: FAO. 2011. FAO Statistical Database.

of meat and meat products increased by almost 3% during the period 1992–2006, and by 0.56% per year during the period 1990–2007 in Solomon Islands. However, while consumption of fish and seafood products rose by nearly 8% per year in Fiji over the 1992–2006 period, consumption of fish and fish products declined by almost 2% per year in Solomon Islands. Such trends indicate a growing preference for, and increasing dependence on imported and processed food products. Overall, a gradual decline in the output of locally produced food (including fish) and subsistence farming, together with an expanding population and relatively rapid urbanization have led to an increasing reliance on food imports (Ahmed et al. 2011a).

Trade

The agriculture sectors of Fiji, PNG, and Solomon Islands depend on a small number of primary export products that are greatly influenced by world market prices. Table 2.4 shows the top five (in terms of value) agriculture-based products exported and imported by the three study countries during the period 2000–2009. While most of the top five exported products were destined for commercial or industrial use, those products imported were for direct human consumption. Notably, husked or milled rice, prepared (or processed) food, and sheep meat were included in the top five imports, confirming the growing shift away from traditional diets with their heavy emphasis on indigenous grains or starchy roots, vegetables, and fish, to a diet with a greater emphasis on processed foods such as canned fish or meat, bread, and particularly, white bread.

In Fiji, this shift away from consumption of indigenous foods has led to increased reliance on imported agricultural products. Some argue that Fiji should not be importing agricultural products to such degree, since the country has sufficient production resources such as land and labor, and climate conditions favorable to agricultural production (Prasad 2010).

In PNG, rice and wheat are considered to be of utmost importance to the population's diet. From an average of 152,000 mt of rice imported annually during the 1990s, rice imports increased to 184,000 mt in 2006. Most of PNG's food imports come from Australia or New Zealand (Bourke et al.

Table 2.4 The Five Most Important Agricultural Commodities Traded by the Three Study Countries in Terms of Volume and Value (2000–2009 average values)

Top Exports			Top Imports		
Commodity	Volume (mt)	Value ($ '000)	Commodity	Volume (mt)	Value ($ '000)
FIJI					
Sugar, raw centrifugal	258,650	117,434	Wheat	117,504	32,883
Pastry	5,941	10,387	Sheep meat	8,874	14,338
Taro (cocoyam)	10,098	10,368	Milk, whole dried	2,823	8,820
Molasses	112,834	7,081	Rice, husked	20,943	8,682
Wheat flour	14,301	5,792	Food, prepared (not otherwise specified)	2,763	6,615
PAPUA NEW GUINEA					
Palm oil	357,719	177,867	Rice, milled	139,922	55,529
Coffee, green	61,872	114,731	Sheep meat	25,748	33,867
Cocoa beans	47,317	83,081	Wheat	138,513	28,406
Coconut (copra) oil	43,852	26,628	Food, prepared (not otherwise specified)	5,828	17,281
Palm kernel oil	29,085	18,316	Buckwheat	30,191	8,613
SOLOMON ISLANDS					
Palm oil	26,527	14,229	Rice, milled	25,384	15,946
Cocoa beans	3,581	5,671	Food, prepared (not otherwise specified)	1,429	2,541
Copra	12,379	5,097	Wheat	8,134	2,400
Palm kernels	6,770	2,540	Sugar, refined	2,804	1,417
Coconut (copra) oil	1,057	935	Bread	750	778

mt = metric ton.
Source: FAO. 2011. FAO Statistical Database. (accessed on 12 June 2011). Rome, Italy http://faostat.fao.org/default.aspx?lang=en

2009). PNG also imports low-value fish species such as tinned mackerel and barracuda fillets often used in fast-food restaurants. Imported tinned fish is critical to the diets of the urban poor. In general, though people would prefer to add more fish protein to their diets, limited cash income often precludes this (Bourke et al. 2009). In the Solomon Islands, the top four imported food commodities are rice, wheat, sugar, and bread (Table 2.4). The increase in food imports can be attributed to population growth, and a shift in consumer preferences away from traditional diets.

Fish Production, Consumption, and Trade

Fisheries in the Pacific islands comprise six main categories: coastal subsistence fishing, coastal commercial fisheries, offshore locally based fishing, offshore foreign-based fishing, freshwater fishing, and aquaculture. Fisheries activities inspire rural development in isolated communities, with aquaculture enhancing food and nutrition security, as well as the economic conditions of fish farming families. Across Fiji, PNG, and Solomon Islands, coastal subsistence fisheries ranked highest in terms of production (Table 2.5), signifying the important contribution of coastal fisheries to food security, livelihood, and income generation for subsistence fishers.

Having the smallest water area, Fiji appears to have the smallest fish harvest compared with PNG and Solomon Islands. In 1990–1999, Solomon Islands harvested a larger volume of fish than did Fiji. However, ethnic tensions in the late 1990s and early 2000s disrupted the Solomon Islands' fishing industries and other economic activities. Fiji experienced similar political instability during the mid-1990s and 2000s. More recently, in 2007, Fiji posted the highest annual volume and value of aquaculture production among the three study countries at $1.75 million (Table 2.5). This indicates that aquaculture can be an alternative source of livelihood and food security for Pacific island countries, and can as well lessen pressure on these countries' coastal resources.

PNG has the largest water area and thus a considerably larger fish harvest and value of production as compared with Fiji and Solomon Islands. PNG's offshore foreign-based (tuna) fisheries provide the largest catch in value terms. Solomon Islands is similar to PNG in terms of offshore foreign-based fisheries, in that these account for a significant share of GDP.

At the national level, average annual per capita fish consumption was highest in Fiji at 53.4 kg in 2006 (Table 2.5) (Bell et al. 2009). In PNG and Solomon Islands, fish consumption in urban areas is higher than in the rural areas due to greater consumption of processed (tinned) fish. Due to their significant dependence on subsistence fishing, rural areas posted lower levels of fish consumption. Across the three study countries, coastal communities posted the highest levels of average annual fish consumption, mainly due to ease of access and availability of fish as compared to the inhabitants of urban and rural areas.

Of Fiji's annual total tuna production, 51% is exported to Japan and the United States (US), and 49% is exported to Australia, the People's Republic of China, the European Union (EU), and New Zealand (FAO 2010). However, tuna exports to the EU were banned in 2008, PNG is expanding its tuna processing plants in order to strengthen fish exports. Exports of lobster tails, barramundi fillets, mud crabs, and other fish products go to Australia; tinned

Table 2.5 Volume and Value of Fish Production, Consumption, and Exports in the Three Case Study Countries, 2007

	Fiji (2007)		PNG (2007)		Solomon Islands (2006/2007)	
Production Category[a]	Production (mt)	Value ($ '000)	Production (mtons)	Value (Kina '000)	Production (m tons)	Value (SBD '000)
Coastal subsistence	17,400	33,812.50	30,000	105,000	15,000	84,000
Coastal commercial	9,500	33,750.00	5,700	80,000	3,250	25,300
Locally-based offshore	13,740	29,293.75	256,397	1,024,090	23,619	249,865
Foreign-based offshore	490	527.50	327,471	1,143,631	98,023	1,174,649
Freshwater fisheries	4,150	4,287.50	17,500	49,000	2,000	11,200
Aquaculture fisheries	247 + 48,100 pieces	1,749,375	200	2,000	165 + 8,202 pieces	311
Total	45,527 + 48,100 pieces	1,851,046.25	637,268	2,403,721	142,057 + 8,202 pieces	1,545,325

	Fiji	PNG	Solomon Islands
Fish Consumption (kg/capita/year) (2006)[b]			
Urban areas	–	28.1	45.5
Rural areas	–	10.2	31.2
Coastal areas	113.0	53.3	118.3
National overall	53.4	13.0	33.0
Exports (2007)[a]			
Value of fishery exports ($ millions)	63.3	101	22.0
Value of total exports ($ millions)	518.0	1,010	169.2
Contribution of fishery exports to total exports (%)	12.2	10	13.0
Contribution of tuna industry to fishery exports (%)	60.0	87	90.0

mt = metric ton.
Sources:
[a] FAO. 2010. FAOSTATJ statistical database; Gillett, R. 2009. *Fisheries in the Economies of the Pacific Island Countries and Territories*. Manila: ADB.
[b] Bell, J.D., M. Kronen, A.Vunisea, W.J. Nash, G. Keeble, A. Demmkea, S. Pontifex, and S. Andre. 2009. Planning the use of fish for food security in the Pacific. *Marine Policy.*
Based on household income survey and socioeconomic survey (coastal communities).

fish (imported mackerel) goes to Solomon Islands; fresh fish is exported to the US; crabs, lobsters, and fish meal go to Southeast Asia; and fresh tuna goes to Japan. In Solomon Islands, the tuna industry is the main driving force of the export sector, with Japan being the country's major export market.

III. Impacts of Climate Change on Agriculture, Fisheries, and Food Security: Models Used and Analysis of Results

Given their vulnerability to erratic weather and climate conditions as discussed in earlier chapters, the need for the three study countries as well as neighboring nations to adapt their agricultural and food production systems to climate change is urgent. The question is no longer if the region should adapt to climate change, but rather how current and future climate change impacts should be addressed. This chapter discusses the economic models used in performing the quantitative aspects of the analysis and the results achieved for the agriculture sector. Ultimately, the study results indicate how climate change adaptation might proceed in the three study countries. Due to data limitations and a host of other constraints, the analysis of the impacts of climate change on the fisheries sector in the three study countries is of a heuristic rather than quantitative nature, this analysis being based on relevant existing literature. Discussions on the impacts of climate change on fisheries is provided in Section F, page 62 of this Chapter.

Appendix 1 discusses the models and methodology used in greater detail.

Overview of Models Used by the Study

Economic models that integrate climate change scenarios take account of the wide-ranging processes that drive markets, ecosystems, and human behavior (Nelson et al. 2010). One of the major strengths of these models is that they provide policy makers with quantitative information regarding the climate change challenges that particular countries face. Further, quantitative analysis of the impacts of climate change on specific crops and geographic regions in a country enables policy makers to maximize the likelihood of success of policies that address a country's unique vulnerabilities to the negative impacts of climate change.

That said, achieving projections reliable enough to enable policy makers to formulate policies appropriate to the challenges a particular country faces is a relatively complex task. For this reason, the quantitative portion of the present study required the use of four separate computer models in an integrated manner. The first of these is the *Spatial Production Allocation Model,* which is a crop allocation model. The second is the *Decision Support System for Agrotechnology Transfer*. The third is the *International Model for Policy Analysis of Agricultural Commodities and Trade,* and the fourth is the *Dynamic Research*

Evaluation for Management model, these latter two models being developed by the International Food Policy Research Institute (IFPRI). The four models, the manner in which their use was integrated, and the contribution of each to the analysis carried out under the present study are each discussed in turn below.

The *International Model for Policy Analysis of Agricultural Commodities and Trade* (IMPACT) was originally developed by IFPRI for the purpose of projecting food supply, demand, and security to the year 2020 and beyond (Rosegrant et al. 2008). IMPACT analyzes 32 crop and livestock commodities in 281 regions of the world, these 281 regions effectively covering the earth's entire land surface with the exception of Antarctica. Further, because the IMPACT model takes international trade flows into account, it is able to link production of agricultural commodities with demand for them. Finally, the 2009 version of IMPACT includes a hydrology model, and links IMPACT to the *Decision Support System for Agrotechnology Transfer* (DSSAT) crop growth simulation model briefly referred to above. This link with DSSAT allows estimation of the impact of climate change on crop yields.

DSSAT, which was developed by Jones et al. (2003), integrates the effects of soil, crop phenotype, weather (e.g., precipitation, temperature) and crop management decisions (e.g., those regarding cultivar, planting date and density, and use of fertilizer and irrigation). Because it incorporates both weather and crop management parameters, DSSAT is able to combine crop, soil, and weather data bases into standard formats that can be accessed by other crop models and application programs. Incorporating both actual weather statistics and projections of the latter generated by climate models into DSSAT allows the model to estimate crop yields both under the existing climate profile, as well as under a wide range of future climate profiles. DSSAT can thus estimate the yields that would result from particular crop management regimes over multiyear periods well into the future. Further, DSSAT can estimate such yields for 26 different types of crops planted at any location in the world (Jones et al. 2003).[6] In short, when used in this manner, DSSAT can estimate crop yields under a wide variety of crop management regimes for a wide range of climate change trajectories.

IFPRI's *Dynamic Research Evaluation for Management* (DREAM) model (Wood et al. 2000) is used to evaluate the economic impacts of agricultural research and development on specific crops. It allows researchers to simulate a range of market, technology adoption, research spillover, and trade policy scenarios. Under the present study, the DREAM model used the crop yield results from DSSAT to estimate the economic outcomes of adoption or use of specific agricultural technologies, and ultimately, to assess the most appropriate adaptation technologies for the three study countries.

In short, the present study assessed the impact of climate change on specific crops and regions in the three study countries, and identified the most appropriate technologies for adapting to these impacts. By linking the four models described above together, the study was able to deliver results that help determine: (i) the range of climate profiles likely to exist in the future [i.e., wetter vs. drier, hotter vs. cooler]; (ii) the impact of climate change on

6 While DSSAT's developers regularly expand the number of crops the model is capable of analyzing; at the time the present study was conducted, DSSAT was capable of analyzing 26 different types of crops.

the yields of specific crops within a particular country [i.e., the crops that will be most affected by climate change, and those that likely to benefit most from adaptation measures]; (iii) how the impacts of climate change are likely to vary across regions; (iv) specific adaptation practices for specific crops that farmers can employ to prevent crop yields from declining in the face of climate change; and (v) the potential loss in revenue from the cultivation of specific crops due to climate change.

DSSAT Model: Application and Analysis of Results

Application

As described above, the DSSAT model estimates crop yields under varying crop management systems and climate change scenarios. Application of the DSSAT model in this study used the following data and information as the basis for analysis:

(i) Climate data from WorldClim 1.4 (Hijmans et al. 2005) for the year 2000, and data from four internationally recognized general circulation models (GCMs). The GCMs included: (a) the model developed by *Centre National de Recherches Météorologiques* (the National Center for Meteorological Research [of France] or CNRM), (b) the model developed by the Commonwealth Scientific and Industrial Research Organisation ([of Australia] or CSIRO), (c) the model developed by the European Centre Hamburg ([Germany] or ECHAM) and (d) the Model for Interdisciplinary Research on Climate ([of Japan], or MIROC). The specific versions of these models used by the study were: CNRM-CM3, CSIRO Mark 3, ECHAM 5, and MIROC 3.2 medium resolution, all for the year 2050;[7]

(ii) Scenario A1B drawn from the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4). Scenario A1B was used because the present study is primarily concerned with changes to 2050. Scenario A1B assumes rapid economic growth, global population peaking in mid-century, and rapid introduction of new and technologies more efficient than those currently in use;

(iii) Data downscaled by Jones et al. (2003) to a 5 arc-minute resolution. This translates into approximately nine kilometers (km) at the equator, but increasingly shorter distances the further one moves away from it. These data were rounded up to a 10-km resolution.[8] Instead of using simple interpolation, Jones et al. (2003) used information relating to the current

7 The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) identified 24 officially recognized and publicly available GCMs. These forecast climate change by modeling the physics and chemistry of the atmosphere and its interaction with oceans and land surfaces. The present study employed four of these models as referred to above: CNRM-CM3, CSIRO Mark 3, ECHAM 5, and MIROC 3.2 medium resolution.

8 The various GCMs provide different levels of spatial resolution. Thus, they estimate global precipitation and temperature levels at spatial intervals of 20 km to 500 km. However, most of the values these models deliver range from 100 km to 200 km. Spatial intervals on this scale are deemed to be coarse, in that this level of spatial resolution may hide important differences in precipitation and temperature levels that occur on a more local scale. To achieve a finer level of spatial resolution, climatologists and other scientists "downscale" the coarse data reported by GCMs.

climate at a fine scale, coupled with broad-scale GCM results for the future to achieve an "informed interpolation" of the future climate profile;

(iv) GCM weather statistics at a monthly time interval (e.g., mean monthly precipitation and mean daily high and low temperatures for each month), which were then refined by stochastically generating daily values for rainfall, temperature, and solar radiation based on the monthly values; and

(v) Data on soil profiles at each location, adapted by Dimes and Koo (2009) from the Harmonized World Soil Database (HWSD ver. 1.1) by Batjes et al. (2009). The climate and soils data enabled analysis of the impact on crop yields for every 10-km grid cell in the three study countries.

The study included 90 weather simulations. This allowed outcomes to be averaged across 90 growing seasons for each of the three study countries. This procedure resulted in a long-term yield perspective not unduly influenced by stochastic extremes. It also identified the best planting month and best cultivars to plant by simulating growth and yield scenarios for each crop included under the study. For example, this allowed the optimum rice cultivar to be selected from the 51 rice cultivars DSSAT is capable of analyzing, and the optimum maize cultivar from the 142 maize cultivars that DSSAT accommodates.[9] Results are presented in tables and in map format, the latter showing the spatial distribution of the changes in crop yield projected by the study under conditions of climate change.

Crop yields at the grid-cell level were computed using the optimal cultivar and month to plant. The projected crop yield for each grid cell was then aggregated into a detailed map that showed the spatial distribution of projected changes in crop yield. To analyze data at the subnational level (e.g., province or district), the weighted average yield was estimated, the weight applied being the percentage share of the area planted to the crop in question in the total land area represented by each grid cell. To determine this percentage share for each grid cell, the following satellite land use and land cover datasets were used[10]: GLC2000 (Bartholome and Belward 2005) with a 1-km resolution; MODIS MCD12Q1 Land Cover 2008 L3 Global 500m (NASA 2009), with a 500-meter resolution; and GlobCover 2009 (ESA 2010) at 300-meter resolution.

For each crop, yields for both rainfed and irrigated scenarios were estimated for the purpose of simulating the potential increases in yield possible from a switch from rainfed to irrigated farming. However, efficient versus inefficient irrigation technologies were not modeled, in part because this distinction depends on field data that were unavailable at the time of the study. Yields at various levels of fertilizer use (particularly nitrogen) were also computed to

9 Achieving the fine level of spatial resolution (and thus the range of possible future precipitation and temperature levels appropriate to the present study) greatly increased the computational requirements of the analysis. In fact, these computational requirements were so great that continuous operation of 20 computers for nearly 3 months was required.

10 These datasets sometimes misclassify large amounts of land because they misinterpret the meaning of the data sourced from satellite imagery. Savanna, for example, looks a lot like low-intensity cropland; seasonably flooded areas look like water; and fallowed areas often resemble secondary forest or bush. This latter category is relevant to the three study countries, PNG in particular. To avoid accidental misclassification, three satellite datasets were used, which were those referred to in the text.

show the effect of applying additional nitrogen both before and after climate change. The DSSAT model likewise considered drought-, flood-, and salt-resistant crop varieties, as well as shifts in planting months, switching to new cultivars, and changes in the level of fertilizer use. DSSAT was also used to assess the impact on yields for crops not currently grown in the study countries to see if the projected yields under conditions of climate change would make their adoption financially feasible. This subsection analyzes the results for each of the study countries. Additional details concerning the results, as well as their presentation in graph form can be found in Appendix 5 for Fiji, Appendix 6 for Papua New Guinea (PNG), and Appendix 7 for Solomon Islands.

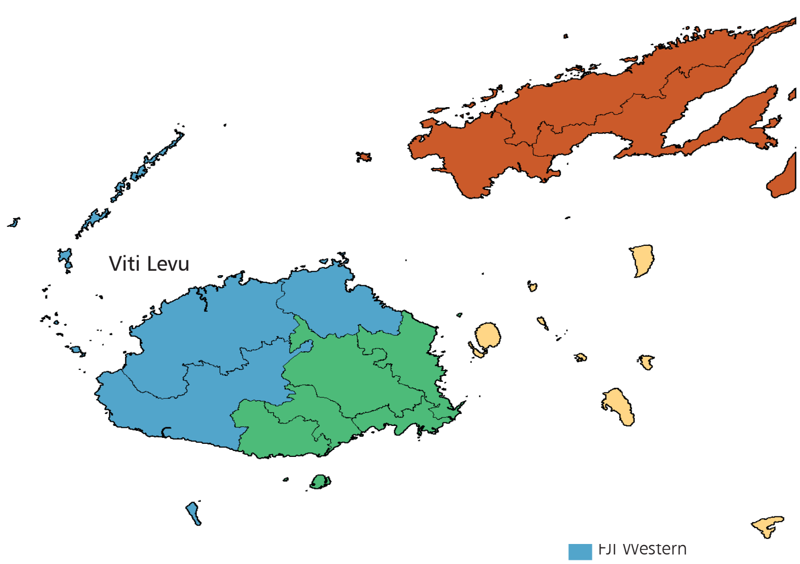
Analysis of Results: Fiji

Baseline Climate, Environment, and Extent of Cropland

Figure 3.1 shows Fiji's geographic divisions. These were used as the basis for aggregating data generated by the study. Topographically, Fiji is flatter along some coasts than would be optimal for cultivation. The central parts of both Viti Levu and Vanua Levu, the two major islands in the country, have some steeper slopes that are generally poor for use as cropland (unless terraced), but can often be productive for production of livestock or forest-based products.

In terms of soil type, the Western Division has mostly high levels of soil organic carbon (SOC), and shallow clay soils. The Northern Division has mostly medium SOC, medium-depth loam soils. Finally, both the Eastern and Central divisions mostly have high SOC, deep clay soils. The Central Division also has shallow clay soils with high organic matter, indicating higher soil fertility. These potentially more fertile areas appear to be mostly in flatter areas, and on moderate to high slopes.

Figure 3.1 Geographic Divisions of Fiji Used in the Study, 2011



Source: GADM v 1.0 (University of Berkeley et al. 2010).

Historically, rainfall has been lowest in the western portion of Viti Levu, and highest in the central portion of the island where the highlands are located. Vanua Levu does not appear to have as much rainfall variation as Viti Levu, although higher rainfall levels are also observed in the island's central elevated areas. The highest annual rainfall level in the Central Division is approximately 3,000 millimeters (mm) per year. Parts of the Western Division receive less than 2,000 mm per year. In general, February appears to be the hottest month in Fiji, with daily high temperatures of up to 32°C in some locales, but only 26°C in high elevations.

Satellite-based land cover results from GLC2000 and MODIS 2008 are largely in agreement concerning the geographic distribution of cropland in Fiji. GlobCover 2009 identifies much of the land classified as forest or as a mosaic of forest and natural vegetation as a mosaic of cropland and natural vegetation. The present study used the median value of the extent of cropland reported by three land cover datasets as the actual extent of cropland for each grid cell (Figure 3.2).[11]

Results from Application of General Circulation Models

Table 3.1 presents the climate change results for Fiji from the four GCMs—CNRM, CSIRO, ECHAM, and MIROC[12]—based on Scenario A1B for 2000–2050. Table 3.1 reports these results by division, with equal weighting being attached to each grid cell (i.e., rather than weighting the result for each grid cell by the percentage share of cropland in the total area represented by each grid cell). The results include changes in annual precipitation, changes in precipitation during the wettest and driest 3 months of the year, and changes in normal daily maximum temperature during the warmest month (see also Appendix 5, Figures A5.3–A5.5).

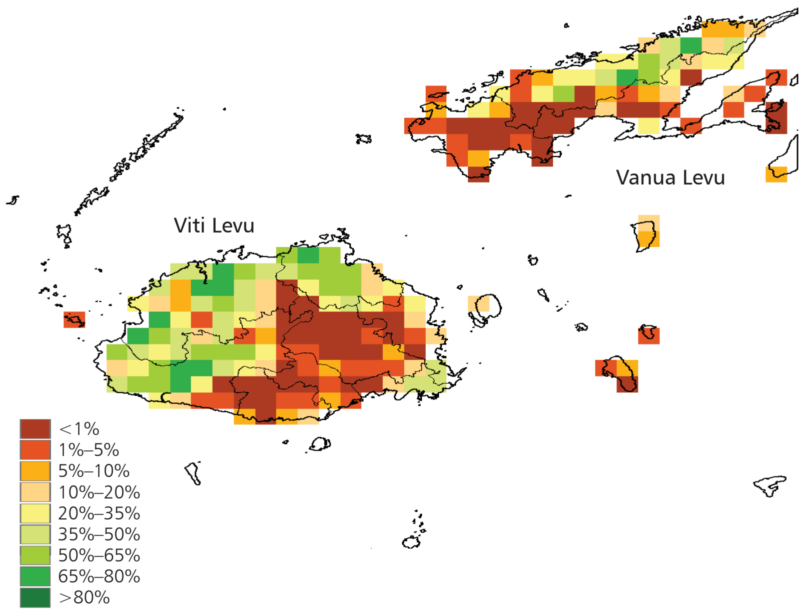
The wettest 3 months of the year vary across grid cells, but generally appear to occur during January through March, although for some grid cells, the wettest 3 months are February through April. Similarly, the driest 3 months appear to be June through August, but in some cases, July through September.

Comparing the projected changes in maximum temperature and annual precipitation for the year 2050 as calculated from the results delivered by the four GCMs (Table 3.1), the CNRM registers the greatest temperature increase (about 1.8°C) and CSIRO the smallest (0.7°C). The CSIRO model also projects increases in annual precipitation (a maximum of 105 mm in

11 "Cropland" in the 5 arc-minute composite was taken as the median value of the extent of cropland as computed by GLC2000, MODIS 2008, and GlobCover 2009. For GLC2000, cropland was computed by counting all small grid cells in each of the larger 5 arc-minute grid cells classified as cultivated and managed areas (Category 16), and adding those to 0.5 times the number of cells classified as mosaics of cropland and vegetation (Categories 17 and 18). Similarly, in MODIS 2008, cropland was computed by counting all grid cells classified as cropland (Category 12), and adding those to 0.5 times the number of cells classified as mosaics of cropland and vegetation (Category 14). Finally, for GlobCover 2009, cropland was computed by counting all grid cells classified as irrigated and rainfed croplands (Categories 11 and 14), and adding those to 0.6 times the number of cells classified as a 50%–70% mosaic of cropland and vegetation (Category 20), and 0.35 times the number of cells classified as a mosaic of 20%–50% cropland and vegetation (Category 30).

12 CNRM = *Centre National de Recherches Météorologiques* (National Center for Meteorological Research [of France]); CSIRO = Commonwealth Scientific and Industrial Research Organisation (of Australia); ECHAM = European Center Hamburg (Germany); and MIROC = Model for Interdisciplinary Research on Climate (Japan).

Figure 3.2 Percentage Share of Cropland in the Total Area Represented by Grid Cells Comprising Fiji



Source: IFPRI calculations. The percentage shares of cropland in the total area represented by the various grid cells that comprise Fiji as shown in Figure 3.2 were calculated from the median value of the extent of cropland per grid cell as reported by the three land cover datasets identified above.

the Northern Division), while the three other GCMs project decreases, with MIROC posting significant declines in projected annual precipitation (the greatest decline being nearly 400 mm, also in the Northern Division). For the wettest 3 months, CSIRO projects only increases in rainfall, while MIROC projects only decreases, ECHAM projecting the greatest increase (87 mm), and MIROC the greatest decrease (-147 mm). For rainfall during the driest 3 months, the four GCMs project a general decline, although CNRM shows a slight increase of 3 mm (for the Northern Division) and ECHAM projects the greatest decrease (-107 mm for Rotuma). Table 3.2 summarizes the projected changes in maximum temperature and annual rainfall in Fiji projected to occur by the year 2050.

DSSAT Results

Table 3.3 shows Fiji's 10 major agricultural crops in terms of average area harvested during the period 2005–2007. The present study assessed which major annual crops currently planted, as well as which annual crops not currently planted, would be financially viable under the conditions of climate change projected by the study for the year 2050.

Table 3.4 shows the percentage change in crop yields under the 2050 climate conditions projected by the study, as compared to the climate

Table 3.1 Projected Changes in Maximum Temperature (°C) **and Precipitation** (mm) **in Fiji by Region, 2000–2050** (under IPCC Scenario A1B)

Region	Baseline Average for 1950–2000	Change Projected to Occur by the Year 2050			
		CNRM[a]	CSIRO[b]	ECHAM[c]	MIROC[d]
Projected Change in Maximum Temperature (°C)					
Nationwide	29.1	1.8	0.8	1.3	1.3
Central	29.1	1.7	0.8	1.4	1.3
Eastern	29.5	1.8	0.7	1.3	1.3
Northern	30.4	1.8	0.9	1.4	1.2
Rotuma	30.5	1.8	1.0	1.4	1.2
Western	29.0	1.8	0.8	1.3	1.3
Projected Change in Annual Precipitation (mm)					
Nationwide	2,559	–27	57	–131	–266
Central	2,879	–24	57	–126	–260
Eastern	2,346	–7	40	–150	–284
Northern	2,488	–68	105	–194	–399
Rotuma	3,446	–172	92	–34	–366
Western	2,402	–31	59	–129	–263
Projected Change in Precipitation During the Wettest 3 Months (mm)					
Nationwide	984	–5	41	–12	–107
Central	1,020	–10	37	–22	–95
Eastern	884	9	34	–17	–107
Northern	978	18	61	–3	–147
Rotuma	1,044	3	57	87	–87
Western	985	–6	44	–7	–114
Projected Change in Precipitation During the Driest 3 Months (mm)					
Nationwide	360	–20	–17	–32	–32
Central	436	–18	–15	–30	–30
Eastern	337	–16	–23	–30	–38
Northern	294	3	–32	–38	–53
Rotuma	624	–31	–41	–107	–65
Western	315	–22	–17	–33	–32

[a] CNRM = *Centre National de Recherches Météorologiques* (National Center for Meteorological Research [of France]).
[b] CSIRO = Commonwealth Scientific and Industrial Research Organisation (Australia).
[c] ECHAM = European Center Hamburg (Germany).
[d] MIROC = Model for Interdisciplinary Research on Climate (Japan).
Source: Authors' calculations from GCM data (Jones et al. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for the International Livestock Research Institute, Nairobi, Kenya.

Table 3.2 Summary of Projected Changes in Temperature and Rainfall in Fiji Over the Period 2000–2050, by General Circulation Model

Global Climate Model	Temperature	Rainfall
CNRM[a]	Much hotter	Little change in wet season; drier dry season
CSIRO[b]	Slightly hotter	Wetter wet season; drier dry season
ECHAM[c]	Hotter	A little drier wet season; a lot drier dry season
MIROC[d]	Hotter	Substantially drier in both wet and dry seasons

[a] CNRM = *Centre National de Recherches Météorologiques* (National Center for Meteorological Research [of France].
[b] CSIRO = Commonwealth Scientific and Industrial Research Organisation (Australia).
[c] ECHAM = European Center Hamburg (Germany).
[d] MIROC = Model for Interdisciplinary Research on Climate (Japan).
Source: Authors' calculations from GCM data (Jones et al. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI, Nairobi, Kenya.

Table 3.3 Major Agricultural Crops of Fiji: Average Area Harvested Annually During the Period 2005–2007

Rank	Crop	Area Harvested ('000 ha)	% of Total Area Harvested
	All crops	129	100.0
1	Sugarcane	55	42.9
2	Coconuts	50	38.8
3	Rice, paddy	6	4.3
4	Taro (cocoyam)	3	2.5
5	Cassava	2	1.9
6	Pepper (*Piper* spp.)	2	1.4
7	Other roots and tubers	1	1.0
8	Other fruits, fresh	1	0.9
9	Other pulses	1	0.8
10	Vegetables, fresh	1	0.7

Source: FAO. 2011. FAO Statistical Database.

conditions prevailing under the year-2000 base case.[13] The results for the worst-case scenario were taken from the GCM with the worst crop-yield outcome under climate change, while the results for the best-case scenario were taken from the GCM that projected the most favorable crop yields under conditions of climate change. For most crops, three of the four GCMs reported results similar to those projected for the worst-case scenario. The percentage changes

13 The crop yield results of the DSSAT analysis were aggregated to the subnational level by estimating the weighted average yield of all crops grown in the area represented by the grid cells comprising the geographical division in question. The weight applied was the percentage share of the area planted to the crop in question in the total land area represented by each grid cell. Calculating these percentage shares required knowing the total area planted to each crop within the area represented by each grid cell. As the values for the total area planted to each crop as reported by the three landcover datasets used by the study differed, the median value of those reported by the three landcover datasets was used for this purpose.

Table 3.4 Percentage Change in Crop Yields Projected to Occur in Fiji by the Year 2050 as Compared with Year 2000 Crop Yields

	Low Rate of Fertilizer Application[a]				High Rate of Fertilizer Application[b]			
	Current Cultivar and Planting Month[c] in Year 2000		Optimal Cultivar and Planting Month[c] for Year 2050		Current Cultivar and Planting Month[c] in Year 2000		Optimal Cultivar and Planting Month[c] for Year 2050	
Crop	Worst Case	Best Case	Worst Case	Best Case	Worst Case	Best Case	Worst Case	Best Case
Cassava								
Irrigated	–34.6	–10.9	–33.9	–8.3	–34.0	–10.6	–33.1	–7.6
Rainfed	–36.5	–12.8	–35.8	–9.9	–36.0	–12.6	–34.8	–8.8
Groundnuts, rainfed	–4.0	4.2	–2.6	4.8	–4.1	4.1	–2.7	4.7
Maize								
Irrigated	–1.9	0.3	0.6	2.3	–6.1	–2.2	–5.0	–1.2
Rainfed	–4.2	–1.1	–0.8	1.0	–7.0	–2.1	–5.3	–1.0
Rice								
Irrigated	3.0	7.4	5.1	11.7	–7.1	–2.7	–4.0	–1.0
Rainfed	–3.9	0.1	2.5	3.5	–11.0	–4.0	–5.3	0.2
Sorghum, rainfed	–9.3	–3.4	–8.1	–2.6	–9.6	–3.3	–8.8	–2.4
Soybeans, rainfed	–9.2	–2.1	–9.1	–2.0	–9.6	–2.4	–9.5	–2.4
Sweet potatoes, rainfed	–2.1	0.8	–0.9	2.0	–13.4	–5.1	–12.5	–4.5
Sugarcane, rainfed	–8.3	2.3	–7.6	2.8	–8.3	2.3	–7.6	2.8
Taro								
Irrigated	–4.2	2.2	–3.8	2.8	–8.6	–3.4	–7.4	–2.5
Rainfed	–14.5	0.1	–7.0	1.1	–17.5	–3.9	–12.3	–2.5
Wheat								
Irrigated	–30.6	–12.2	–22.1	–7.6	–26.7	–12.6	–21.7	–8.2
Rainfed	–24.9	–12.5	–22.7	–8.7	–25.3	–12.4	–23.1	–8.9

[a] Low fertilizer application rate = 10 kilograms of nitrogen per hectare (kg N/ha).
[b] High fertilizer application rates varied from crop to crop. For taro, sweet potatoes, cassava, rice, maize, sugarcane, and sorghum, high application rate was 90 kg N/ha; for soybeans and wheat, 60 kg N/ha; and for groundnuts, 30 kg N/ha.
[c] Cultivars and planting months were those that produced the highest yields for the year indicated. Because the yields for groundnuts, sorghum, soybeans, sugarcane and sweet potatoes were similar in both rainfed and irrigated fields, the results for irrigated crops were excluded from this table.
Source: Authors' calculations using DSSAT results.

in the yields of selected crops under the climate conditions projected to prevail in the year 2050 as compared with the average yields reported for the baseline period as projected by each of the four GCMs also appear in Appendixes 5–7.

Without changing the cultivar or planting month, changes in yield for rainfed sugarcane in the year 2050 are projected to range from an 8.3% decline to a 2.3% increase, the latter projection assuming a high rate of fertilizer application. With a shift to the optimal cultivar and planting month for the year 2050, the projected change in yield ranges from a 7.6% decline to a 2.8% increase. Thus, the benefit of shifting to a superior cultivar and planting month only produces an increase in yield of about 0.5%. The worst-case scenario results from the GCM projections indicate that the Western region is likely to suffer yield losses greater than those in other regions.

Taro yields are projected to suffer greater negative impacts under climate change than sugarcane yields. Without adjusting the cultivar or planting month, the projected decline in yield for rainfed taro ranges from 3.9% to 17.5%, the latter projection assuming a high rate of fertilizer application. Shifting to the optimal cultivar and planting month results in projected yield losses of 2.5% to 12.3%.Thus, adjusting the cultivar and planting month for rainfed taro in the worst-case scenario reduces yield losses by approximately 5.2 percentage points. Rainfed taro in both the Western and Northern regions is projected to incur major yield losses due to climate change.

Similarly, rainfed rice yields could fall by as much as 11% due to climate change, while the yield loss for irrigated rice is projected at 7.1%. While not presented in the table, the analysis shows that with high rates of fertilizer application in the absence of climate change, irrigation increases yields by 10.8%. Further, when the results from the four GCMs are averaged, under conditions of climate change, irrigation results in a 15.7% increase in yield as compared to rainfed cultivation, and a 12.8% greater yield when the optimal cultivar and planting month are employed. For many other crops, yield losses due to climate change are not likely to exceed 6%, as long as farmers are able to adapt to the effects of climate change by adjusting the cultivar and planting month.

For most crops, climate change has a less adverse impact on yield at lower rates of fertilizer application than at higher rates of fertilizer use. The literature commonly reports that yields of more intensively cultivated crops (i.e., crops cultivated with higher rates of fertilizer application) are more sensitive to climate change than in cases in which fertilizer application rates are lower (ADB and IFPRI 2009). However, the negative impact on crop yields of climate change appears to be overwhelmed by the yield-boosting impact of higher rates of fertilizer application. In the year 2050 under conditions of climate change, rice yields in the high fertilizer application case are 70% higher than in the low fertilizer application case, given that the median values of the projections from the relevant models are used in the analysis. For taro, yields are 50% higher in the high fertilizer application case as compared to the low fertilizer case as shown in Table 3.5.

Table 3.5 Percentage Increase in Per-Hectare Yield Resulting from Nitrogen Application Rates of 90 Kilograms per Hectare as Opposed to Year 2000 Application Rates for Rainfed Staple Crops Grown in Fiji

Crop	Nitrogen Use Under High- Fertilizer Scenario (kgN/ha)	Percentage Change in Crop Yield	
		With Cultivar and Planting Month Optimal for Year 2000	With Cultivar and Planting Month Optimal for Year 2050
Sugarcane[a]	90	na	na
Rice	90	71.17	71.22
Taro	90	53.34	50.72
Cassava	90	3.55	4.72

[a] na = not applicable; no change in sugarcane yield under high fertilizer scenario because average fertilizer levels in year 2000 were greater than 90kg/ha.

Source: Author's calculations using DSSAT results.

Analysis of Results: Papua New Guinea

Baseline Climate, Environment, and Extent of Cropland

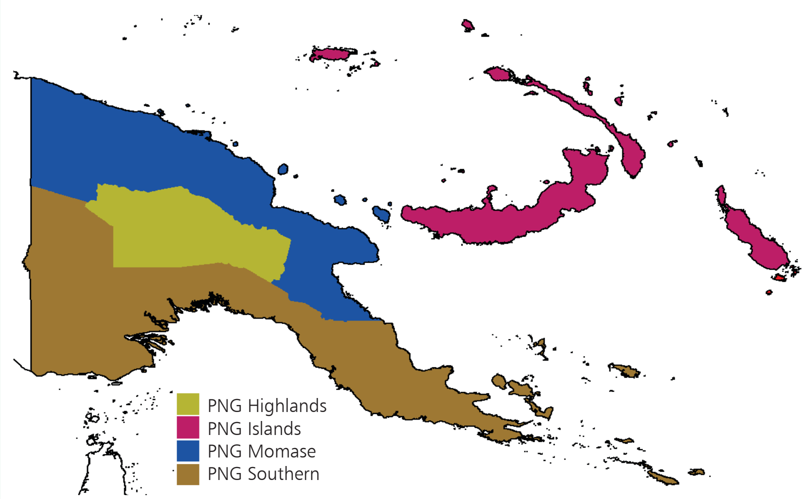
Figure 3.3 shows the four geographic regions of PNG used as the basis for aggregating study results. Most of PNG's flat areas are in the southern region, the steeper slopes being located in the middle highlands and islands. Based on the maximum temperature of the warmest month, higher elevations are generally much cooler, and the Islands region is generally cooler than the mainland coastal areas.

In terms of soil types, the Highland Region has mostly shallow clay and medium-depth loam soils, both with high soil organic carbon (SOC). The Momase Region has primarily medium-depth loam soil, with either high or medium SOC. The Southern region has 36% each of high SOC, medium-depth loam soil and high SOC, deep clay soil, whereas the Islands are almost half medium SOC, medium-depth loam soil, and high SOC, deep clay soils.

The mean annual rainfall during the period 1950–2000 appears to be smaller on portions of the southern coast and on an area on the northern coast than in other areas. The country has very high rainfall in the central eastern region, in areas just south and north of the Highlands region, and in the Islands region.

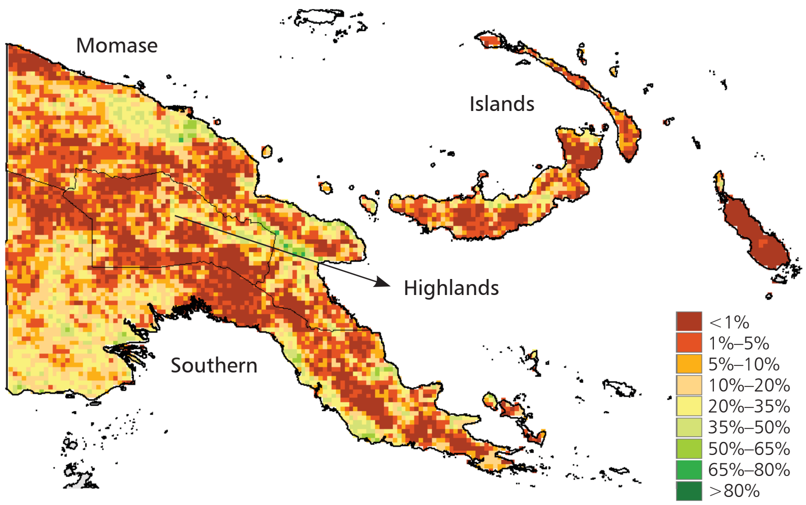
Satellite-based land cover data from GLC2000 and GlobCover 2009 are largely in agreement as to the location of cropland and cropland mosaics in PNG. MODIS 2008 shows that much of the land classified as cropland or cropland mosaic with natural vegetation is actually forest. This study computed the extent of cropland as the median value for this variable of the results from the three land cover datasets referred to earlier (Figure 3.4).

Figure 3.3 Geographic Regions of Papua New Guinea Used in the Study, 2011



Source: GADM v 1.0 (University of Berkeley et al. 2010).

Figure 3.4 Percentage Share of Cropland in the Total Area Represented by Grid Cells Comprising Papua New Guinea



Source: IFPRI calculations. The percentage shares of cropland in the total area represented by the various grid cells that comprise Papua New Guinea as shown in Figure 3.4 were calculated from the median value of the extent of cropland per grid cell as reported by the three land cover datasets referred to in the text.

Results from Application of General Circulation Models

Table 3.6 presents the climate change results for PNG from the four GCMs based on Scenario A1B for 2000–2050, by region, weighting each grid cell alike. The results include changes in annual precipitation, changes in precipitation during the wettest and driest 3 months of the year, and changes in the maximum temperature during the warmest month (see also Appendix 6, Figures A6.5–A6.8).

The changes projected by the four GCMs in the levels of precipitation and temperature for the year 2050 as compared with the year 2000 may be summarized as follows. CNRM indicates the greatest temperature increase (2.1°C in the Highlands), but shows only moderate changes in precipitation. CSIRO shows relatively small increases in temperature (about 1.0°C), but a considerably wetter climate across all measurements. ECHAM reports the second-greatest projected temperature increase, which is not substantially smaller than the CNRM result. The mainland, consisting of the Highlands, Momase, and Southern regions, is projected by the CNRM to undergo moderate changes in rainfall, with the dry season becoming drier, and the Islands region becoming considerably drier across all measures. The projections of the MIROC model indicate temperature increases, but of a smaller magnitude than the temperature increases projected by the ECHAM model. Overall, the MIROC results indicate a drier mainland, but wetter Islands. This can be seen in the projected annual rainfall, and the projected rainfall during the driest 3 months, the latter increase in rainfall being more moderate than the projected rainfall during the wettest 3 months of the year. Table 3.7 summarizes these projected changes.

DSSAT Results

Table 3.8 shows PNG's 10 most important crops in terms of average area harvested during the period 2005–2007. Table 3.8 shows the percentage change in crop yields under year-2050 climate conditions projected by the study, as compared to the crop yields under climate conditions prevailing in

Table 3.6 Projected Changes in Maximum Temperature (°C) **and Precipitation** (mm) **in Papua New Guinea by Region, 2000–2050** (under IPCC Scenario A1B)

Region	Baseline Average for 1950–2000	Change Projected to Occur by the Year 2050			
		CNRM[a]	CSIRO[b]	ECHAM[c]	MIROC[d]
Projected Change in Maximum Temperature (°C)					
Nationwide	29.2	1.9	1.0	1.7	1.4
Highlands	24.3	2.1	1.1	1.9	1.4
Islands	29.1	1.7	1.0	1.4	1.4
Momase	29.1	1.9	1.0	1.6	1.4
Southern	30.7	1.9	1.0	1.7	1.4
Projected Change in Annual Precipitation (mm)					
Nationwide	3,049	1	88	–14	–86
Highlands	3,078	–9	76	79	–126
Islands	3,409	–18	161	–243	120
Momase	2,809	39	96	–31	–87
Southern	3,107	–17	67	32	–132
Projected Change in Level of Precipitation During Wettest 3 Months (mm)					
Nationwide	1,009	6	23	9	6
Highlands	949	–9	12	14	8
Islands	1,129	–8	35	–61	39
Momase	920	19	39	6	15
Southern	1,057	6	12	29	–10
Projected Change in Level of Precipitation During Driest 3 Months (mm)					
Nationwide	522	–15	15	–28	–45
Highlands	562	–3	12	–24	–51
Islands	660	–14	24	–67	18
Momase	455	–8	9	–44	–35
Southern	517	–24	18	–7	–68

[a] CNRM = *Centre National de Recherches Météorologiques* (National Center for Meteorological Research [of France]).
[b] CSIRO = Commonwealth Scientific and Industrial Research Organisation (Australia).
[c] ECHAM = European Center Hamburg (Germany).
[d] MIROC = Model for Interdisciplinary Research on Climate (Japan).
Source: Authors' calculations based on GCM data (Jones et al. 2009).

Table 3.7 Summary of Projected Changes in Temperature and Rainfall in Papua New Guinea Over the Period 2000–2050, by Global Climate Model

General Circulation Model	Temperature	Rainfall
CNRM[a]	Much hotter	Little change in wet season; drier dry season, although changes are moderate
CSIRO[b]	Slightly hotter	Wetter
ECHAM[c]	Much hotter	Islands much drier; mainland has moderate changes, although dry season is drier
MIROC[d]	Hotter	Drier mainland, but wetter islands

[a] CNRM = *Centre National de Recherches Météorologiques* (National Center for Meteorological Research [of France]).
[b] CSIRO = Commonwealth Scientific and Industrial Research Organisation (Australia).
[c] ECHAM = European Center Hamburg (Germany).
[d] MIROC = Model for Interdisciplinary Research on Climate (Japan).
Source: Authors' calculations based on GCM data (Jones et al. 2009).

Table 3.8 Major Agricultural Crops Grown in Papua New Guinea in Terms of Average Area Harvested During the Period 2005–2007

Rank	Crop	Area Harvested ('000 ha)	% of Total Area Harvested
	All crops	958	100.0
1	Coconuts	201	21.0
2	Cocoa beans	120	12.5
3	Sweet potatoes	114	11.9
4	Fruit, fresh not else specified	111	11.6
5	Oil palm fruit	95	9.9
6	Coffee, green	68	7.1
7	Bananas	63	6.6
8	Taro (cocoyam)	43	4.5
9	Maize, green	24	2.5
10	Roots and tubers, not else specified	21	2.2

Source: FAO. 2011. FAO Statistical Database.

the year 2000.[14] (Appendix 6 likewise reports the percentage change in yield of selected crops under the climate conditions projected to prevail in the year 2050 by each of the four GCMs, as compared with the average yields reported for the baseline period.)

14 The crop yield results from the DSSAT analysis were aggregated to the subnational level by estimating the weighted average yield of all crops grown in the area represented by each grid cell comprising the geographical division in question. The weight applied was the percentage share of the area planted to the crop in question in the total land area represented by each grid cell. Calculating these percentage shares required knowing the total area planted to each crop within the area represented by each grid cell. As the values for the total area planted to each crop as reported by the three landcover datasets used by the study differed, the median value of those reported by the three landcover datasets was used for this purpose.

Table 3.9 shows the percentage change in crop yields under the 2050 climate conditions projected by the study, as compared to the climate conditions prevailing under the year-2000 base case.[15] The changes in yield of selected crops between the baseline and 2050 climates for each of the four GCMs are also presented in Appendix 6.

For rainfed taro, climate change is projected to result in lower yields. Without changing the cultivar or planting month, the crop yield for rainfed taro is projected to decline by 6.7%–13.0% as compared with year-2000 levels, even with a high rate of fertilizer application. With a shift to the cultivar

Table 3.9 Percentage Change in Crop Yields Projected to Occur in Papua New Guinea by the Year 2050 as Compared with Year 2000 Crop Yields

	Low Rate of Fertilizer Application[a]				High Rate of Fertilizer Application[b]			
	Current Cultivar and Planting Month[c] in Year 2000		Optimal Cultivar and Planting Month[c] for Year 2050		Current Cultivar and Planting Month[c] in Year 2000		Optimal Cultivar and Planting Month[c] for Year 2050	
Crop	Worst Case	Best Case	Worst Case	Best Case	Worst Case	Best Case	Worst Case	Best Case
Cassava								
Irrigated	–27.8	–18.8	–26.7	–18.2	–27.6	–18.6	–26.3	–18.4
Rainfed	–30.8	–18.3	–30.0	–18.2	–29.9	–18.0	–29.2	–17.7
Groundnuts, rainfed	–6.7	–1.8	–4.3	0.1	–6.8	–1.9	–4.4	0.1
Maize								
Irrigated	-0.1	1.5	1.8	4.0	–3.2	–1.2	–1.1	0.1
Rainfed	1.3	5.3	6.7	9.0	–3.8	–1.1	–1.3	0.2
Rice								
Irrigated	2.4	6.2	5.5	12.4	–8.3	–3.5	–1.1	0.9
Rainfed	0.1	3.8	5.0	11.7	–7.5	–3.7	–2.5	–0.4
Sorghum, rainfed	–7.3	–4.2	–5.6	–3.0	–7.5	–4.3	–5.8	–3.1
Soybeans, rainfed	–7.8	–3.6	–6.4	–2.1	–8.3	–3.9	–6.6	–2.5
Sweet potatoes, rainfed	–7.4	–4.5	–4.7	–1.2	–10.9	–6.0	–9.0	–5.6
Sugarcane, rainfed	–3.6	1.9	–2.1	3.4	–3.6	1.9	–2.1	3.4
Taro								
Irrigated	–4.2	–2.2	–0.5	4.5	–8.1	–5.6	–2.3	0.3
Rainfed	–9.6	–4.4	0.1	3.6	–13.0	–6.7	–4.5	–1.7
Wheat								
Irrigated	–28.5	–20.2	–26.0	–18.4	–31.6	–21.4	–29.4	–19.5
Rainfed	–45.5	–21.0	–23.8	–19.5	–30.0	–22.4	–27.2	–20.5

Source: Authors' calculations using DSSAT results.

[a] Low fertilizer application rate = 10 kilograms of nitrogen per hectare (kg N/ha).

[b] High fertilizer application rates varied from crop to crop. For taro, sweet potatoes, cassava, rice, maize, sugarcane, and sorghum, the high fertilizer application rate was 90 kg N/ha; for soybeans and wheat, it was 60 kg N/ha; and 30 kg N/ha for groundnuts.

[c] Cultivars and planting months were those that gave the highest yields for the indicated year. Groundnuts, sorghum, soybeans, sugarcane, and sweet potato have similar yields in rainfed and irrigated fields, so results for the irrigated crops were excluded from this table.

15 Results of the DSSAT analysis were aggregated using a weighting given by the median percent cropland from three landcover datasets (as shown in Appendix 6, Figure A6.).

and planting month optimal for the year 2050, yield losses are reduced to a range of 1.7%–4.5%, thus demonstrating the benefits of adaptation. The greatest yield losses are projected for the Southern region. In addition, all four GCMs indicate that under conditions of climate change, rainfed taro could potentially be grown on the fringes of the Highlands region.

The negative impact of climate change on yields of rainfed maize is anticipated to be very small, at no more than -3.8%. Further, at least one of the models indicates that yields could improve slightly with adaptation. Based on results not shown in Table 3.8, for the year-2000 base case, the yield-boosting impact of irrigation is small for higher rates of fertilizer application, and a little more than 5% for low rates of fertilizer application.

Further, when the results from the four GCMs are averaged, under conditions of climate change, the average yield increase resulting from irrigation is much lower at 2.4% for low fertilizer application rates with no adaptation, and only 1.0% with adaptation. This relatively low yield increase from irrigation may be due to the fact that rainfall may be sufficient if maize is planted during the optimal month for planting. Finally, under year-2050 climate conditions, it appears that rainfed maize could be grown in areas previously not planted to that crop, with yields in the Highlands even surpassing current yields. DSSAT results indicate either no change or modest losses in yields for maize for the rest of the country, depending on which GCM is applied.

The projected impact of climate change on sugarcane yields is relatively small. However, for taro and maize, climate change-driven yield losses as compared with year-2000 yield levels are greater for higher rates of fertilizer application than they are for lower rates of fertilizer use.

For example, consider the difference in the projected year-2050 yield of rainfed taro as opposed to the year-2000 yield under the worst-case scenario with adaptation, for both high and low rates of fertilizer application. With a low rate of fertilizer application (10 kg/ha of nitrogen), yields of rainfed taro are projected to be 0.1% higher in 2050 than in 2000. However, for a high rate of fertilizer application (90 kg/ha of nitrogen), the corresponding figure is a yield *decrease* of 4.5%.

While for most crops, the yield-boosting impact of additional fertilizer is slightly smaller under conditions of climate change than in its absence, increasing fertilizer use still results in a substantial positive impact on yields. For example, in the absence of climate change, rainfed taro yields increase by 5.3% for every additional 10kg of nitrogen applied per hectare, while under conditions of climate change, the corresponding projected yield increase is 4.4%.

As shown in Table 3.10, increasing fertilizer application rates from their year 2000 levels to rates optimal for the year 2050 boosts yields of both taro and maize by a projected 35%, and yields of sweet potato by 88%-92%.

Analysis of Results: Solomon Islands

Baseline Climate, Environment, and Extent of Cropland

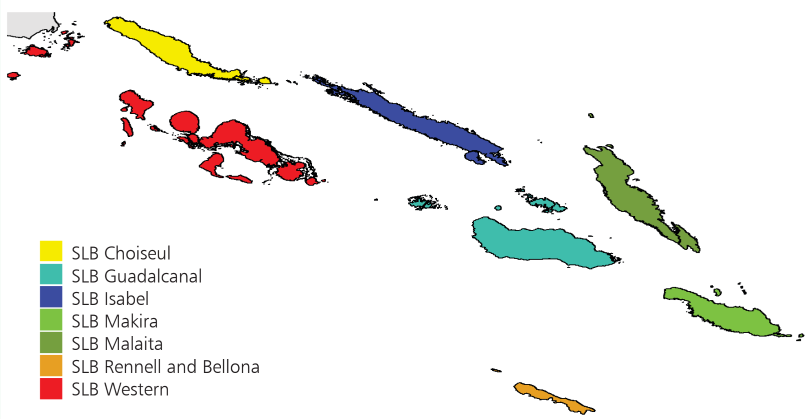
Figure 3.5 shows the regions of the Solomon Islands used as the basis for aggregating data under the study. These regions are the same as the provinces, with one exception: Central and Guadalcanal provinces have been combined because of the relatively small size of the Central Province, and of its geographic

Table 3.10 Percentage Increase in Per-Hectare Yield Resulting from Nitrogen Application Rates of 90 Kilograms per Hectare as Opposed to Year 2000 Application Rates for Rainfed Staple Crops Grown in Papua New Guinea

Crop	Nitrogen Use Under High-Fertilizer Scenario (kgN/ha)	Percentage Change in Crop Yield	
		With Cultivar and Planting Month Optimal for Year 2000	With Optimal Cultivar and Planting Month for Year 2050
Taro	90	36.84	35.48
Maize	90	37.26	35.59
Sugarcane[a]	90	na	na
Sweet potato	90	92.00	88.80

[a] na = not applicable; high rates of fertilizer application do not increase sugarcane yields because average year-2000 rate of fertilizer use exceeds 90kg per hectare (Ahmed 2002).
Source: Author's calculations using DSSAT results.

Figure 3.5 Geographic Divisions of Solomon Islands Used in the Study, 2011



Source: GADM v. 1.0 (University of Berkeley et al. 2010).

proximity to Guadalcanal Province. Since some of these regions have little or no cultivated area, not all of them are included in the tables below.

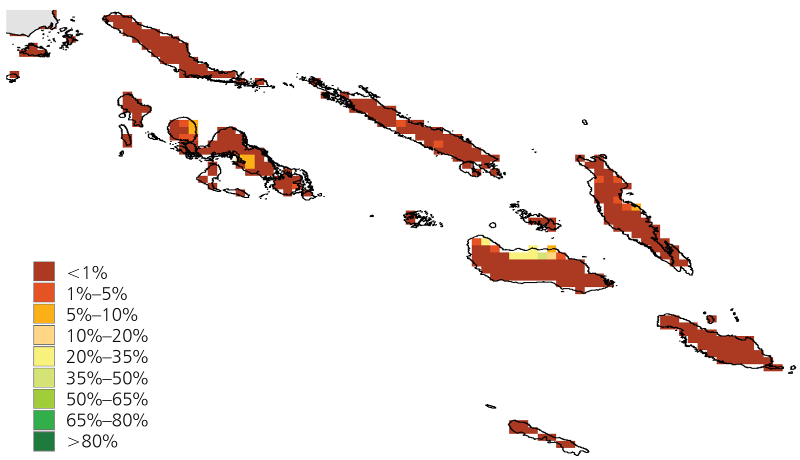
Among Solomon Islands' provinces, Guadalcanal appears to have some of the country's highest elevations, though higher elevations are also found in the Western province. Higher elevations in the Solomon Islands are generally cooler than are low-lying areas.

In terms of soil types, Choiseul and Isabel provinces have mostly medium SOC, medium-depth loam soils. Guadalcanal province has mostly high-SOC, deep clay soils; Makira has mostly high-SOC, shallow clay soils; and Malaita has medium-depth loam soils in about equal proportions of medium and high SOC. The Western province has a roughly even distribution of all four soil types, namely (i) medium-SOC, medium-depth loam soils; (ii) high-SOC, deep clay soils; (iii) high-SOC, shallow clay soils; and (iv) high-SOC medium-depth loam soils.

Mean annual rainfall in 1950–2000 appears to have been lowest in Guadalcanal, and higher in the western- and eastern-most provinces.

Unlike the satellite land cover maps for Fiji and PNG, the results from the various datasets for the Solomon Islands are dissimilar. The MODIS data show very little cropland; the GLC2000 dataset shows a modest amount of cropland along the northern shores of Guadalcanal and in parts of Western province; and GlobCover 2009 suggests that there are large areas of cropland, possibly because it interprets fallow land as cropland. Figure 3.6 shows the median extent of cropland as computed from these three datasets.

Figure 3.6 Percentage Share of Cropland in the Total Area Represented by Grid Cells Comprising Solomon Islands



Source: IFPRI calculations. The percentage shares of cropland in the total area represented by the various grid cells that comprise Solomon Islands as shown in Figure 3.6 were calculated from the median value of the extent of cropland per grid cell as reported by the three land cover datasets referred to in the text.

Results from Application of General Circulation Models. Table 3.11 presents the climate change projections for Solomon Islands from the four GCMs based on IPCC Scenario A1B for 2000–2050. These results are presented by province, with each grid cell receiving the same weighting. The results include projected changes in annual precipitation, projected changes in precipitation during the wettest and driest 3 months of the year, and the projected changes in the maximum temperature for the warmest month of the year (see also Appendix 7, Figures A7.5–A7.8).

Comparing the projected changes in maximum temperature and annual precipitation for the year 2050 as calculated from the results delivered by the four GCMs (Table 3.12), CNRM shows the greatest temperature increase by 2050, but only moderate changes in precipitation; however, the changes in precipitation vary by province.

Annual rainfall is projected to decrease in the southern part of the country (i.e., Temotu, Makira, Rennell and Belona, Guadalcanal, and the southern part of Malaita), but to increase during the wettest 3 months of the year.

Table 3.11 Projected Changes in Maximum Temperature (°C) **and Precipitation** (mm) **in Solomon Islands by Region, 2000–2050** (under IPCC Scenario A1B)

Region	Baseline Average for 1950–2000	Change Projected to Occur by the Year 2050			
		CNRM[a]	CSIRO[b]	ECHAM[c]	MIROC[d]
Projected Change in Maximum Temperature (°C)					
Nationwide	29.6	1.7	1.0	1.4	1.3
Choiseul	29.8	1.7	0.9	1.3	1.3
Guadalcanal	28.8	1.7	1.0	1.4	1.3
Isabel	29.9	1.7	1.0	1.4	1.3
Makira	29.1	1.7	0.9	1.4	1.3
Malaita	29.4	1.7	1.0	1.4	1.3
Rennell and Bellona	30.1	1.7	1.0	1.4	1.3
Temotu	29.9	1.6	1.0	1.4	1.2
Western	30.1	1.7	0.9	1.4	1.3
Projected Change in Annual Precipitation (mm)					
Nationwide	3,282	–25	233	–85	–261
Choiseul	3,553	13	147	–27	–99
Guadalcanal	2,649	–53	272	–111	–387
Isabel	3,050	8	214	–32	–137
Makira	3,568	–56	281	–161	–405
Malaita	3,328	–34	218	–81	–309
Rennell and Bellona	2,700	–73	213	–172	–376
Temotu	4,782	–117	199	–99	–406
Western	3,568	3	250	–72	–166
Projected Change in Precipitation During the Wettest 3 Months (mm)					
Nationwide	1,124	25	50	11	–63
Choiseul	1,115	14	64	–37	–4
Guadalcanal	1,035	43	53	25	–107
Isabel	1,124	14	59	3	–24
Makira	1,119	38	49	54	–102
Malaita	1,181	33	48	22	–80
Rennell and Bellona	967	45	37	28	–128
Temotu	1,333	–9	58	56	–81
Western	1,171	11	35	–12	–35
Projected Change in Precipitation During the Driest 3 Months (mm)					
Nationwide	638	–58	49	–59	–76
Choiseul	746	–42	29	–38	–27
Guadalcanal	437	–57	71	–68	–130
Isabel	571	–55	34	–67	–79
Makira	725	–89	49	–53	–103
Malaita	652	–64	40	–75	–101
Rennell and Bellona	512	–91	36	–88	–96
Temotu	1,079	–41	36	–29	–100
Western	713	–46	59	–46	–12

[a] CNRM = *Centre National de Recherches Météorologiques* (National Center for Meteorological Research [of France]).
[b] CSIRO = Commonwealth Scientific and Industrial Research Organisation (Australia).
[c] ECHAM = European Center Hamburg (Germany).
[d] MIROC = Model for Interdisciplinary Research on Climate (Japan).
Source: Authors' calculations from GCM data (Jones et al. 2009).

Table 3.12 Summary of Projected Changes in Temperature and Rainfall in Solomon Islands Over the Period 2000–2050, by General Circulation Model

General Circulation Model	Temperature	Rainfall
CNRM	Much hotter	Southern parts are drier overall, but wetter during the wettest 3 months; little change elsewhere
CSIRO	Slightly hotter	Wetter overall; wetter during the wet season and drier during the dry season
ECHAM	Hotter	Overall drier in southern parts and during the driest 3 months, but wetter there during the wettest three months; the northern parts are projected to undergo little change overall, but are much drier during the wettest 3 months and during the driest 3 months
MIROC	Hotter	Northern parts are projected to become moderately drier overall and during the wettest three months; southern parts are projected to become much drier overall, in the wettest 3 months, and in the driest 3 months.

CNRM = Model developed by Centre National de Recherches Météorologiques (the National Center for Meteorological Research [of France]), CSIRO = Model developed by the Commonwealth Scientific and Industrial Research Organisation (of Australia), ECHAM = Model developed by the Max Planck Institute for Meteorology at the European Centre Hamburg (Germany), MIROC = Model for Interdisciplinary Research on Climate (of Japan).
Source: Authors' calculations from GCM data (Jones et al. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for International Livestock Research Institute, Nairobi, Kenya.

CSIRO projects relatively small temperature increases, but a much wetter climate for the country overall throughout the year. ECHAM projections indicate higher temperatures, but not as high as those projected by CNRM. Overall, little change is projected for northern part of the country (i.e., northern part of Malaita, Isabel, Western, and Choiseul) with the exception of much drier conditions during both the wettest and driest 3 months of the year. The southern islands are projected to become drier overall in the dry months, but wetter in the wettest 3 months. The MIROC projected temperature changes are similar to those of the ECHAM projections. That is, the southern islands are projected to become much drier throughout, while the northern islands are projected to become a bit drier overall as well as during the wettest 3 months of the year. These projected changes are summarized in Table 3.12.

DSSAT Results

Table 3.13 shows the Solomon Islands' 10 major agricultural crops in terms of average area harvested during the period 2005–2007. While not all of these crops can be accommodated by DSSAT, some of the more important ones can, such as taro and rice.

Table 3.14 shows the percentage change in crop yields under year-2050 climate conditions projected by each of the four GCMs, as compared to year-2000 crop yields.[16] These data also appear in Appendix 6.

16 The crop yield results of the DSSAT analysis were aggregated to the subnational level by estimating the weighted average yield of all crops grown in the area represented by the grid cells comprising

Table 3.13 Major Agricultural Crops of Solomon Islands in Terms of Average Area Harvested, 2005–2007

Rank	Crop	Harvested Area ('000 ha)	% of Total Harvested Area
	All crops	75	100.0
1	Coconuts	37	49.6
2	Cocoa beans	12	15.9
3	Oil palm fruit	9	12.1
4	Sweet potatoes	6	8.0
5	Other pulses	3	4.3
6	Taro (cocoyam)	2	2.7
7	Other fresh fruit	2	2.2
8	Rice, paddy	1	1.9
9	Yams	1	1.7
10	Other fresh vegetables	0	0.5

Source: FAO. 2011. FAO Statistical Database.

Existing yields of rainfed taro are good in most areas of the Solomon Islands, except for a small portion of the southern coast of Guadalcanal where there is currently little or no agriculture. Under conditions of climate change, yields of rainfed taro are projected to decline by a range of 7.4%–16.1% (with high rates of fertilizer application), unless farmers adjust the planting month and cultivar. In the latter case, yields are only projected to decline by 6.4%–12.4%, thus reducing potential losses by about 30%.

All four GCMs project yield losses, with CSIRO showing lower levels of losses as compared to the results of the other GCMs. At the province level, yields of rainfed taro are projected to be the least responsive to increases in fertilizer application rates in Guadalcanal where the losses due to climate change are projected to be relatively great.

As shown in Table 3.14, climate change results in projected yield losses of 12%–16% for taro, rice, and sweet potato with high rates of fertilizer application under the worst-case scenario without adaptation, and a still substantial 7%–8% loss under the best-case. Thus, adaptation appears to have significant benefits. For rice, sweet potato, and, in most cases, taro, percentage yield losses due to climate change relative to year-2000 baseline levels are greater for higher rates of fertilizer application than for lower rates of fertilizer use.

For example, consider the difference in the projected year-2050 yield of rainfed rice as opposed to its year-2000 yield under the worst-case scenario with adaptation, for both high and low rates of fertilizer application. With a low rate of fertilizer application (10 kg/ha of nitrogen), yields of rainfed taro

each geographical division in question. The weight applied was the percentage share of the area planted to the crop in question in the total land area represented by each grid cell. Calculating these percentage shares required knowing the total area planted to each crop within the area represented by each grid cell. As the values for the total area planted to each crop as reported by the three landcover datasets used by the study differed, the median value of those reported by the three landcover datasets was used for this purpose.

Table 3.14 Percentage Change in Crop Yields Projected to Occur in Solomon Islands by the Year 2050 as Compared with Year 2000 Crop Yields

	Low Rate of Fertilizer Application[a]				High Rate of Fertilizer Application[b]			
	Current Cultivar and Planting Month[c] in Year 2000		Optimal Cultivar and Planting Month[c] for Year 2050		Current Cultivar and Planting Month[c] in Year 2000		Optimal Cultivar and Planting Month[c] for Year 2050	
Crop	Worst Case	Best Case	Worst Case	Best Case	Worst Case	Best Case	Worst Case	Best Case
Cassava								
Irrigated	–26.7	–20.3	–25.2	–17.6	–26.7	–19.7	–24.7	–17.0
Rainfed	–27.8	–20.1	–26.4	–18.5	–27.5	–19.7	–26.0	–17.9
Maize								
Irrigated	–5.0	–0.3	–1.8	0.7	–9.6	–3.8	–6.8	–2.5
Rainfed	–8.4	–1.3	–2.8	–0.3	–16.5	–3.1	–7.6	–1.7
Rice								
Irrigated	0.7	8.2	3.7	10.8	–7.6	–4.6	–5.7	–2.8
Rainfed	–16.2	1.8	2.1	5.9	–15.3	–7.9	–7.0	–2.5
Sorghum, rainfed	–12.0	–4.2	–8.6	–3.8	–12.2	–4.3	–8.7	–3.7
Soybeans, rainfed	–11.1	–3.5	–9.9	–3.0	–14.6	–2.6	–9.1	–0.8
Sweet potatoes, rainfed	–15.0	0.3	–6.7	1.5	–14.8	0.3	–6.7	1.5
Sugarcane, rainfed	–12.9	0.0	–11.5	0.9	–12.9	0.0	–11.5	0.9
Taro								
Irrigated	–7.2	–4.7	–6.9	–3.7	–8.9	–6.5	–8.3	–6.1
Rainfed	–18.6	–5.5	–7.3	–4.7	–16.1	–7.4	–12.4	–6.4
Wheat								
Irrigated	–60.0	–25.3	–32.7	–23.2	–32.0	–25.7	–29.8	–23.9
Rainfed	–37.3	–24.4	–34.3	–22.3	–37.9	–24.4	–34.7	–22.3

[a] Low fertilizer application rate = 10 kilograms of nitrogen per hectare (kg N/ha).
[b] High fertilizer application rates varied from crop to crop. For taro, sweet potatoes, cassava, rice, maize, sugarcane, and sorghum, the high application rate was 90 kg N/ha; for soybeans and wheat, it was 60 kg N/ha; and 30 kg N/ha for groundnuts.
[c] Cultivars and planting months were those that gave the highest yields for the indicated year. Sorghum, soybeans, sugarcane, and sweet potatoes have similar yields in rainfed and irrigated fields, so results for the irrigated crops were excluded from this table.
Source: Authors' calculations using results from DSSAT.

are projected to be 2.1% higher in 2050 than in 2000. However, for a high rate of fertilizer application (90 kg/ha of nitrogen), the corresponding figure is a yield *decrease* of 7.0%.

While for most crops, the yield-boosting impact of additional fertilizer is slightly smaller under conditions of climate change than in its absence, increasing fertilizer use still results in a substantial positive impact on yields. For example, in the absence of climate change, rainfed rice yields increase by 8.4% for every additional 10kg of nitrogen applied per hectare, while under conditions of climate change, the corresponding projected yield increase is 6.5%.

As shown in Table 3.15, increasing nitrogen application rates from their year-2000 levels to 90kg per hectare boosts projected yields of taro by 30%–33%, rice yields by 52%–54%, and sweet potato yields by 65%.

Table 3.15 Percentage Increase in Per-Hectare Yield Resulting from Nitrogen Application Rates of 90 Kilograms per Hectare as Opposed to Year 2000 Application Rates for Rainfed Staple Crops Grown in Solomon Islands

Crop	Nitrogen Use Under High-Fertilizer Scenario (kgN/ha)	Percentage Change in Crop Yield	
		With Cultivar and Planting Month Optimal for Year 2000	With Optimal Cultivar and Planting Month for Year 2050
Taro	90	33.47	30.18
Rice	90	53.64	51.84
Sweet potato	90	65.20	65.01

Source: Author's calculations using DSSAT results.

Analysis of the Returns to Adoption of Climate Change Adaptation Technologies

The study used IFPRI's Dynamic Research Evaluation for Management (DREAM) model (Wood et al. 2000) to estimate the economic returns to adoption of crop management technologies for minimizing the negative impact of climate change on crop yields. The DREAM model is suited to this task, as it can estimate the returns to adoption of particular technologies across regions, and under a relatively broad range of market conditions. Procedurally, DREAM uses a set of linear equations to represent supply and demand for the each commodity in question in the technology-receiving region, with market clearing being enforced by a set of quantity and price identities.

That said, DREAM is a single-commodity model. That is, it does not address cross-commodity substitution effects in either production or consumption. In other words, DREAM is not able to estimate changes in the price or quantity demanded of any production input used for producing the commodity being analyzed. Nor can it estimate changes in the price or quantity demanded of any good that a consumer might use to replace the commodity being analyzed, should the price of the latter rise. However, DREAM is able to implicitly capture the impact of such substitution effects by applying supply and demand price elasticities relevant to the commodity under study.

Estimating Baseline Values for the Variables Used in Assessing the Returns to Adoption of Climate Change Adaptation Technologies

Assessing the returns to adoption of climate change adaptation technologies requires estimating baseline values for certain variables relating to the major agricultural commodities under study. These variables include the quantity produced and consumed of the commodity under study during the base period, as well as the price elasticities of supply and demand for each commodity analyzed.

Initially, the study estimates the returns to adoption of climate change adaptation technologies by using DREAM to compare the level of crop yields in a baseline year, to the level of crop yield likely to occur in a year far enough in the future that climate change would have already occurred. Thus, in addition to the variables relevant to the baseline year as referred to above, the study projected the crop yield that would result in a future year under conditions of climate change, with the crop management technology applied during the base year continuing to be used throughout that future year. The study then reestimated the level of crop yield likely to occur in the future year under conditions of climate change, had a climate change adaptation crop management technology been adopted.

The two levels of crop yield estimated for the future year—i.e., the levels of crop yield with and without adoption of climate change adaptation crop management technologies—are then compared, the difference in crop yield being taken as the return to adoption of the climate change adaptation technology in question. Note that this procedure for estimating the returns to adoption of climate change adaptation technologies requires netting out any increase in crop yield for the commodity in question caused by factors other than adoption of a climate change adaptation technology. This is accomplished by assuming that any such exogenous increase in quantity supplied of the commodity in question will immediately be met by an equal increase in the quantity demanded for it (see below).

The assumptions under which the estimates for the baseline values of the variables referred to above, as well as the estimates of crop yield following adoption of a climate change adaptation technology are produced are presented below.

Calculation of Baseline Values for Variables, Assumptions, and Years Used for Comparison

The values for the variables used in the analysis estimated for the baseline year reflect market conditions relating to production and consumption in the initial year of the analysis. In this context, the term "market conditions" includes the prices of all relevant inputs and outputs. In order to minimize the possibility of selecting a year in which such market conditions were skewed for one reason or another, the analysis used the average (i.e., mean) value of all relevant variables over the three-consecutive-year period 2007–2009. The choice of this particular three-year time period was in part based on availability of data. For the future year used as a comparator, the study chose the year 2050 for the reasons discussed immediately below.

In evaluating the impacts of adoption of new agricultural technologies, a 20–30-year time period is often deemed appropriate to ensure that all lags in generating, commercializing, diffusing, and adopting new technologies are taken into consideration. For climate change adaptation technologies, this time lag is likely to be even longer. The study thus used the 43-year period 2008–2050, the year 2050 being the comparator against which the values for the baseline year of 2008 are evaluated. This length of time period had the added advantage that it roughly corresponds to the time period used by DSSAT in formulating projected values of relevant variables.

Table 3.16 summarizes the assumptions and baseline conditions relevant to all simulations performed under the study.

Regional Aggregation

DREAM assumes that all commodities being analyzed are tradable to some degree. Based on data availability, Fiji's districts (except for cassava) and PNG

Table 3.16 Baseline Conditions and Assumptions Relating to the Study

Parameters	Value	Remarks
Scenario constants		
Base year	2008	Mean value of relevant variable over 2008–2010
Simulation period	43 years	2008 to 2050
Real discount rate	5%	Used to calculate the present value of relevant parameters
Market		One market is equivalent to one region as defined by DREAM
Initial prices		Border prices, i.e., prices net of any taxes, subsidies or other distortions
Price transmission elasticity	0.8	A value of <1.0 is used to reflect imperfect transmission of the effects of price changes from one region to another
Supply		
Initial quantity		Average level of output for time period 2007–2009
Elasticity		Estimated by IMPACT model
Exogenous growth	Variable	Growth in output of the commodity in question (other than growth induced by adoption of the new technology) is set equal to projected demand growth
Tax/Subsidy	0	
Demand		
Initial quantity	Variable	Initial quantity demanded of the commodity in question is set equal to average quantity demanded for time period 2007–2009
Price elasticity	Variable	Estimated by IMPACT model
Exogenous growth in demand for commodity in question	Variable	Derived from projected population and income growth rates in the region concerned
Tax/Subsidy	0	
Research and Development parameters		
Probability of success	100%	
Gestation lag	7 years	Technology is available for adoption 7 years following the date of innovation
Supply shift		
Supply shifts k	Variable	Percentage of innovating region's producer price. (from DSSAT simulations/scenarios)
Adoption profile		
Time to ceiling	10 years	Maximum adoption level is reached after 10 years
Ceiling level	100%	Maximum adoption level
Functional form	Sigmoid	Sigmoidal from date of technology availability to maximum adoption, i.e., no dis-adoption occurs
Technological Spillover Effects		
Not considered		Technology spillover from innovating region to others

Source: IFPRI DREAM model simulations.

states were used as the regions DREAM used to perform the analysis. However, for Solomon Islands, lack of subnational data required using the entire country as a DREAM region.

DREAM evaluates agricultural technologies by focusing on a particular region (i.e., the technology-receiving region). This raises the challenge of how to handle that technology-receiving region's interactions with the rest of the world (ROW). In the case of the present study, it was neither necessary, nor would it have been desirable, to list all countries outside each study country as separate regions for purposes of performing the analysis. Instead, the study identified the most important trading partners of each region in terms of volume or value of imports and exports, and grouped all other trading partners into a "ROW" category. Since the districts of Fiji and the states of PNG were considered as separate regions for purposes of the analysis, the study used Asia as the ROW for rice and sugarcane, which are the most important tradable crops produced in the study countries. As taro, cassava, and sweet potatoes are produced and consumed only locally, the ROW category is not relevant in these cases.

Initial Market Conditions

The analysis begins by defining the market conditions relevant to the baseline year. These include (i) the initial quantities produced and consumed of the commodity under study; (ii) the initial market prices specific to the region concerned; (iii) any relevant price distortions such as producer or consumer taxes or subsidies; (iv) the price elasticities of supply and demand; (v) any relevant price transmission elasticities; and (vi) the exogenous rate of growth in supply and demand, i.e., the rate of growth of supply and demand *not* due to application of the technology under study (Table 3.16).

Production and Consumption

National crop production data (both quantity and form) were taken from the Food and Agriculture Organisation of the United Nations (FAO) (2011). Subnational data were collected from national or regional agricultural research institutions. Domestic consumption data, expressed in the same quantity and form as production data, were obtained from FAO *Commodity Balance Sheets*. For any country, in year t, current consumption is given by C_t, where

$$C_t = Q_t + (M_t - E_t) - (S_t - S_{t-1}),$$

Q_t is domestic production, M_t is imports, E_t is exports, S_{t-1} is stocks carried forward from the previous year, and S_t is stocks at the end of the current year carried forward into the next year. Baseline production and consumption data were estimated as the mean annual values for the period 2007–2009.

Market Prices

All commodities were assumed to be tradable, for which the relevant prices are the local market prices. Since local commodity prices were not available, national-level FAO producer prices were used instead. Transactions costs were partially accounted for (see below).

Price Elasticities

Both supply and demand price elasticities were estimated by IMPACT (Rosegrant et al. 2010). Supply elasticities unable to be estimated by IMPACT were set to a value of 1.0. This simplifies the initial cross-commodity comparison of research-and-development impacts, and eliminates a possible problem of interpreting the supply shift. Demand elasticities unable to be estimated by IMPACT were set to a value of 0.5, a value of price elasticity of demand typical for food items in low- and middle-income countries.

Structural Price Differences and Price Transmission Elasticities

The model accommodates region-specific, baseline equilibrium prices. To model transportation costs and other trade barriers, a price wedge, v_i, and price transmission elasticity, w_i, were introduced, assuming that

$$P_{i,t} = v_i + w_i P_t ,$$

where $P_{i,t}$ is the price in region i in year t, v_i is the structural price wedge between region i and the global market equilibrium price P_t, and w_i is the price transmission elasticity between region i and all other regions. The structural price wedge v_i can be calculated by initially equating prices among all regions ($t = 0$):

$$v_i = P_{i,0} - w_i P_0 .$$

A price transmission elasticity of less than 1 dampens the impact of the change in price in the receiving region that is generated by a change in price in the innovating region. A coefficient of $w_i = 1.0$ thus represents perfect, costless, free trade among regions. Under such a scenario, the price change in the receiving region would be exactly equal to the price change in the innovating region. Conversely, a coefficient of $w_i = 0$ represents a closed economy (autarky) in which the market of the receiving region functions completely independently of all other markets. Under the latter scenario, the price in the receiving region would remain constant, despite change in price of any magnitude in the innovating region.

Exogenous Supply and Demand Growth

The total benefits from a *k*-percent technical change depend directly on the size of the industry affected, which in turn depends on the projected rate of growth in demand for the commodity in question over the simulation period. Projecting demand is a complex task, as future demand is determined by the relevant rate of population growth, the level or rate of change in income in the region concerned, any dietary changes that may arise in the future, and many other factors. The study used the estimates of projected demand generated by IMPACT (Rosegrant et al. 2010; Nelson et al. 2010).

The study assumes that any growth in output of the commodity in question *not* induced by technological change is exactly equal to the rate at which demand for the commodity in question grows in each country. Thus, in the absence of adoption of technological change, the quantity demanded of the commodity in question always equals the quantity supplied.

Following the overall methodology outlined in Appendix 6, DREAM baseline data were estimated for the major crops grown in the three study countries (Tables 3.17–3.23). Because rice (Table 3.17) and sugarcane (Table 3.18) are internationally traded commodities, values for the quantity produced, the quantity consumed, and the price elasticities of demand and supply for the rest of the world (i.e., all markets outside the region under study taken in aggregate) are included in addition to the corresponding values for the various provinces of Fiji. These values for the rest-of-the-world (i.e., external) market are provided for rice, despite the fact that rice production in the three study countries is quite limited (ADB 2010).

Since cassava and taro (in Fiji), and sweet potatoes (in PNG and Solomon Islands), are grown solely for domestic consumption, no values for quantity produced, quantity consumed, and price elasticities of demand and supply for these commodities are presented for the external, rest-of-the-world market.

Specification and Adoption of Technology

The analysis represents technological change as a downward shift in the supply curve by a given number of percentage points (referred to as *k*-percent). This *k*-percent downward shift in the supply curve for the commodity in question refers to a net reduction of *k* percentage points in the average and marginal cost of producing one unit of output as a result of adopting the climate change adaptation crop production technology concerned. *K* represents an absolute

Table 3.17 Baseline Values for Variables Used in Analyzing Rice Production in Fiji (2007–2009 average values)

Division	Province	Production (ton)	Consumption (ton)	Prices ($/ton)	Elasticity Supply	Elasticity Demand
Central	Naitasiri	6		650.50	0.25	
	Namosi	0		650.50	0.25	
	Rewa	0		650.50	0.25	
	Serua	0		650.50	0.25	
	Tailevu	11		650.50	0.25	
Western	Ba	30		650.50	0.25	
	Nadroga	9		650.50	0.25	
	Ra	11		650.50	0.25	
Northern	Bua	3,403		650.50	0.25	
	Cakaudrove	0		650.50	0.25	
	Macuata	9,225		650.50	0.25	
Eastern	Kadavu	0		650.50	0.25	
	Lau	0		650.50	0.25	
	Lomaiviti	0		650.50	0.25	
	Rotuma	0		650.50	0.25	
	Fiji total		60,289	650.50		0.30
	Rest of Asia	618,230,856	618,183,260	800.00	0.40	0.30

Source: IFPRI DREAM simulations.

Table 3.18 Baseline Values for Variables Used for Analyzing Sugarcane Production in Fiji (2007–2009 average values)

Division	Province	Production (ton)	Consumption (ton)	Prices ($/ton)	Elasticity Supply	Elasticity Demand
Central	Naitasiri	0		437.28	0.32	
	Namosi	0		437.28	0.32	
	Rewa	0		437.28	0.32	
	Serua	0		437.28	0.32	
	Tailevu	0		437.28	0.32	
Western	Ba	1,139,809		437.28	0.32	
	Nadroga	216,047		437.28	0.32	
	Ra	257,648		437.28	0.32	
Northern	Bua	0		437.28	0.32	
	Cakaudrove	13,496		437.28	0.32	
	Macuata	570,948		437.28	0.32	
Eastern	Kadavu	0		437.28	0.32	
	Lau	0		437.28	0.32	
	Lomaiviti	0		437.28	0.32	
	Rotuma	0		437.28	0.32	
	Fiji total		2,843,667	437.28		0.44
	Rest of Asia	700,397,460	699,751,742	157.00	0.45	0.40

Source: IFPRI DREAM simulations.

Table 3.19 Baseline Values for Variables Used in Analyzing Taro Production in Fiji (2007–2009 average values)

Division	Province	Production (ton)	Consumption (ton)	Prices ($/ton)	Elasticity Supply	Elasticity Demand
Central	Naitasiri	24,805		729.69	0.50	
	Namosi	2,703		729.69	0.50	
	Rewa	1,127		729.69	0.50	
	Serua	2,607		729.69	0.50	
	Tailevu	9,372		729.69	0.50	
Western	Ba	579		729.69	0.50	
	Nadroga	650		729.69	0.50	
	Ra	1,855		729.69	0.50	
Northern	Bua	2,742		729.69	0.50	
	Cakaudrove	7,273		729.69	0.50	
	Macuata	541		729.69	0.50	
Eastern	Kadavu	1,454		729.69	0.50	
	Lau	350		729.69	0.50	
	Lomaiviti	1,004		729.69	0.50	
	Rotuma	197		729.69	0.50	
	Fiji total		62,742	729.00		0.50

Source: IFPRI DREAM simulations.

Table 3.20 Baseline Values for Variables Used in Analyzing Cassava Production in Fiji (2007–2009 average values)

Division	Production (ton)	Consumption (ton)	Prices ($/ton)	Elasticity Supply	Elasticity Demand
Central	36,612		210	0.50	
Western	10,741		240	0.50	
Northern	7,501		100	0.50	
Eastern	3,915		80	0.50	
Fiji total		58,769	200		0.40

Source: IFPRI DREAM simulations.

Table 3.21 Baseline Values for Variables Used in Analyzing Rice Production in Papua New Guinea (2007–2009 average values)

Region	Province	Production (ton)	Consumption (ton)	Prices ($/ton)	Elasticity Supply	Elasticity Demand
Papua	Western	0		899	0.25	
	Gulf	0		899	0.25	
	Central	92		899	0.25	
	Milne Bay	8		899	0.25	
	Oro	94		899	0.25	
Highlands	Southern Highlands	0		899	0.25	
	Enga	0		899	0.25	
	Western Highlands	0		899	0.25	
	Simbu	0		899	0.25	
	Eastern Highlands	0		899	0.25	
Momase	Morobe	2		899	0.25	
	Madang	0		899	0.25	
	East Sepik	0		899	0.25	
	Sandaun	0		899	0.25	
Islands	Manus	0		899	0.25	
	New Ireland	0		899	0.25	
	East New Britain	0		899	0.25	
	West New Britain	0		899	0.25	
	Bougainville	603		899	0.25	
	PNG total		185,000	899		0.30
	Rest of Asia	618,235,856	618,051,656	800	0.40	0.30

Source: IFPRI DREAM simulations.

Table 3.22 Baseline Values for Variables Used in Analyzing Sweet Potato Production in Papua New Guinea (2007–2009 average values)

Province	Production (ton)	Consumption (ton)	Prices ($/ton)	Elasticity	
				Supply	Demand
Western	1,274		301.28	0.5	
Gulf	3,770		301.28	0.5	
Central	9,145		301.28	0.5	
Milne Bay	8,136		301.28	0.5	
Oro	9,896		301.28	0.5	
Southern Highlands	115,006		301.28	0.5	
Enga	63,251		301.28	0.5	
Western Highlands	79,070		301.28	0.5	
Simbu	54,705		301.28	0.5	
Eastern Highlands	87,233		301.28	0.5	
Morobe	36,140		301.28	0.5	
Madang	14,432		301.28	0.5	
East Sepik	4,859		301.28	0.5	
Sandaun	4,647		301.28	0.5	
Manus	831		301.28	0.5	
New Ireland	7,219		301.28	0.5	
East New Britain	7,915		301.28	0.5	
West New Britain	8,372		301.28	0.5	
Bougainville	17,187		301.28	0.5	
PNG total		533,089	310.28		0.42

Source: IFPRI DREAM simulations.

Table 3.23 Baseline Values for Variables Used in Analyzing Rice and Sweet Potato Production in Solomon Islands (2007–2009 average values)

Crop/Region	Province	Production (ton)	Consumption (ton)	Prices ($/ton)	Elasticity	
					Supply	Demand
Rice						
Solomon Islands	Solomon Islands	3,469	48,445	640	1.0	0.4
Rest of the World	Rest of Asia	618,230,856	618,185,880	800	0.4	0.3
Sweet potatoes						
Solomon Islands	Solomon Islands	86,667	86,667	301	0.5	0.4

Source: IFPRI DREAM simulations.

number, as it is calculated by multiplying the percentage reduction in cost per unit of output times the initial producer price, PP_0. That is, $K= k\ PP_{0,}$ given absence of producer taxes and subsidies, as well as transactions costs. Under such conditions, the initial producer price PP_0 would be the same as the initial market equilibrium price P_0. Since the DSSAT crop simulation model is able to estimate the impact on crop yields of various climate change adaptation technologies, it is likewise able to estimate the value of *k*.

The baseline scenario assumes no climate change adaptation. That is, the baseline scenario assumes that the cultivars, planting dates, and crop management system used are those employed in producing the crop in question in the base year 2008. Further, the baseline scenario assumes the climatic conditions prevailing in the year 2000.

Five technology adoption scenarios are then used o illustrate the impact of a commodity producer's adopting alternative climate adaptation crop production technologies. The first of these is the *Business as Usual* (BAU) scenario. Under the BAU scenario, no climate change adaptation technologies are adopted at any point during the period 2008–2050. Thus, any change in crop yields that occurs over this time period can only be attributed to climate change.

Under the second scenario, *Crop Management*, farmers adapt to climate change by altering the month of planting of the commodity concerned, and employ best practices as disseminated to them by the relevant agricultural extension service. Under the third scenario, *Fertilizer,* farmers use optimal crop cultivars and increase the rate of application of fertilizer. Thus, under this third scenario, any yield changes observed are attributed to a combination of climate change, increased fertilizer application rates, and a switch to planting optimal cultivars. Regarding the fourth scenario, *Irrigation*, climate change-driven deleterious rainfall patterns have a considerable negative impact on crop yields. Thus, use of irrigation is the primary adaptation technology under consideration. Under this fourth scenario, any changes in crop yield observed are due to a combination of climate change and a shift toward the use of irrigation.

Finally, under the fifth scenario, *Agricultural and Extension Investment,* investment in agricultural research is increased to boost the productivity of the crops affected by climate change. Adoption of optimum cultivars is also included in this scenario,

For each of the commodities analyzed, the study used the DSSAT model[17] to estimate the changes in crop yield that would occur under the first four scenarios described above. These changes in crop yields estimated for each of the first four scenarios were then compared to the baseline yields for each of the crops under analysis grown in the three study countries. The difference between the crop yield under each of the first four scenarios described above and the baseline yield is taken to comprise the benefits forthcoming as a result of adoption of the climate change adaption crop production technologies that

17 The GCMs do not provide variances for their monthly climate variables. It would therefore be somewhat misleading to attempt to provide measures of uncertainty in yields from the crop modeling in DSSAT using such data as inputs. However, as we saw from Table 3.1 for Fiji, there is significant variation between GCMs, and one of the advantages of the analysis in this study is we show the variations in yield resulting from the various GCMs (see, for example, Table 3.4).

comprise the scenario in question. The benefits accruing from adoption of climate change adaptation technologies as per the first four scenarios under are summarized in Tables 3.24–3.27. The analysis relating to the fifth scenario was estimated directly in DREAM through assessment of the potential for yield growth due to increased investment.

Under the BAU scenario, crop yields decrease in most regions over the period 2008–2050, though yields projected for rice increase in some regions. Of the three climate change adaptation technologies, increasing the rate of fertilizer application results in the greatest gains in yield for all crops with the exception of cassava. For cassava, the impact on yields of increasing the rate at which fertilizer is applied is similar to the gain in yield resulting from irrigation and switching to optimal planting months, cultivars, and crop production techniques.

For Fiji, the projected increases in yields resulting from increased use of fertilizer for the commodities analyzed are greater than 50% for the most part (as compared with the BAU scenario), and in Bua Province, these increases in yield reach a level of 112%. In both PNG and Solomon Islands, irrigation is projected to have a negligible impact on yields of sweet potatoes. This is because nearly all production of sweet potatoes in these countries depends on rainfall, a practice that is likely to continue well into the future. As a result, irrigation is not relevant as a climate change adaptation technology in either PNG or Solomon Islands.

The changes in crop yield from adoption of climate change adaptation crop production technologies described above (Tables 3.24–3.27) constitute the downward shift in the supply curve of *k* percentage points referred to earlier, as they reflect a decrease in both the average and marginal cost of production of each commodity in question.

However, for a climate change adaptation technology to reduce unit production costs, it must be adopted by farmers. Thus, analyzing the benefits forthcoming from adoption of climate change adaptation technologies requires that the functional form, maximum rate of adoption, and relevant time lag (i.e., the amount of time required for the maximum adoption rate to be attained) associated with the technology in question be specified. In estimating the values of the relevant parameters for the baseline scenario, the values for all of these latter parameters were set to the same level for each region analyzed by DREAM, and for each commodity. In particular, the rate of adoption was set to zero in the year the technology in question was released. The rate of adoption then rose in sigmoidal fashion to a 100% adoption rate 10 years later.

Specifying the rate of adoption in this manner allowed each one percentage point reduction in cost forthcoming from adoption of the technology concerned to translate into a one percentage-point downward shift in the supply curve relevant to the commodity in question. Once attained, this reduction in cost of production for the commodity concerned was assumed to be maintained for the remainder of the study period (Figure 3.7).

Table 3.24 Percentage Change in Yield of Rice, Sugarcane, and Taro Relative to 2008 under Alternative Climate Change Adaptation Scenarios, Fiji, 2008–2050

		Rice				Taro				Sugarcane		
Division	Province	Business As Usual[a]	Fertilizer[b]	Irrigation[c]	Crop Management[d]	Business As Usual[a]	Fertilizer[b]	Irrigation[c]	Crop Management[d]	Business As Usual[a]	Fertilizer[b]	Irrigation[c]
Central	Naitasiri	7.72	70.94	0.52	2.59	–2.52	29.65	2.96	0.64	–3.82	0.24	1.12
	Namosi	8.52	95.50	2.26	1.87	–3.54	62.15	4.18	0.49	–0.92	0.40	0.65
	Rewa	6.69	69.31	0.79	3.68	–3.71	17.41	1.97	0.61	–4.10	0.18	0.99
	Serua	5.41	83.70	7.47	2.78	–5.00	51.05	9.73	1.20	–0.56	0.83	1.52
	Tailevu	5.92	78.70	3.92	2.15	–2.56	43.57	4.28	1.22	–3.22	0.45	1.74
Western	Ba	–2.06	70.38	21.69	5.47	–10.91	63.61	39.82	5.75	–6.53	0.73	1.19
	Nadroga	–3.60	56.13	13.44	5.26	–13.16	38.78	33.52	6.90	–3.95	1.20	0.93
	Ra	–1.04	91.01	15.58	5.38	–2.50	77.95	17.32	3.19	–3.32	0.15	1.01
Northern	Bua	–8.70	112.19	24.52	11.22	–1.42	113.76	22.21	4.94	–6.10	0.66	1.03
	Cakaudrove	–4.75	76.96	7.86	4.18	–7.75	56.37	21.54	6.93	–3.38	1.09	0.25
	Macuata	–5.18	80.19	16.04	8.54	–11.30	48.74	26.44	8.93	–3.93	1.08	0.51
Eastern	Kadavu	–0.44	82.10	11.76	6.45	–9.90	21.32	18.63	0.78	–3.85	2.81	4.45
	Lau											
	Lomaiviti	1.39	81.06	9.04	4.41	–3.23	35.29	8.18	1.42	–3.65	0.63	1.01

Scenarios:
[a] Business as usual (BAU): No climate change adaptation strategies are taken; changes in crop yields only reflect the impact of the future climate.
[b] Fertilizer: Farmers use optimal crop cultivars and increase the use of fertilizer as an adaptation strategy, so any yield changes are due to both climate change and fertilizer change under optimal cultivars.
[c] Iirrigation: Crop yield changes are due to climate change and the shift from rainfed to irrigated conditions.
[d] Crop management: Farmers change their planting time and use best practices with technical assistance from extension services to adapt to the changing climate.
Source: IFPRI DSSAT simulations.

Table 3.25 Percentage Change in Yield of Cassava Relative to 2008 under Alternative Climate Change Adaptation Scenarios, Fiji, 2008–2050

Division	Business As Usual[a]	Fertilizer[b]	Irrigation[c]	Crop Management[d]
Central	–24.82	2.93	0.21	2.38
Western	–27.28	3.00	8.55	6.81
Northern	–25.24	9.83	5.55	1.66
Eastern	–20.00	2.09	2.03	14.80

Scenarios:
[a] Business as usual (BAU): No climate change adaptation strategies are taken; changes in crop yields only reflect the impact of the future climate.
[b] Fertilizer: Farmers use optimal crop cultivars and increase the use of fertilizer as an adaptation strategy, so any yield changes are due to both climate change and fertilizer change under optimal cultivars.
[c] Irrigation: Crop yield changes are due to climate change and the shift from rainfed to irrigated conditions.
[d] Crop management: Farmers change their planting time and use best practices with technical assistance from extension services to adapt to the changing climate.
Source: IFPRI DSSAT simulations.

Table 3.26 Percentage Change in Yield of Rice Relative to 2008 under Alternative Climate Change Adaptation Scenarios, Papua New Guinea, 2008–2050

Region	Province	Business As Usual[a]	Fertilizer[b]	Irrigation[c]	Crop Management[d]
Papua	Western	–0.91	42.72	14.44	4.85
	Gulf	0.13	53.72	6.62	4.83
	Central	–1.06	51.25	28.27	5.61
	Milne Bay	2.27	61.32	18.53	4.14
	Oro	–1.37	45.83	6.62	3.37
Highlands	Southern Highlands	21.06	147.50	1.77	14.26
	Enga	25.06	103.88	6.79	10.50
	Western Highlands	29.70	78.79	5.03	11.47
	Simbu	–0.91	87.20	–2.21	17.13
	Eastern Highlands	24.93	60.38	–8.20	10.56
Momase	Morobe	1.63	65.40	14.42	9.13
	Madang	3.50	54.66	11.70	5.75
	East Sepik	–1.37	39.99	18.91	5.37
	Sandaun	2.50	79.11	10.80	7.11
Islands	Manus	3.50	56.34	31.01	9.96
	New Ireland	3.09	90.75	2.25	3.65
	East New Britain	6.90	101.64	3.57	4.27
	West New Britain	3.22	72.56	10.63	5.38
	Bougainville	1.90	45.16	10.31	4.93

Scenarios:
[a] Business as usual (BAU): No climate change adaptation strategies are taken; changes in crop yields only reflect the impact of the future climate.
[b] Fertilizer: Farmers use optimal crop cultivars and increase the use of fertilizer as an adaptation strategy, so any yield changes are due to both climate change and fertilizer change under optimal cultivars.
[c] Irrigation: Crop yield changes are due to climate change and the shift from rainfed to irrigated conditions.
[d] Crop management: Farmers change their planting time and use best practices with technical assistance from extension services to adapt to the changing climate.
Source: IFPRI DSSAT simulations.

Table 3.27 Percentage Change in Yield of Sweet Potato and Rice Relative to 2008 under Alternative Climate Change Adaptation Scenarios, Papua New Guinea and Solomon Islands, 2008–2050

Crop	Region	Business As Usual[a]	Fertilizer[b]	Irrigation[c]	Crop Management[d]
Papua New Guinea					
Sweet potatoes	Papua	–0.46	76.46	0.00	0.87
	Highlands	–11.65	160.42	0.00	4.55
	Momase	–4.39	54.24	0.00	0.99
	Islands	–2.38	46.63	0.01	1.90
Solomon Islands					
Rice		–5.70	56.34	31.01	9.96
Sweet potatoes		–4.21	65.22	0.00	1.82

Scenarios:

[a] Business as usual (BAU): No climate change adaptation strategies are taken; changes in crop yields only reflect the impact of the future climate.

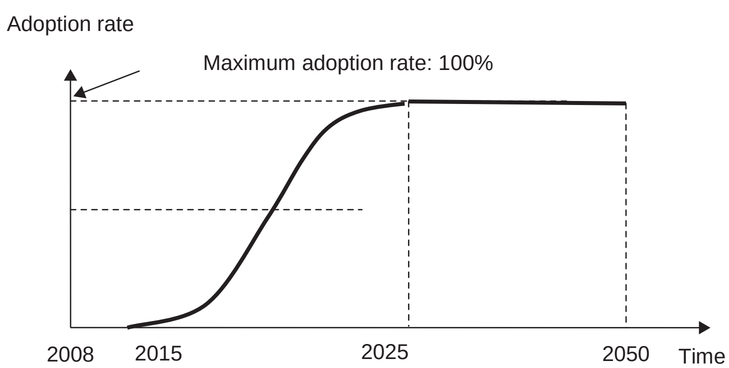
[b] Fertilizer: Farmers use optimal crop cultivars and increase the use of fertilizer as an adaptation strategy, so any yield changes are due to both climate change and fertilizer change under optimal cultivars.

[c] Irrigation: Crop yield changes are due to climate change and the shift from rainfed to irrigated conditions.

[d] Crop management: Farmers change their planting time and use best practices with technical assistance from extension services to adapt to the changing climate.

Source: IFPRI DSSAT simulations.

Figure 3.7 Rate of Adoption of Climate Change Adaptation Crop Production Technologies Assumed Under the Study



Source: IFPRI DREAM model (Wood et al. 2000).

Potential Benefits from Adoption of the Climate Change Adaptation Crop Production Technologies Analyzed under the Study

Under this scenario, annual yields for the commodities under study decrease as compared to the baseline year. This implies an increase in the marginal and average cost of production of the staple commodity concerned. This increase in the cost of production ultimately translates into monetary *dis*benefits (losses) that are shared by producers (whose profits fall) and consumers (whose food prices rise). While these losses are shared between producers and consumers, such losses ultimately represent a cost to the national economy overall. The projected financial losses (disbenefits) that accrue under the BAU scenario in the three study countries over the period 2008–2050 are shown in Table 3.28.

Only in the case of rice production in PNG does the BAU scenario result in a minimal benefit of about $40,000. For all of the other commodities, the total losses over the period 2008–2050 exceed $1 million. Losses from sweet potato production in the BAU scenario exceed $132 million in PNG, and nearly $10 million in Solomon Islands. The greatest overall loss—of $375 million—is suffered by sugarcane in Fiji. This amounts to a loss of approximately $8 million per year during every year of the period 2008–2050, which translates into nearly 1% of the total value of annual sugarcane production, which is the country's primary source of foreign exchange earnings from commodity exports. Since taro and cassava are both staple foods in Fiji, the losses to producers and consumers of these two commodities of $34 million and $24 million, respectively, are considerable.

Given the projected losses presented in Table 3.28, the BAU scenario is an inefficient and costly policy option in all three study countries. The projected gains to each of the study countries under the second, third, and fourth scenarios are each discussed in turn below.

Table 3.28 Projected Aggregate Change in the Value of Crop Yields Resulting from Crop Production Under the Business-As-Usual Scenario Over the Period 2008–2050 in Fiji, Papua New Guinea, and Solomon Islands ($'000s)

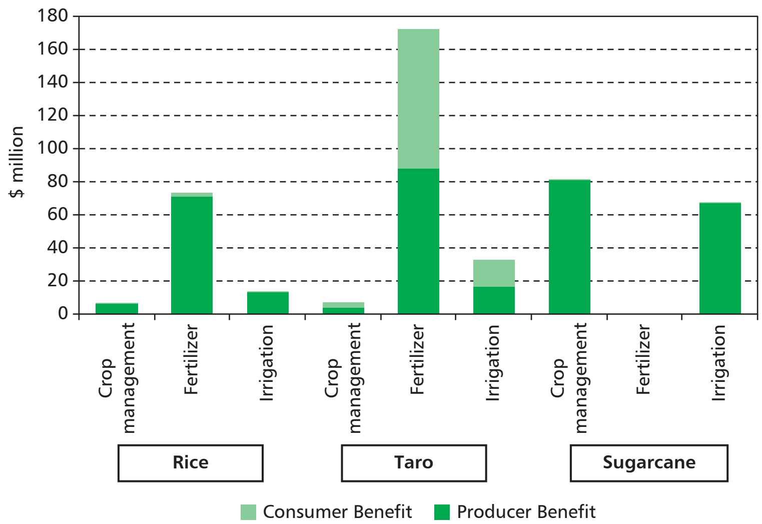
Commodity	Fiji	Papua New Guinea	Solomon Islands
Rice	–1,738.8	40.1	–1,164
Taro	–34,343.5		
Sugarcane	–375,385.7		
Cassava	–24,559.8		
Sweet potatoes		–132,351	–9,795

Source: IFPRI DREAM simulations.

Fiji

Because rice and sugarcane are internationally traded goods, their prices are set in the international market (which under the present study is assumed to be the Asia-wide [ROW] market). This means that any difference between the international (Asia [ROW]) price and the domestic price of these commodities in Fiji is due to the price wedge discussed earlier in this chapter. Because of this price wedge between international (Asia [ROW]) prices and domestic prices, consumers of rice and sugarcane in Fiji will benefit from a marginal decrease in the domestic prices of these goods that results from adoption of particular climate change adaptation crop production technologies (Figure 3.8). However, since taro produced in Fiji is not traded internationally, all of the financial benefits resulting from adoption of climate change adaption crop production technologies will accrue to producers and consumers of taro in the country, consumers enjoying nearly the same share of benefits as producers.

Figure 3.8 Estimated Benefits Accruing to Producers and Consumers of Rice, Taro, and Sugarcane in Fiji Resulting from Adoption of Climate Change Adaptation Crop Production Technologies Over the Period 2008–2050
($ million)



Source: IFPRI DREAM model simulations.

The reduction in production costs for taro more than offset the decrease in the market price that taro fetches due to its increased supply from adoption of climate change adaptation production technologies. As a result, producers of taro enjoy a financial gain from adopting the climate change adaptation production technology concerned.

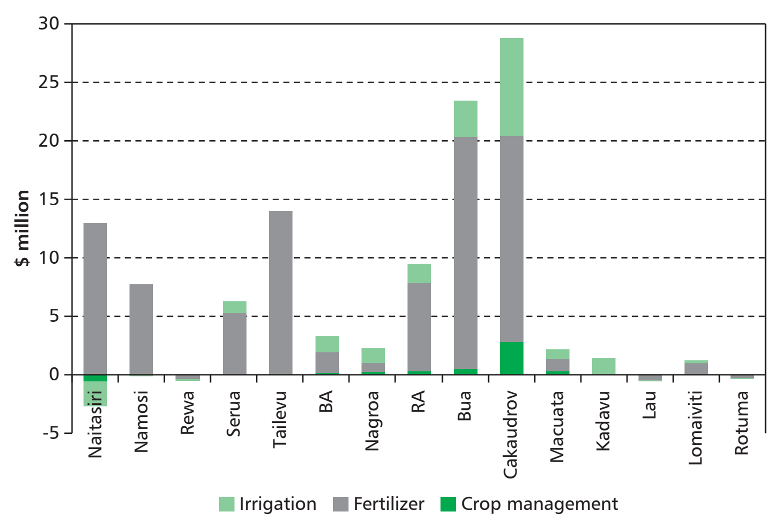
Of the three scenarios represented graphically in Figure 3.8, the greatest projected benefits as compared to the baseline scenario accrue under the *Fertilizer* scenario, these totaling $70 million and $170 million for rice and taro respectively. These results suggest that increasing the rate at which fertilizer is applied to rice and taro can more than offset any projected yield losses due to climate change. However, since fertilizer application rates in sugarcane production in Fiji already equal or exceed the rate assumed by the study under the *Fertilizer* scenario, the benefits from further increasing fertilizer application rates as a means of adapting to climate change are projected to be zero. However, projected benefits in the range of $10 million to $80 million each for rice and taro during the period 2008–2050 are forthcoming under the *Crop Management* scenario. This increase offsets one-third of the negative impact of climate change on taro. Benefits from irrigation are even greater, the cumulative gains from climate change adaptation through increased use of irrigation enjoyed by rice, taro, and sugarcane being $15 million, $30 million, and $70 million, respectively, for the period 2008–2050.

The beneficial impact on crop yields that arise under the *Crop Management, Fertilizer, and Irrigation* scenarios varies widely across provinces. For example, the projected increases in taro yields in *Bua* and *Cakaudrove* provinces exceed those for all other provinces under all three scenarios. However, financial losses in taro production are projected to occur in *Naitasiri* province under the *Crop Management* and *Irrigation* scenarios. This is because taro yields in *Naitasiri* province under the business-as-usual scenario tend to be lower than in other provinces. Thus, the yield gains for taro from the *Crop Management* and *Irrigation* scenarios cause the supply of taro to increase to such a degree that the market price of taro falls, the financial loss per ton due to the price reduction overwhelming the financial gain from the increase in crop yield (Figure 3.9). For rice, the projected benefits arising under all three scenarios are greatest in *Bua* and *Macuata* provinces, Fiji's primary rice-producing regions, which are expected to remain so well into the future.

Fiji's cassava market is quite fragmented geographically, this giving rise to substantial price differences across regions. For example, prices range from $80 per ton in the Eastern Division to $240 per ton in the Western Division. Such wide differences in price cause the baseline price of cassava to vary widely, which means that the financial gains from cassava yield increases resulting from adoption of climate change adaptation technologies are considerably greater in the areas where the baseline prices are highest.

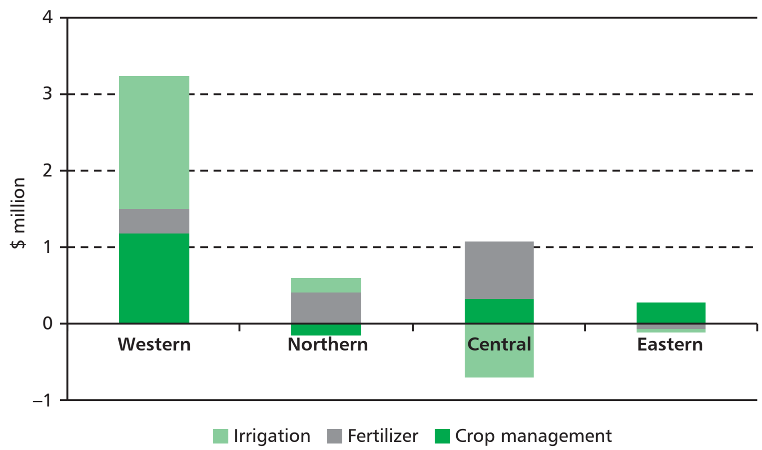
Thus, cumulative projected financial benefits to cassava production over the period 2008–2050 arising under the *Crop Management, Fertilizer,* and *Irrigation* scenarios vary widely across the country's four geographic divisions (Figure 3.10). The Western Division is projected to reap the greatest financial benefit because of the relatively higher initial price and level of output for cassava there. The projected financial benefits accruing to Central Division, which produces more cassava than any other division, are the second largest. That said, despite the increase in yields from adoption of climate change adaptation crop production technologies, the Central and Eastern divisions

Figure 3.9 Estimated Benefits Accruing from the Production of Taro in Fiji from Adoption of Alternative Climate Change Adaptation Technologies Over the Period 2008–2050 ($ million)



Source: IFPRI DREAM simulations.

Figure 3.10 Estimated Benefits Accruing to Producers of Cassava in Fiji from Adoption of Alternative Climate Change Adaptation Technologies Over the Period 2008–2050 ($ million)



Source: IFPRI DREAM simulations.

are projected to experience a slight loss in financial benefits under the three scenarios referred to above, the projected reduction in cassava prices due to yield increases causing a total revenue loss that exceeds the total projected financial gain from the projected increase in output from the adoption of climate change adaptation technology concerned.

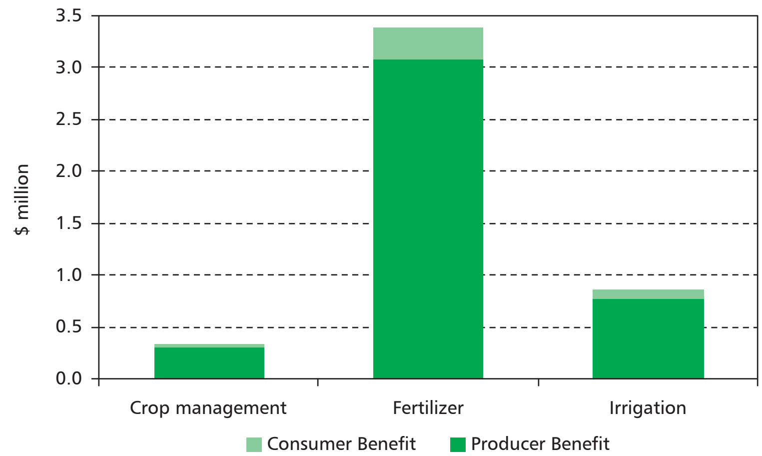
Papua New Guinea and Solomon Islands

The cumulative projected benefits over the period 2008–2050 from rice production in PNG under the *Fertilizer* scenario exceed those accruing under the baseline scenario by nearly $3.4 million (Figure 3.11). However, the corresponding levels of projected benefits under the *Crop Management* and *Irrigation* scenarios are only about $0.3 million and $0.8 million respectively. These lower levels of financial benefits from adoption of climate change adaptation technologies primarily arise because of PNG's relatively limited output of rice.

For sweet potato production, the greatest financial benefit likewise accrues under the *Fertilizer* scenario, the latter reaching nearly $1,400 million, as compared to only $100 million under the *Crop Management* scenario. Gains under the Irrigation scenario are projected to be minimal (Figure 3.12). The projected financial benefits accruing under the *Fertilizer* and *Crop Management* scenarios are projected to be equally shared between producers and consumers, the producers benefiting from a revenue gain due to increased output, and the consumers benefiting from a lower market price. In sum, adoption of the climate change adaptation crop production technologies under these three scenarios is projected to produce financial gains that more than offset the decrease in yields due to the negative impacts of climate change.

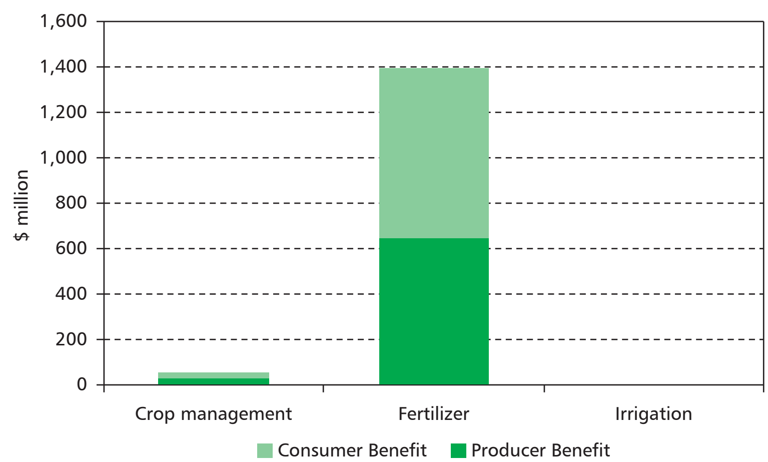
At the division level in PNG, the projected financial benefits from adoption of climate change adaptation technologies in sweet potato

Figure 3.11 Estimated Benefits Accruing to Producers and Consumers of Rice in Papua New Guinea from Adoption of Alternative Climate Change Adaptation Crop Production Technologies Over the Period 2008–2050 ($ million)



Source: IFPRI DREAM model simulations.

Figure 3.12 Estimated Benefits Accruing to Producers and Consumers of Sweet Potatoes in Papua New Guinea from Adoption of Alternative Climate Change Adaptation Technologies Over the Period 2008–2050 ($ million)



Source: IFPRI DREAM model simulations.

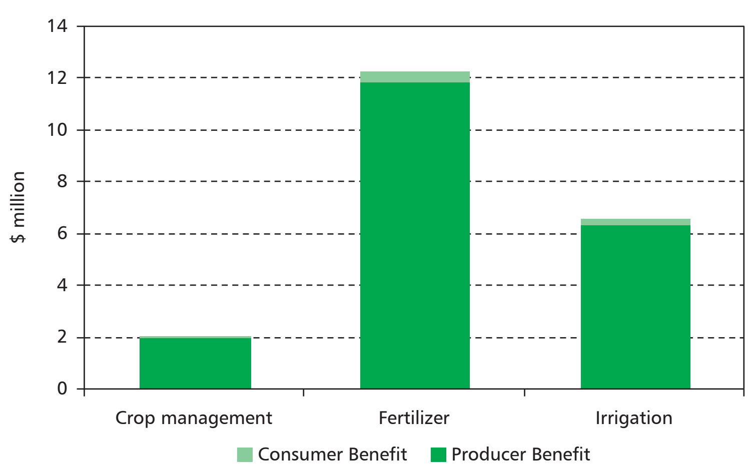
production are greatest for the Highlands at more than $600 million for both consumers and producers, due to that division's significant output of sweet potatoes. Under the *Fertilizer* scenario, the Islands region suffers losses from adoption of climate change adaptation technologies in sweet potato production, as do *Momase* and *Papua* under the *Crop Management* scenario.

This is mainly due to the lower levels of increase in the output of sweet potato resulting from adoption of adaptation technologies as compared to other regions, the Highlands region in particular. The projected increase in sweet potato output from adoption of climate change adaptation technologies in the Highlands region was so great that it substantially depressed sweet potato prices, thus negatively impacting producers in the Islands region, *Momase,* and *Papua*. Finally, since rainfed production of sweet potato is typical in PNG, the projected benefit accruing to sweet potato production under the *Irrigation* scenario is zero.

In Solomon Islands, the cumulative projected benefits for the period 2008–2050 accruing to rice production under the *Crop Management, Fertilizer,* and *Irrigation* scenarios are substantial at more than $12 million for the *Fertilizer* scenario, more than $6 million for the *Irrigation* scenario, and $2 million for the *Crop Management* scenario (Figure 3.13). For sweet potato production, the cumulative projected benefits under the *Fertilizer* scenario slightly exceed $160 million, whereas under the *Crop* Management scenario they amount to about $4 million, and under the *Irrigation* scenario, they are negligible (Figure 3.14).

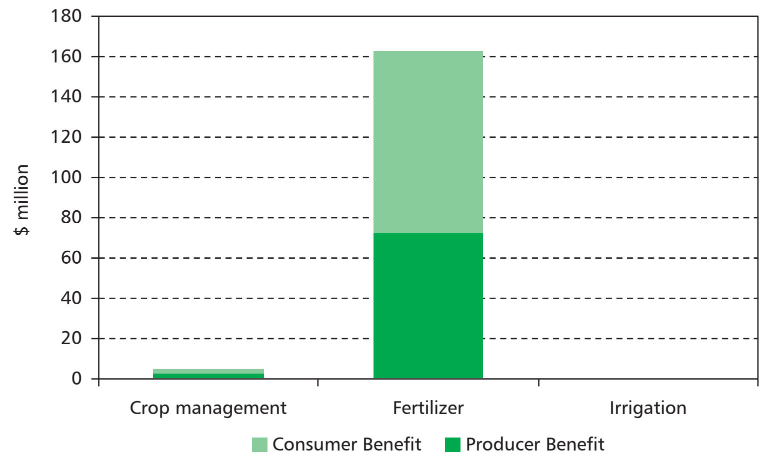
Rice is the only crop for which the benefits from adoption of climate change adaptation production technologies were analyzed for all three study countries (Figure 3.15). The projected benefits accruing to rice production from adoption of climate change adaptation production technologies under all three scenarios were highest in Fiji, these totaling more than $70 million under the *Fertilizer* scenario, $14 million under the *Irrigation* scenario, and $7 million under the *Crop Management* scenario; they were the smallest in PNG under all three scenarios.

Figure 3.13 Estimated Benefits Accruing to Producers and Consumers of Rice in Solomon Islands from Adoption of Alternative Climate Change Adaptation Technologies Over the Period 2008–2050
($ million)



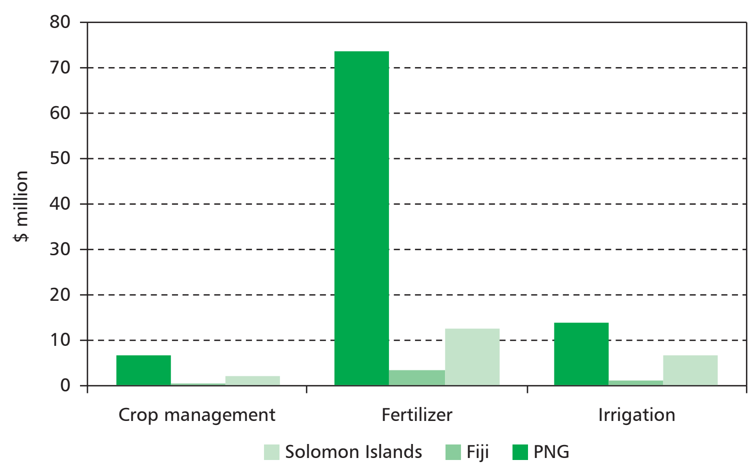
Source: IFPRI DREAM model simulations.

Figure 3.14 Estimated Benefits Accruing to Producers and Consumers of Sweet Potatoes in Solomon Islands from Adoption of Alternative Climate Change Adaptation Technologies Over the Period 2008–2050 ($ million)



Source: IFPRI DREAM model simulations.

Figure 3.15 Estimated Benefits Accruing to the Production of Rice in Fiji, Papua New Guinea, and Solomon Islands From Adoption of Alternative Climate Change Adaptation Technologies Over the Period 2008–2050 ($ million)



Source: IFPRI DREAM model simulations.

Benefits of Increased Investment in Agricultural Research and Extension

The results of the DREAM analysis presented above indicate that the estimated returns to increasing fertilizer use are significant for most crops other than sugarcane, the latter already benefiting from relatively high rates of fertilizer application. More specifically, increasing fertilizer application rates and employing improved fertilizer technology would likely boost yields of sweet potato in PNG and Solomon Islands and yields of taro in Fiji. Further, while expanding the use of irrigation in the cultivation of sugarcane would likely boost yields to a considerable extent, the benefits of doing so in the case of taro, cassava, and sweet potato would likely be limited or nonexistent.

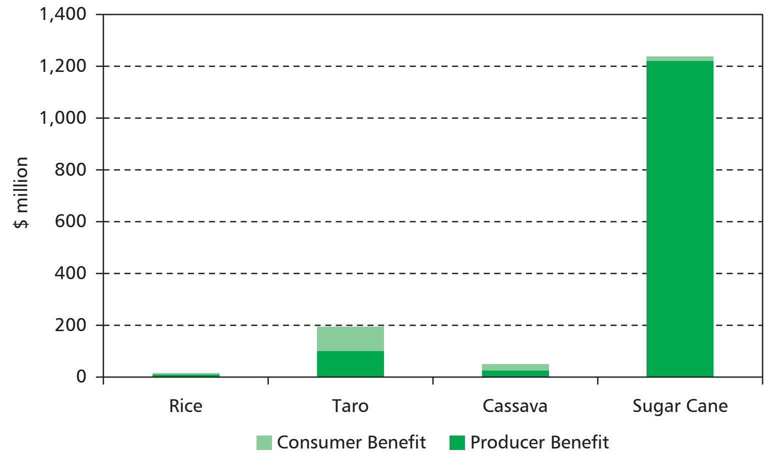
Conversely, in the case of several crops, the study results indicate that shifting to optimal cultivars and planting dates would result in yield increases that to a substantial degree counterbalance the yield-depressing effects of climate change to the year 2050. However, simply selecting optimal cultivars from those already in existence without making use of optimal planting dates is unlikely to boost yields sufficiently to accomplish this. Given the above, the fifth scenario, *Agricultural and Extension Investment,* assesses the financial benefits of a phased 50% increase in crop yields by the year 2050.

The results regarding the *Agricultural and Extension Investment* scenario for Fiji, PNG, and Solomon Islands are presented in Figures 3.16, 3.17, and 3.18 respectively. These figures graphically illustrate the significant benefits from increasing investment in agricultural research and extension likely to accrue to both the producers and consumers over the period 2008–2050. In Fiji, the benefits accruing to producers are estimated at $1,227 million for sugarcane growers. However, since sugar is an internationally traded good, expanding sugarcane output is likely to result in little gain for consumers, if any.

However, in the case of taro and cassava, the estimated financial benefits from increased investment in agricultural research and extension are significant. Further, these gains are shared approximately equally by producers and consumers. In the case of taro, the estimated gains are $97 million each for producers and consumers, and in the case of cassava, $25 million for producers and $27 million for consumers (Figure 3.16). Producers of these crops would benefit from increased yields and thence revenue, while consumers would gain from lower market prices, the distribution of the total gains for these crops depending on the relevant elasticities of supply and demand.

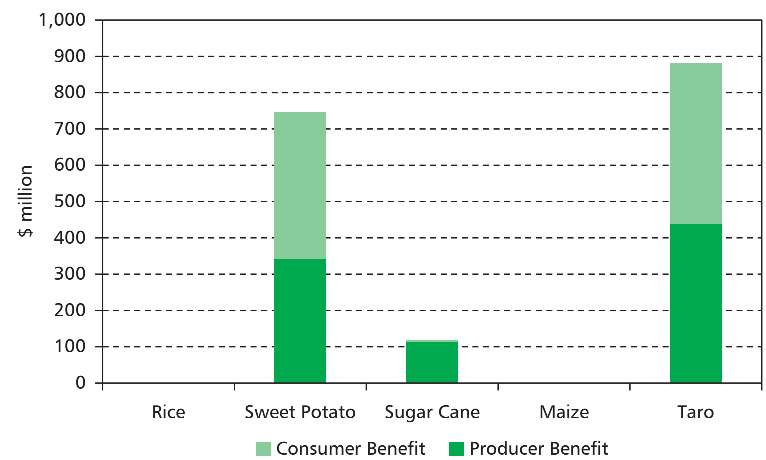
For PNG, producers and consumers of staple crops likewise benefit significantly from increased investment in agricultural research and extension. Total gains for producers and consumers of taro over the period 2008–2050 are $443 million and $440 million, respectively, the corresponding figures for sweet potato being $340 million and $405 million (Figure 3.17). In Solomon Islands, the corresponding figures for taro are $80 million for producers, and $79 million for consumers, while those for sweet potato are $55 million and $69 million respectively (Figure 3.18).

Figure 3.16 Estimated Cumulative Benefits Accruing to Producers and Consumers Resulting from Increased Investment in Agricultural Research and Extension for Cassava, Rice, Sugarcane, and Taro Grown in Fiji, 2008–2050 ($ million)



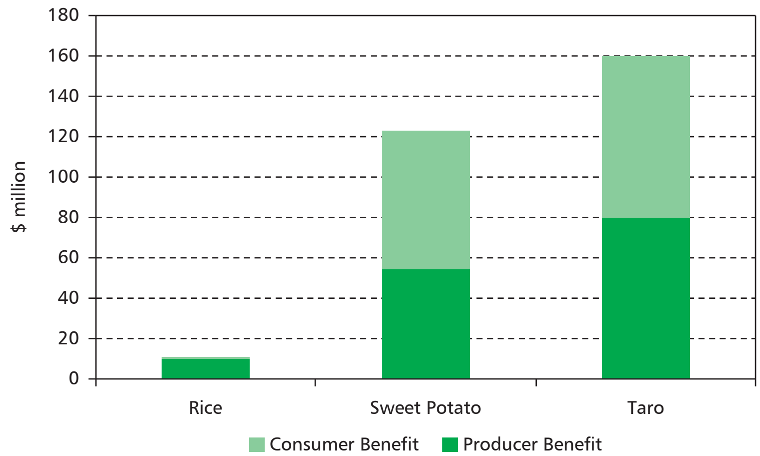
Source: IFPRI DREAM model simulations.

Figure 3.17 Estimated Cumulative Benefits Accruing to Producers and Consumers Resulting from Increased Investment in Agricultural Research and Extension for Maize, Rice, Sweet Potato, Sugarcane, and Taro Grown in Papua New Guinea, 2008–2050 ($ million)



Source: IFPRI DREAM model simulations.

Figure 3.18 Estimated Cumulative Benefits Accruing to Producers and Consumers Resulting from Increased Investment in Agricultural Research and Extension for Rice, Sweet Potato, and Taro Grown in Solomon Islands, 2008–2050 ($ million)



Source: IFPRI DREAM model simulations.

Impact of Climate Change on Fisheries

Aquaculture, coastal fisheries, and offshore fisheries comprise the three broad categories of fisheries in the Pacific, all three being essential to the conomic livelihood and food security of the populace in the three study countries. Unfortunately, adverse changes in water quality in the Pacific brought about by global warming and ocean acidification—themselves a consequence of increased atmospheric levels of CO_2 and other GHG emissions—are likely to negatively impact all three categories of fisheries in all three study countries. Thus, understanding the impact of climate change on coastal areas in the three study countries—and even on particular species of fish—is essential to devising ways in which these countries can adapt to climate change.

Building on an earlier assessment performed by the IPCC that was based on detailed projections of climate change, the Pacific Climate Change Science Program (PCCSP) evaluated 24 general circulation models (GCMs), 18 of which depict changes in the climate of the western tropical Pacific Islands. Based on this latter evaluation by the PCCSP, three emissions scenarios (B1 [low emissions], A1B [medium-level emissions], and A2 [high emissions]) were used to assess the impacts of climate change on fisheries in the three study countries (ABM and CSIRO 2011).

The PCCSP projections indicate that threats to the integrity of coastal areas and fisheries resources in the three study countries are already apparent, even in the absence of climate change. Population growth, urbanization, and industrial and economic development are exerting environmental pressure on both terrestrial and coastal areas, including mangrove ecosystems. The conversion of mangroves to industrial, tourism, or residential areas results in loss of breeding grounds for fish and other aquatic mammals, and loss of buffer protection against the sea during cyclones and tsunamis (Woodward et al.

2000). Other factors have likewise led to deterioration of coastal and aquatic ecosystems and resources in the three study countries, and have increased the vulnerability of these systems to sea-level rise and coastal erosion brought about by climate change. These factors include improper disposal of industrial, commercial, and household waste and discharges of other pollutants; inappropriate agricultural practices; soil erosion and siltation; extensive beach-sand mining; inappropriate development such as the construction of jetties; and use of destructive fishing practices.

Bell, Johnson, and Hobday (2011) and Bell et al. (2011) discuss the low-emissions (B1) and high-emissions (A2) scenarios, both of which project an increase in sea-surface temperatures of 0.6°C to 0.8°C by 2035 in all three study countries. Such an increase in sea-surface temperatures would negatively impact the productivity of phytoplankton, the primary source of food for fish, thus altering the marine food chain in the three study countries. In particular, a decline in nutrient supply is projected to occur under the B1 and A2 scenarios by 2035 due to increased stratification and a shallower mixed layer (Bell, Johnson, and Hobday 2011; Bell et al. 2011), such conditions having the potential to negatively impact production of phytoplankton. Spawning and recruitment of fish species incapable of tolerating higher water temperatures would also be affected.

Further, thermal expansion of the oceans due to rising ocean temperatures would trigger melting of glaciers and land ice, resulting in a projected sea-level rise of about 50 cm in all three study countries by the year 2100 under the A2 scenario (Bell, Johnson, and Hobday 2011; Bell et al. 2011). Similarly, increased acidification of seawater could hinder shell formation in marine organisms such as shrimp, oysters, and corals, as well as zooplankton—creatures that lie at the base of the food chain—thus further altering the marine food chain. Finally, an increase in the frequency and intensity of cyclones and other natural disasters would lead to increased damage to aquaculture infrastructure. Such an outcome would raise the probability of culture species escaping into the wild, loss of financial investments on a large scale, and permanent alteration of the marine ecosystem in all three study countries.

Overall, the potential effects of climate change on fisheries may be a reduction—or in some limited cases, an increase—in the abundance of certain species. These impacts could in turn lead to increased fluctuation in fish prices and thence incomes, changes in the level of fishing and postharvest employment, and social stresses associated with declining income and employment levels.

Coastal fisheries comprise four categories (Bell et al. 2011): (i) demersal fisheries, (ii) nearshore pelagic fisheries, (iii) fisheries that produce invertebrates for export (e.g., sea cucumber), and (iv) fisheries from which invertebrates from inter-tidal and subtidal areas are harvested. Of these four categories, demersal fish contribute 65% to Fiji's total coastal fish catch. However, the B1 and A2 scenarios project potential declines in Fiji's demersal fish catch of 13% and 23%, respectively, by the year 2100, the corresponding figures for PNG being 8% and 14%, and those for Solomon Islands being 10% and 17% respectively.

With regard to the output of tuna, Bell et al. (2011) evaluated the projected impact of climate change under the B1 and A2 scenarios in 2035 and 2100 for all three study countries. The catch of skipjack tuna is estimated to increase by 24% and 33% under the B1 and A2 scenarios, respectively, by the year 2100 in Fiji. However, for PNG and Solomon Islands, the projected catch of skipjack tuna is projected to decline by 2100 under the B1 and A2 scenarios by 11% and 30%, respectively, in PNG, the corresponding figures for Solomon Islands being 5% and 15%.

On a positive note, given that the rising sea-surface temperatures under the B1 (low) and A2 (high) emission scenarios occur as projected for 2035 and 2100, it would be possible to raise tilapia—the simplest species to grow in small ponds—at higher altitudes in inland PNG and other Pacific countries (Bell et al. 2009). However, this would require proper infrastructure, quality fingerlings, and suitably formulated feed based on local ingredients (Bell, Johnson, and Hobday 2011). In this regard, heavy rains might be favorable to the expansion of aquaculture, as they could increase the area suitable for rainfed inland aquaculture. However, cyclones and other natural disasters could potentially damage aquaculture infrastructure.

Table 3.28 summarizes some reported indications of the impacts of climate change in the three study countries, while Table 3.29 presents some potential impacts of climate change on the fisheries sector, particularly in Solomon Islands.

Finally, despite the possible limited benefits to fisheries output in the three study countries referred to above, threats to the productivity of coastal areas and fisheries in the Pacific are already apparent, even in the absence of climate change. A host of factors related to economic development overall have led to deterioration of coastal and aquatic ecosystems and resources, and to vulnerability to the impacts of climate change-driven sea-level rise and coastal erosion. The most important of these include improper industrial, commercial, and household waste disposal and pollution discharges, inappropriate agricultural practices, soil erosion and siltation, extensive beach sand mining, unsuitable physical development such as construction of jetties, and use of destructive fishing practices.

Further, population growth, urbanization, and industrial and economic development all exert environmental pressure on coastal areas, the latter including mangrove ecosystems. Conversion of mangroves to industrial, tourism, or residential uses results in the loss of breeding grounds of fish and other aquatic mammals, and loss in buffer protection against the sea during cyclones and tsunamis (Woodward et al. 2000).

Food Security Impacts of Climate Change

In addition to the negative impact of climate change on crop yields and agricultural output discussed earlier, food security in the three study countries will be indirectly impacted by climate change-driven reductions in agricultural output in other countries, as these will, in turn, impact the international price of the commodities the three study countries import.

IMPACT simulations project a significant increase in international food prices—even in the absence of climate change—as a result of population and income growth, increasing scarcity of water and arable land, and slowing growth in agricultural productivity (Appendix 1). Particularly important for the three study countries are the international prices of rice and wheat,

Table 3.28 Reported Indications and Consequences of Climate Change in Fiji, Papua New Guinea, and Solomon Islands

Climate Feature/Threat	Fiji	PNG	Solomon Islands
Increase in sea surface temperature[a]	An estimated 0.07°C increase in water temperature from 1970 to the present. Coral bleaching observed during the 1997–1998 El Nino and in April 2000. Value of loss of fisheries, their habitat, and tourism may reach $14 million a year by 2050.	Steady increase in water temperatures since the 1950s, with 0.11°C warming per decade from the 1970s.	Steady increase in water temperatures since the 1950s, with 0.12°C warming per decade from the 1970s.
Ocean acidification[b]	Slow rise in carbon dioxide (CO_2) concentration since the 18th century. Projected increase of seawater aragonite ($CaCO_3$) saturation by year 2035, leading to marginal conditions for coral growth.	Aragonite concentration has declined from 4.5 in the late 18th century to about 3.9±0.1 as of 2000. Values below 3.5 maximum aragonite concentration projected by year 2040.	Aragonite concentration has declined from 4.5 in the late 18th century to about 3.9±0.1 as of 2000. Maximum annual saturation value projected to be below 3.5 by year 2045 with subsequent reductions thereafter.
Sea-level rise[b]	A rise of about 6 mm/year since 1993, which is higher than the global average of 3.2±0.4 mm/year. Projections of 3–6 cm increase in sea-level rise under high-emissions scenario in 2030, which may intensify the impact of storm surge and coastal flooding.	Estimated at about 7 mm/year since 1993, higher than the global average of 3.2±0.4 mm/year. La Nina years triggered significantly higher seasonal water levels, and El Nino years led to lower water levels. Projections of 4–15 cm sea-level rise based on a high-emissions scenario in 2030.	High tides observed to be largest near the equinoxes, April–May and November–December. ENSO influences through a sea-level rise of about 0.1 m during La Nina season and a decrease of the same level during El Nino season. Estimated at more than 8 mm/year since 1993, higher than the global average of 3.2±0.4 mm/year. Projections of sea-level rise of about 4–15 cm in 2030 based on high-emissions scenario.

Sources:

[a] Fiji Islands: Australian Bureau of Meteorology (ABM) and Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2011. *Climate Change in the Pacific: Scientific Assessment and New Research*. Volume 2: Country Reports. Aspendale, Victoria, Australia. http://www.cawcr.gov.au/projects/PCCSP/Nov/Vol2_Ch5_Fiji.pdf ; World Bank (WB) 2000. Cities, Seas and Storms. Managing Change in Pacific Island Economies. Volume IV. Adapting to Climate Change. Washington, DC: The World Bank. http://siteresources.worldbank.org/INTPACIFICISLANDS/Resources/4-TOC.pdf . PNG: ABM and CSIRO 2011. *Climate Change in the Pacific: Scientific Assessment and New Research*. Volume 2: Country Reports. Aspendale, Victoria, Australia. http://www.cawcr.gov.au/projects/PCCSP/Nov/Vol2_Ch11_PNG.pdf. Solomon Islands: ABM and CSIRO 2011. *Climate Change in the Pacific: Scientific Assessment and New Research*. Volume 2: Country Reports. Aspendale, Victoria, Australia. http://www.cawcr.gov.au/projects/PCCSP/Nov/Vol2_Ch13_Solomonislands.pdf

[b] Fiji Islands: ABM and CSIRO. 2011. *Climate Change in the Pacific: Scientific Assessment and New Research*. Volume 2: Country Reports. Aspendale, Victoria, Australia. http://www.cawcr.gov.au/projects/PCCSP/Nov/Vol2_Ch5_Fiji.pdf. PNG: ABM and CSIRO 2011. *Climate Change in the Pacific: Scientific Assessment and New Research*. Volume 2: Country Reports. Aspendale, Victoria, Australia. http://www.cawcr.gov.au/projects/PCCSP/Nov/Vol2_Ch11_PNG.pdf. Solomon Islands: ABM and CSIRO 2011. *Climate Change in the Pacific: Scientific Assessment and New Research*. Volume 2: Country Reports. Aspendale, Victoria, Australia. http://www.cawcr.gov.au/projects/PCCSP/Nov/Vol2_Ch13_Solomonislands.pdf

since all three countries import substantial amounts of these commodities each year.

One of the many benefits of the IMPACT model is that it is able to assess the impact on food security in the home country of the combined effects of global price fluctuations and country-specific changes in agricultural output, and to explore the potential benefits of climate change adaptation policies

Table 3.29 Potential Impacts of Climate Change on the Fisheries Sector in the Pacific

Variable	Potential Impacts
Physical	
Water temperature and heat content	Warming intermediate in strength between coastal Southeast Asia and central Pacific
Salinity and stratification	Possibility of increase in salinity concentration and stratification
Ocean circulation and upwelling	Potential changes possible in south equatorial current and south subtropical current
Acidification and chemical changes	Ocean-wide, with potential effects on coral reef formation
Sea and lake levels	Less impact than in more northerly regions of the world
Sediment levels	Possible increase, with deforestation affecting atoll lagoon fisheries, but probably limited change given low levels of riverine outflows
Extreme weather events	Exposure to extreme events; impact varies by country (in Pacific, Caribbean, Bay of Bengal)
Low frequency variability	Changes to Western Pacific Warm Pool during El Niño periods. Not clear whether or not global warming will result in stronger and more frequent ENSO
Biological (Fisheries and Related Ecosystems)	
Physiological spawning and recruitment	Possible effect on balance of species not tolerant to higher temperatures
Primary production	Likely to decrease
Secondary production	Likely to decrease, but local/regional models not available
Distribution of fish	Shift in distribution of skipjack may favor Micronesia over Melanesia. Temperature changes may impact depth at which tuna and tuna-like species are found.
Abundance of fish	Possible changes in species mix of both commercial and non-commercial species (the latter important for tourism). But impacts not clear.
Phenology	Changes in timing of spawning, migration seem likely, but specific details unknown
Species invasion and disease	Little information available for aquaculture; impacts unlikely to be significant
Food web impacts	Potential simplification and changes to food webs as species mix changes, implying greater volatility of output of fisheries

Sources: Daw, T., Adger, W.N.; Brown, K.; Badjeck, M.C. 2009. Climate change and capture fisheries: potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. pp. 107–150

relating to the home country's agriculture sector. IMPACT simulations were used to perform such assessments under the present study through the use of three scenarios.

The *Baseline* scenario assumes no change in current trends in agricultural output, or in the home-country policy trajectory relating to the agriculture sector. This scenario uses the "medium" population growth projections published by the Population Statistics Division of the United Nations, along with income projections performed by the authors, the latter drawing on data from the Millennium Ecosystem Assessment (2005) with appropriate updates to account for recent GDP growth. The *Baseline* scenario assumes absence of any climate change-driven impacts on agricultural output through the year 2050.

The C*limate Change* scenario incorporates the impacts of climate change on agricultural output by applying the mean values of climate-related variables as projected by the four GCMs, the overall effect of which is to drive the international price of food commodities higher. Conversely, the *Adaptation* scenario explores the likely impact of climate change adaptation policies in the agriculture sector for counterbalancing the negative impacts of climate change on agricultural output that are simulated under the *Climate Change* scenario.

The *Baseline* scenario—which projects changes in international food prices *in the absence of climate change*—indicates an increase of 34% in the real price of rice over the period 2010–2050, the corresponding figure for wheat being 31%. However, climate change is projected to boost rice and wheat prices by an *additional* 20% and 23%, respectively, by 2050 (Nelson et al. 2010).

The *Adaptation* scenario assesses the impact of investments for reducing child malnutrition both in the absence and presence of climate change, these investments comprising both those that increase agricultural output, as well as nonagricultural investments that positively impact child malnutrition through maternal education and increased access to clean water. Since the maximum realistic increases in agricultural output resulting from investments in the agriculture sector were alone insufficient to meet the child malnutrition target set by the authors, the analysis assessed the impact of both types of investments taken together.

The approach used under the analysis was to assess the levels of both types of investments that would be necessary for reducing child malnutrition rates to those that occur under the *Baseline* scenario. The estimated rate of increase in the output of each crop analyzed assumes implementation of the *Crop Management* scenario described earlier, one-half of the increase in optimal fertilizer application rates assumed under the *Fertilizer* scenario, as well as the optimal increases in investment under the *Agricultural Research and Extension* scenario described above. Table 3.30 summarizes the targets set for this latter analysis relating to food security.

Table 3.30 Targets for Agriculture- and Non-Agriculture-Sector Investments under the Analysis

Targets Set for Investments in the Agriculture Sector
0.50 percentage-point increase in annual growth rate of crop yield relative to corresponding baseline rate
0.25 percentage-point increase in annual growth rate of output of meat and fish over corresponding baseline rate
0.50 percentage-point increase in annual growth rate fertilizer use
Targets Set for Nonagricultural Investments
30% increase in growth of female secondary-school enrollment rates
30% increase in the growth rate of access to clean water

Source: Authors.

The analysis used three measures of food security: (i) average calorie consumption, (ii) number of persons at risk of hunger, and (iii) number of malnourished children. Calorie consumption was estimated directly by IMPACT. The methodologies used for estimating the number of persons at risk of hunger and the number of malnourished children are summarized in Appendix 1. For Fiji, it was only possible to analyze average calorie consumption, since data for persons at risk of hunger and malnourished children were unavailable. Data available for both variables from the World Health Organisation (WHO) and the Food and Agriculture Organisation of the United Nations (FAO) indicate that both the percentage share of the total population of Fiji at risk of hunger and the percentage share of malnourished children in the total population under 5 years of age are likely below 4%.

Results from the *Baseline* scenario indicate that calorie consumption over the period 2000–2050 will increase by 26% in Solomon Islands, the corresponding figures for Fiji and PNG both being 20% (Table 3.31). However, under the *Climate Change* A1B scenario, calorie availability declines by 17% in PNG, 13% in Solomon Islands, and 7% in Fiji relative to the respective baseline values for 2050. Under the *Adaptation* scenario, daily per-capita calorie consumption is restored to levels slightly greater than the relevant year-2050 levels under the *Baseline* scenario, these *Adaptation*-scenario levels being 3,506 kCal for Fiji, 3,074 kCal for PNG, and 3,009 kCal for Solomon Islands in 2050 (Table 3.31).

Table 3.31 Daily Per-Capita Calorie Availability in Fiji, Papua New Guinea, and Solomon Islands under Alternative Climate Change Scenarios
(kCal)

		2050		
Country	2000	Baseline, No Climate Change	Climate Change, A1B Scenario	Climate Change with Agricultural Adaptation
Fiji	2,854	3,437	3,205	3,506
Papua New Guinea	2,498	3,012	2,504	3,074
Solomon Islands	2,343	2,943	2,558	3,009

Source: IMPACT model results compiled by authors.

In short, the results of the analysis are as follows. For both PNG and Solomon Islands (Figure 3.32), population growth is so rapid that the number of people at risk of hunger increases, even under the baseline scenario (Table 3.33). Climate change worsens this outcome, the number of people at risk of hunger in PNG rising by 21% in 2050 relative to the corresponding level under the *Baseline* scenario. For Solomon Islands, the number of people at risk of hunger increases by 45% under the *Climate Change* scenario. However, under the *Adaptation* scenario, the number of people at risk of hunger in the year 2050 declines by 5% in both PNG and Solomon Islands relative to the corresponding year-2050 baseline levels (Table 3.33).

Under the *Baseline* scenario, the number of malnourished children under 5 years of age falls by 21% in PNG and 33% in Solomon Islands. Climate change erases this progress, raising both the percentage share and total number of malnourished children even higher than in the year 2000 (Tables 3.34–3.35).

Aggressive agricultural productivity investments under the *Adaptation* scenario raise calorie consumption significantly, and erase about three-fourths of the increase in childhood malnutrition due to climate change. Non-agricultural investments in improving access to clean water and maternal education reduce child malnutrition further, but do not contribute directly to

Table 3.32 Percentage Share of Total Population at Risk of Hunger in Fiji, Papua New Guinea, and Solomon Islands Under Alternative Climate Change Scenarios

Country	2000	2050		
		Baseline, No Climate Change	Climate Change, A1B Scenario	Climate Change with Agricultural Adaptation
Fiji	na	na	na	na
Papua New Guinea	21.5	15.4	19.1	15.0
Solomon Islands	12.0	9.7	14.0	9.3

na = no data available.
Source: IMPACT model results compiled by authors.

Table 3.33 Total Number of Persons at Risk of Hunger in Fiji, Papua New Guinea, and Solomon Islands Under Alternative Climate Change Scenarios ('000s)

Country	2000	2050		
		Baseline, No Climate Change	Climate Change, A1B Scenario	Climate Change with Agricultural Adaptation
Fiji	na	na	na	na
Papua New Guinea	1,275	2,156	2,616	2,054
Solomon Islands	45	114	165	109

na = no data available.
Source: IMPACT model results compiled by authors.

Table 3.34 Percentage Share of Malnourished Children in the Total Population Under 5 Years of Age in Fiji, Papua New Guinea, and Solomon Islands Under Alternative Climate Change Scenarios

Country	2000	2050		
		Baseline, No Climate Change	Climate Change, A1B Scenario	Climate Change with Agricultural Adaptation
Fiji	na	na	na	na
Papua New Guinea	18.1	11.4	17.9	11.2
Solomon Islands	12.0	7.9	13.3	7.9

na = no data available.
Source: IMPACT model results compiled by authors.

Table 3.35 Total Number of Malnourished Children Under 5 Years of Age in Fiji, Papua New Guinea, and Solomon Islands Under Alternative Climate Change Scenarios ('000s)

		2050		
Country	2000	Baseline, No Climate Change	Climate Change, A1B Scenario	Climate Change with Agricultural Adaptation
Fiji	na	na	na	na
Papua New Guinea	172	138	217	136
Solomon Islands	9	6	10	6

na = no data available.
Source: IMPACT model results compiled by authors.

calorie availability. An additional benefit from the climate change adaptation scenario is the substantial increase in the consumption of taro, sweet potato, and cassava relative to the amounts of imported rice and wheat consumed. The increases in the output of these staple crops under the *Adaptation* scenario reduce domestic prices of these commodities, thus increasing the amounts consumed, while the import prices of rice and wheat remain high due to the impacts of climate change on the production of rice and wheat in countries exporting these commodities. It thus appears that adaptation to climate change can improve dietary diversity in all three study countries.

IV. Agriculture and Fisheries Policies for Development and Adaptation to Climate Change

This chapter (i) outlines direct policies for influencing agricultural output in the face of climate change such as policies relating to crop management, fertilizer, irrigation, and agricultural research and extension services, and (ii) policies for facilitating successful implementation of climate change adaptation practices such as land tenure policy, governance of fisheries, and investment in infrastructure. The current status of the policy regime in Fiji, Papua New Guinea (PNG), and Solomon Islands together with the challenges faced by each country are first discussed. Following this, specific policy recommendations are made for climate change adaptation in the agriculture and fisheries sectors in all three countries.

With regard to the agriculture sector, the key policy issues relate to land tenure, productivity of the sector overall, and agricultural research, training, and extension. In the fisheries sector, the key policy issues relate to coastal subsistence fisheries, commercial tuna fisheries (caught offshore by commercial fishing vessels), and aquaculture (commercial). The policy issues, challenges, status of the current policy regime, and policy recommendations relating to the agriculture sector are first discussed, after which those relating to the fisheries sector are addressed.

Land Tenure

Land-use rights and ownership are complex and politically sensitive issues in Pacific island countries. Customary land ownership—the dominant form of land tenure in Fiji, PNG, and Solomon Islands—has its foundation in longstanding cultural traditions. However, this system of land tenure discourages adoption of agricultural practices that would increase the sector's level of output and efficiency. Thus, a more flexible land tenure system is essential to achieving these objectives in all three study countries, as well as being essential to improving their respective abilities to respond to climate change.

Effective land-use rights provide benefits that range from stimulating long-term investment and increasing agricultural productivity, to incentivizing sustainable land use and facilitating adaptation to climate change. Tenure insecurity undermines incentives for longer-term investments in land, thus discouraging farm-level climate change adaptation (Rashid 2010). Securing land-use rights is therefore a fundamental strategy in addressing climate change concerns (Deininger 2004). In Fiji, PNG, and Solomon Islands, land-use rights are thus a critical factor in promoting the climate change adaptation policies for the agriculture sector recommended in this report. This is because secure land-use rights provide incentives for increasing current rates of fertilizer use, adopting improved cultivars, and crop management systems that result in productivity growth. In recent years, all three countries have taken initial steps toward land policies that enable improved farm-level decision-making as it relates to climate change adaptation. This section discusses the current status of land ownership and related policies, the reform steps being initiated, and the policies recommended for long-term adaptation to climate change in the agriculture sector.

Land Tenure in Fiji

Current Status of Customary Land and Ownership

The land problem in Fiji is complex in nature primarily because unlike in many other countries beyond the South Pacific region, most of it is under communal ownership. Of the total land area, 7.5% is held by the government; 10% is freehold[18] and the Fijian landowning units (native land) hold 82.5% (Naidu and Reddy 2002). Since the small portion of state and freehold land was not sufficient for the demands for agricultural leaseholds, native land, which is inalienable, was opened up for agricultural expansion. This land was leased out to tenants under the provision of the 1880 Native Land Ordinance, then through the Native Land Trust Board and the Native Land Trust Act of 1940, and later under the Agricultural Land Ordinance of 1966 and the Agricultural Landlord and Tenant Act (ALTA) of 1976 (Naidu and Reddy 2002).

Challenges Confronting Land Tenure Reform

In recent years, the economic performance of rural enterprises in Fiji has suffered from declining prices of key commodities and disruption in land tenure arrangements, those relating to sugarcane growers in particular (Hone et al. 2008). Specifically, the reluctance of some traditional landowners to renew leases for sugarcane growers has been a significant factor in the decline of sugarcane output, this in turn contributing to agriculture's declining percentage share in GDP. These issues arose in 1997 when the first leases expired (Anderson and Jenshagen 2010). The fact that these issues were unresolved increased uncertainty on the part of farmers, causing them to reduce investment in new sugarcane plantings, and in some cases to exit the industry (Fiji Department of Agriculture 2011). Ultimately, most of these leases expiring after 1997 were not renewed. This caused these otherwise productive lands to remain idle to such an extent that many tracts of such land have reverted to the status of bushland (Narayan 2004).

Evolution of Land Policy and Reforms

Native Land Trust Board, 1940

Established in 1940, the Native Land Trust Board (NLTB) is a statutory body that retains complete control over all *iTaukei-* owned land. The stated purpose of the NLTB was to manage *iTaukei*-owned lands for

18 Freehold can be owned by individuals regardless of race in comparison to native land owned by indigenous Fijians and state land owned by the state of Fiji (Naidu and Reddy 2002)

the benefit of their *iTaukei* owners. This included the leasing of land to non-*iTaukei* citizens of Fiji. However, tensions arose due to arrears in rental payments and the distribution of these payments, since the *iTaukei* owners do not receive the full amount of such payments. Instead, statutory arrangements require that the NLTB receive 15% of all rental payments, and that further percentage shares accrue to chiefs of various levels. As a result, the *iTaukei* owners receive only about 50% of the total value of rental payments (Naidu and Reddy 2002).

Agricultural Landlords and Tenants Act, 1976

The Agricultural Landlords and Tenants Act of 1976 (ALTA) provides for 30-year leases with no automatic right of renewal. However, these leases permit issuance of legal titles that can be traded and used as collateral for loans from lending institutions, including banks (Prasad 2006). ALTA increased the level of stability in the agriculture sector, particularly among sugarcane growers. However, concerns regarding the collection and distribution of land rental payments and rental arrears caused tensions to arise in the implementation of ALTA (Naidu and Reddy 2002).

Creation of Lank Banks, 2010

In 2010, land banks were created to facilitate leasing of *Itaukei*-owned lands, while at the same time protecting communal land ownership. Under the land-bank system, these lands are "deposited" at the bank and leased to commercial farmers and developers. This system has the advantage of making the land banks a clearing house for available tracts of land and prospective tenants. Thus, the land banks in effect lease tracts of land from *iTaukei* owners, and then sublease these to farmers, investors, and even the government when it requires additional tracts of land for its operations. Land banks also identify idle and underutilized lands, and then encourage the owners to deposit these tracts of land with the land bank in question to allow such tracts to be used for productive purposes. Creation of the land banks anticipated approval of the Land Use Decree of 2010 that allows the government to sublease land (Government of Fiji Land Use Decree 36 2010). This decree created a Land Use Unit being administered by the Ministry of Lands and Mineral Resources. The latter body will in turn establish and operate a land bank that will accept "deposits" of land from either *iTaukei* or government landowners (Ministry of Lands and Mineral Resources, Government of Fiji 2011).

Since land banks essentially administer *iTaukei* -owned land, they are an alternative to the NLTB. However, any land deposited at land banks must be unencumbered and free of any dispute in any court, tribunal, or commission, or other entity that exercises judicial functions. Such a requirement rules out all *iTaukei* -owned lands currently under NLTB leasing arrangements. However, upon expiration of any current NLTB-administered land lease, *iTtaukei* landowners are free to deposit their lands at a land bank. Those that do are promised rental payments of 10% of the unimproved capital value of the parcel in question, as opposed to the 6% the NLTB charges tenants. Further, the land banks promise both timely distribution of land rental payments, and the full amount of the rental payment as opposed to the 50% they would receive under the NLTB's distribution formula (Ministry of Lands and Mineral Resources, Government of Fiji 2010).

The duration of all land-bank-issued leases is 99 years (Ministry of Lands and Mineral Resources, Government of Fiji 2011). While the administrative details of the Land Use Decree of 2010 are still being finalized, concerns have already been raised regarding it. First, any land lease created under the decree will be immediately terminated if any party to it challenges either the decree itself or any of its associated processes in a court of law. Second, the issue of how grievances relating to land leases created under the decree are to be addressed has yet to be resolved. In this regard, Prasad (2006) argues for a permanent solution with a positive impact on investment and thence, agricultural productivity and economic growth. Specifically, he proposes that the government lease all agricultural lands from the NLTB, and then sublease them to tenants. In his view, this would satisfy both the tenants' need for secure land tenure, and the desire of the Great Council of Chiefs and the NLTB to have all land leased under the latter body.

Land Tenure in Papua New Guinea

The majority of land in PNG is under customary ownership, this arrangement involving a complex land tenure system. The impacts of this system are widespread, since an estimated 85% of lands are under customary ownership for food, water, and shelter (National Land Development Taskforce NGO response 2008, cited by Tararia and Ogle 2009). The legislation regarding the registration and titling of customary lands is expansive, and the processes relating to their administration are cumbersome (MAL 2007b). The percentage share of lands under leasehold or freehold arrangements in the country's total land area was estimated to be approximately 3% in 2006 (MAL 2007b). Such lands include townships and urban centers, plantations, roads, government and mission stations, land under special mining leases and agricultural leases, and airstrips. Customary land ownership is a tradition so highly valued both by the populace in general and the government that the Land Act of 1996 (Part XX Sec 132) specifically prohibits sale of such lands (MAL 2007b). However, use rights can be obtained from traditional landowners, often without the issuance of formal land titles (MAL 2007b).

Land Policy Challenges in PNG

PNG's complicated land tenure system has contributed to the slow pace of agricultural development. The majority of land is under customary ownership, and the administrative system is inefficient and ineffective. As most customary lands are unregistered (and often under disputed ownership), farmers can't use the land as collateral to obtain loans to invest in their farms. The government recognizes that weak administration and ineffective legal frameworks prevent the productive use of customary and alienated lands (DNPM 2010), so improving the system, particularly with regard to agriculture-led economic development, has become an important focus of the government.

According to government policy, all freehold land must be made leasehold prior to any transfer of ownership (MAL 2007b). This was supported by the Land Tenure Conversion Act of 1963, which explains the process of permanently ending customary land tenure and issuing a freehold title (Yala 2010). Disagreements relating to customary land ownership impede any lending arrangements for agricultural development since land under such disagreements cannot be used as collateral (MAL 2007b). The PNG government endeavored to register customary lands, but widespread opposition prevented this (MAL 2007b). Moreover, general disregard for the land registration system, diminishing confidence in the courts, lack of funding, inconsistent government support, and questions over the system's capacity to process high-volume registrations caused the system to become inactive (MAL 2007b).

Land Policy and Reform

Land Groups Incorporation Act, 1974

The corporate bodies formed by PNG landowners under the Land Groups Incorporation Act 1974 would have allowed these landowners to manage their own customary lands, had associated legislation relating to land registration been enacted concurrently. Further, these corporate bodies were used to acquire the consent of the landowner in question to exploit the resources such lands contain (e.g., through industrial logging), and to establish a system for distributing the proceeds of forestry and oil and mining projects that disproportionately favors project proponents (Filer 2007). Tararia and Ogle (2009) described how the Land Groups Incorporation Act 1974 included a lenient incorporation process poorly administered by the Department of Lands and Physical Planning, in part due to minimal staffing.

Land Act, 1996

The Land Act of 1996 introduced a lease-leaseback system for facilitating agricultural development of lands under customary ownership, as recommended by the World Bank and Australian Aid-funded Land Evaluation and Demarcation Project (MAL 2007b; Manning 2008; Fider 2011). This system allowed coffee and cocoa farmers to secure a loan using a 20-hectare block of land under customary ownership as collateral (MAL 2007b). Over time, the lease-leaseback scheme came to accommodate parcels of land of any size leased for a fixed period, following which the parcel in question would be returned to its original owners (MAL 2007b). Once leased under these arrangements, the parcel of land in question is designated as alienated land under state lease (MAL 2007b).

Given the need for the PNG government to safeguard the interests of landowners while at the same time tapping the potential of land for economic development, legislation permitted voluntary registration of customary land. Certificates of title were issued to incorporated land groups to facilitate negotiations (MAL 2009b), but such certificates could not be used as collateral for loans (MAL 2007b). The Land Act of 1996 enables the state to acquire customary land for the purpose of granting special agricultural and business leases, such leases serving as proof that the customary rights to such lands have been suspended for period of the lease.

Land Reform Under the National Land Development Program, 2007

A National Land Summit was convened in 2005 for the purpose of formulating recommendations relating to the administration and management of land reform (Manning 2008). The outcome of this meeting was 67 specific recommendations synthesized by a small working group related to two aspects of land reform: (i) administration of alienated land, including dispute resolution and provision of compensation, and (ii) administration of customary lands, including issues relating to their registration, the role of incorporated land groups, and use of land as loan collateral (Manning 2008). All of these recommendations were implemented, including establishment of the National Land Development Taskforce (Manning 2008).

Thereafter, a series of consultations with key stakeholders led to the submission and acceptance of a further 18 recommendations, including proposed reform of the Land Groups Incorporation Act 1974 to ensure that incorporated land groups operated in a manner that would develop customary land (Manning 2008). In 2006, all the endorsements of the task force were implemented, including the creation of a National Land Development Program for improving the system of land administration and dispute settlement, developing a framework for customary land tenure reform, and building the necessary institutions to support the implementation of a viable land and properties market, while at the same time improving the security of land tenure (Mal 2009b). A draft National Land Research Framework was also developed under the National Land Development Program focusing on (i) protecting customary land tenure; (ii) advocating radical changes to customary land tenure, in particular, changing to individual land titles; and (iii) reconciling customary land ownership with agricultural development in a manner that ensured security of tenure (Yala and Lyons 2010).

In 2009, the National Parliament passed the Land Groups Incorporation (Amendment) Act 2007 (Kimas 2010), the purpose of this legislation being to impose more rigorous requirements on incorporated land group memberships. For example, following passage of the Act, members could only belong to one incorporated land group, land boundaries had to be clearly defined, and any disputes relating to land ownership were required to be declared (Tararia and Ogle 2009). The Land Registration (Customary Land) (Amendment) Act of 2007, which was also passed in 2009, encourages voluntary registration of customary lands for the purpose of facilitating their development. However, the lands registered comprise only those parcels suitable for development, rather than the entire landholding in question (Tararia and Ogle 2009). In short, following passage of the above acts, landowners have only two options for developing their lands: registration under the Land Tenure Conversion Act of 1963 which results in permanent alienation, or the lease-leaseback arrangements referred to earlier (Tararia and Ogle 2009).

Land Tenure in the Solomon Islands

Current Status of Customary Land and Ownership

As with Fiji and PNG, the majority of the total land area of Solomon Islands—87% as of 2000—is under customary ownership (UN 2002). The country's limited amount of land available for nonfarm use makes land an important issue, both in general, and even more so at the village level, particularly with regard to any transformation of, or changes to land that alienate, degrade, or redistribute land in a way that influences the livelihoods, identity, or culture of Solomon Islanders (Solomon Islands Government Ministry of Development Planning and Aid Coordination [SIG MDPAC] 2007). As a result, changes to customary land tenure arrangements lead to community tensions. Similarly, land is often the major issue in disagreements that negatively impact agricultural production and infrastructure development within and among villages (CBSI 2006; SIG MDPAC 2007). As previously discussed, tensions stemming from changes in customary land tenure arose in the late-1990s to early 2000s (SIG MDPAC 2007). CBSI (2006) reported that land has been the main cause of disagreements affecting agricultural production and infrastructure development within and among villages.

Key Challenges to Land Policy

In Solomon Islands, disagreements over ownership of customary lands can seriously impede access to land and its commercial use, thus constituting an important major barrier to economic development (ADB and Australian Aid 2010). This can be further exacerbated when nonmembers of the community treat the land as a reserve of natural resources (SIG MDPAC 2007). Since Solomon Islands has no well-defined property rights or law relating to tenure rights for lands under customary ownership, land leases tend to be poorly enforced (SIG MDPAC 2007; ADB 2008). This is particularly true when outsiders treat land as a reserve of natural resources (SIG MDPAC 2007). The most important issues in this regard are as follows (SIG MDPAC 2007):

- *Community representatives*. Rivalry exists as to who will represent communities and negotiate on their behalf for the resources to be used for development. The risk of elite-capture is also high. For example, in the negotiation over the Isabel Nickel Mine (St. Jorge), female representatives in a matrilineal land system were not present. Instead, community trustees employed by the mining company were made available as negotiators.
- *Capacity of local courts and customary land appeals*. Court cases or disputes regarding customary land ownership can become bogged down, giving an impression of noncooperation.
- *Women's rights*. Female participation in movements for defending the land rights of women is limited.
- *Capability of the land registration office*. The inability of the land registration office to accommodate its workload—its backlog is significant—has had a detrimental impact on a number of opportunities for both land and infrastructure development.
- *Restoration of alienated land to (effectively perpetual) tribal ownership*. The Land and Titles Act of 1996 in Solomon Islands only recognizes individual ownership of alienated land as opposed to communal ownership by tribes. Thus, land that reverts to tribal ownership is sometimes left undeveloped. Relaxing this constraint requires updating current legal and administrative institutions. While the Department of Land is responsible for the legal framework relating to land management (e.g., Land and Titles Act, Customary Land Records Act), lack of human and financial resources hinder the Department's ability to fully fulfill its mandate.

Land Policy and Reform

Land Policy and Reform, 2006

The customary land tenure system is generally accepted as an efficient means of maintaining access to land in Solomon Islands, particularly since this system does not pose major challenges to rural households that rely on traditional semisubsistence systems of livelihood (Australian Aid 2006a). However, population pressure, growing demand for public lands, greater social mobility and migration, and new expectations spawned by a growing cash economy have all created pressure for land reform (SI ARDS 2007). Lack of mechanisms for addressing such issues has led to mistrust among communities and investors, thus impeding efficient use of available land resources (SI ARDS 2007). In May 2006, the government created the Land Reform Unit that would treat customary lands as bankable commodities, facilitate the use of such lands for economic development purposes, and recognize tribal land owners as corporate entities (SI ARDS 2007; Larden and Sullivan 2008). Because alienated land returned to tribal ownership was not being used productively, the new policy also transferred the authority to allocate land from the Commissioner of Land to an independent Land Trust Board (SI ARDS 2007).

Land Tenure Reform Program, 2007

In 2007, the government created a land reform unit under the Department of Lands and Surveys. This body embarked on a reform program, the chief purpose of which was to recognize traditional landowners and secure their titles to customary land (ADB 2010). To mobilize the reform process, a land reform divisions office was established in each province, initially for the purpose of compiling lists of major tribes, identifying tribal lands and their boundaries, and creating maps of all tribal lands (Maenu'u. 2007). The new land legislation recognizes major tribes as landowners, and requires any negotiations on usage of customary land to be undertaken with the participation of the chief and council of elders. Specific areas in need of attention include (i) strengthening the land reform unit, particularly with regard to the financial resources available to it; (ii) coordinating land reform activities that are implemented by the various groups to avoid the possibility of conflicting policies, and (iii) garnering long-term commitment and support on the part of the government, particularly with regard to the identification of tribal boundaries (Evans 2006).

The Solomon Islands Agriculture and Rural Development Strategy (SI ARDS) lists six priority actions for agriculture and rural development. In the short to medium term (approximately to the year 2011), the priorities include (i) improving the human resource capacity of the land-use planning unit; (ii) promoting open public dialogue, as well as availability of information relating to emerging issues, those remaining unresolved in particular; and (iii) identifying priority areas for building capacity in land administration. In the medium to long term (approximately to the year 2020), the priorities include (i) refining land policy and the legal framework relating to it, particularly with regard to customary land tenure rights and reviewing the Land Titles Act; (ii) improving land administration by providing appropriate financial support and resources including staffing to the Ministry of Lands; and (iii) continuing to pilot mechanisms for mobilizing customary land for purposes of economic development, while at the same time addressing the risk of elite capture and the need to provide information to local communities.

Recommendations for Improving Land Policy in Fiji, Papua New Guinea, and Solomon Islands

All three study countries have taken initial steps in land reform for the purpose of increasing agricultural output and adapting to climate change. Both the land bank approach taken in Fiji and Solomon Islands, and the integrated land group approach taken in PNG can help accelerate economic growth, while at the same time protecting customary rights.

Land banks are a decentralized, flexible mechanism for ensuring security of land tenure (Aryeetey and Udry 2010). However, to ensure their smooth operation, land bank shareholders should comprise both community members (including chiefs) and local government representatives. Land banks are land aggregators that (i) resolve conflicts relating to ownership, (ii) separate property use rights from ownership rights, and (iii) reduce transactions costs associated with transfer of land use rights from one party to another (Udry 2011). Land banks encourage participatory processes for delineating the boundaries of customary lands as well as the terms of leases, and ensuring that the level of compensation paid in exchange for land-use rights is appropriate. While land banks operate on the principle of free, prior, and informed consent, their operation would be facilitated by legislation that specifies processes for consultation by the community-at-large in matters that impact the latter to a significant degree. Similarly, establishing formal dispute resolution institutions would lower the transactions costs associated with the transfer of land-use rights (Udry 2011).

There is no best practice for reforming customary land tenure arrangements. As context is important, each country needs to design its land tenure regime to suit its unique circumstances. Reforms also need to be country-driven, and led by national authorities and landowners. Indigenous landowners should be directly and systematically included in discussions. Broad public consultation can promote development of stronger, more accepted land policy.

Australian Aid's (2006b) Pacific 2020 Report contains some valuable lessons: (i) it is essential to adopt a step-by-step approach because the capacity and strength of land administration services is likely to be the primary limitation in the reform process; (ii) efforts should initially focus on the most critically needed land changes, assuming that administrative and financial resources are available to support them; (iii) before attempting broader land reform and legal changes, existing land tenure should be adapted, and modifications pilot-tested; (iv) land tenure should only be changed if absolutely necessary—land ownership should be retained and leasing provisions adjusted to meet the needs of those developing the land; and (v) strict legal settlement should be applied in resolving land disputes. More research, public consultation, and piloting should be carried out to ensure that the public and stakeholders are informed and that broad feedback is elicited (SI ARDS 2007). As indicated, it is imperative that land administration authorities have the necessary capacity to manage responses to, and address potential changes. Top-down approaches do not work; the degree and timing of changes must be driven locally, based on demand.

Incorporated land groups provide similar benefits in that they represent the tribe-at-large within the formal legal system. They thus enable customary land ownership groups to participate in the formal economy, while at the same time retaining group ownership of land (Power 2008). Similarly, Power (2008) outlines important aspects for implementing incorporated land groups as follows: (i) establish processes for group representation of customary landowners that allow groups to hold a group title, thereby preventing groups from being fragmented; (ii) promote land development by the group as a whole in a manner that ensures that landowners can reap significant benefits in terms of income, employment, and social and infrastructure services; (iii) encourage social and economic activities among members of incorporated groups so that, in addition to receiving compensation, groups engage in productive wealth-creating or social development activities; (iv) allow flexibility in the distribution of income within incorporated groups; (v) promote good corporate governance through information, education, and legal support, including clear management guidelines, and accessible legal systems (especially in remote areas) and education and training so that members fully understand their rights, roles, and responsibilities; and (vi) ensure effective government regulation and support, the latter being critical to making sufficient long-term resources available for regulating and supporting the formation and management of groups so as to prevent misuse or disputes (Power 2008).

Agricultural Policies

Overview

The importance of agriculture in rural communities in Fiji was extensively discussed in Chapter II. An estimated 36% of the country's economically active population was involved in agriculture in 2010 (FAO 2011), but agriculture's contribution to GDP fell from 20% in 1995 to 13% in 2009, mainly due to faster nonagricultural growth. Nevertheless, rural communities depend on subsistence farming for food and nutrition security, as well as for income and livelihood, so for many critical reasons developing the agriculture sector should remain a priority.

In PNG, agriculture provided income, employment, and livelihood to around 70% of the country's economically active population in 2010 (FAO 2011). Agriculture contributed an estimated 36% of the country's GDP from 1995 to 2010, although this has more recently fallen to 33% (see Chapter II). Key factors limiting agricultural development in PNG are poor infrastructure (transport and roads) and high transport costs. PNG has one of the highest sea transport costs in the Asia-Pacific region, reducing the economic viability of exports and limiting the growth of domestic import-replacement activities. With higher transportation costs, farmers earn less for their produce, creating a disincentive to reinvest in yield-enhancing inputs and technologies. In this context, investment in agricultural research is needed to identify potential crop technologies that allow increases in yields based on the country unique environmental constraints and other limitations.

As in PNG, almost 70% of the economically active population in the Solomon Islands is involved in agriculture (see Chapter II). Rural communities derive their livelihoods from a combination of subsistence agriculture and small-scale, income-generating activities, particularly the export of cash crops and the local sale of fresh produce. Agricultural GDP has generally followed a declining trend since 1995, but this was further exacerbated by the ethnic tensions of late-1998 to mid-2003. The dominance of agriculture in the Solomon Islands makes agricultural development vital for the country's future well-being.

Current Status of Agricultural Policies in Fiji, Papua New Guinea, and Solomon Islands

In light of the challenges discussed above, the following sections explore the status of agricultural policies in recent years and their impact on the challenges discussed above in the context of a number of the region's key crops.

Coconut Production in Fiji

Copra, coconut oil, copra cake, soap, desiccated coconut, coconut cream, and fresh frozen coconut meat are among the products commercially processed from coconut in Fiji. The government recognizes the risk of depending solely on coconut oil and copra—the traditional products—for the industry's growth, especially because their price is dependent on the prices of other oil commodities on the world market. As such, the government aims to revitalize the coconut industry with the goal of adding value adding and diversifying the product base. In its Joint Country Strategy 2010–14, the Government of the Republic of Fiji and the Secretariat of the Pacific Community (SPC) included among its planned activities developing virgin coconut oil production and improving production processes and standards. According to the Fiji Department of Agriculture, a strategy for diversifying the industry has been developed, including a processing factory, already being built, that is envisioned to provide a training facility for stakeholders and farmers. The strategy includes training on the production of coconut products, as well as planting, marketing, packaging, and labeling (Fiji Department of Agriculture 2011b). The government also aims to stimulate coconut production by maximizing the potential use of coconuts as biofuel.

Coconut Production in Papua New Guinea

In PNG, the government aims to provide national leadership to revive the coconut industry. Strategies for achieving this include leading the development of coconut-based farming systems; facilitating the development of coconut replanting programs; coordinating and facilitating the redevelopment of abandoned coconut plantations; linking coconut development projects to clean development policy; and coordinating peer reviews and institutional collaboration. The government also seeks to mobilize and empower stakeholders, investors, smallholders, and plantations to enhance the production of high-value coconut products for niche markets, thereby promoting the establishment of farmer cooperatives, establishing market networks, facilitating capacity building across the industry, and providing high-quality extension services. Promoting downstream processing for value addition in the coconut industry is also an objective.

Coconut Production in Solomon Islands

While coconut is an important commodity in the Solomon Islands, proper replanting has not been undertaken for more than 20 years. A high percentage of palms are old and in the declining phase of production (MAL 2007a). Recent National Agriculture and Livestock Sector Policy (2009–2014) lists a major coconut replanting scheme among sector priorities. To enhance the economic contribution of coconuts, other priorities included financial support (on a cost-recovery basis) for the construction of copra dryers in strategic areas, provincial (and national) government support for shipping of copra from remote areas, and implementing a review of the coconut sector to develop a focused development strategy. Through the European Union's All ACP (African, Caribbean and Pacific Group of States) Agriculture Commodities Program, the South Pacific Community provided support to the International Trade Center and stakeholders to develop a sector-wide strategy for coconuts and value-added coconut products. The strategy, launched in 2010, uses a value-chain approach and focuses on capitalizing existing opportunities to improve income generation in rural areas and promote investment to develop and strengthen the processing and value-added industries. Overall priorities for 2011–2020 include increasing the value of copra by improving the quality and shipping/commercialization practices; building local markets by strengthening the local processing sector; and developing exports, particularly for oil, animal feed, coir products, pith, charcoal, and coconut milk.

Oil Palm Production in Papua New Guinea

Developing and supporting the oil palm industry is a government priority in PNG, given the industry's importance to the national economy. The government aims to mobilize and empower smallholders and mini-estate plantations to enhance the oil palm industry's performance. Strategies laid out in the National Agriculture Development Plan (NADP), 2007–2016, to achieve this include rehabilitating old plantations and promoting new planting, promoting farmer cooperatives, facilitating industry capacity building, providing high-quality extension advice, providing access to high-quality planting materials, strengthening market access, and improving smallholder access to credit. The government also seeks to promote integrated nucleus estate development by identifying potential target communities, promoting the nucleus estate concept, initiating projects, and providing appropriate training and skills development to smallholder participants. Promoting and facilitating cooperatives and enterprises in the oil palm sector was also an objective. Strategies associated with this goal include promoting strong linkages and coordination with national and international trading partners, enforcing national coordination of cooperatives, promoting private interagency collaborations, and creating awareness in target areas. Promoting small-scale downstream processing to add value in the oil palm industry is also an objective. The plan is to conduct feasibility studies in relevant aspects of downstream processing and initiate downstream processing where feasible. The government is allocating K130.657 million for oil palm development during 2007–2016. Note, however, that palm oil produces greenhouse gas (GHG) emissions when replanted in forest areas; thus, aside from displacing forest, GHG emissions exacerbate the situation, so a balance between economic and environmental protection is needed.

Oil Palm Production in Solomon Islands

Oil palm development is also a priority in the Solomon Islands National Agriculture and Livestock Sector Policy, 2009–2014. Policy includes a review of the oil palm sector, the creation of a focused strategy for developing oil palm sector, and provision of an extension service to support out-grower schemes. The government also plans to develop oil palm plantations nationwide to increase the production of crude palm oil for export through National Oil Palm Development Projects. As of 2009, five national oil palm projects have been initiated, although some have encountered land disputes.

Sugarcane Production in Fiji

According to Asafu-Adjaye et al. (2009), sugarcane yield in Fiji has been declining for some time due to declining land quality, particularly stemming from soil erosion. That study estimates the cost of soil erosion to farmers to be around $8 million per year, and the loss to the sugar industry to be $12 million in yearly sales. The authors note that land degradation could be minimized through policies that discourage the current practice of burning cane, which causes the rapid loss of soil nutrients, soil erosion, and a deterioration of soil quality. The current cane payment system in Fiji, as set out in the Master Award, would need to change because it provides an indirect economic incentive to burn cane by providing payment based on the tonnage delivered to the mill rather than the sugar content.

The Government of Fiji (2011) also ascribes declining cane production to aging sugarcane farmers, whose children have chosen not to pursue cane farming. Sugarcane farmers also face with the problem of declining sugar prices due to the phasing out of preferential EU prices.[19] The sugar industry was to obtain EU assistance through the Accompanying Measures Support Program, but a 2006 military coup caused the EU to suspend the program (Government of Fiji 2011), which contributed to the decline of the industry. In addition, sugarcane farmers are confronted with rising production costs due to increasing fertilizer prices, misapplication of fertilizer, and higher cartage and labor costs (Kumar and Bhati 2010). Unreliable and inefficient sugar mills have contributed to the decline of sugarcane production and output (Government of Fiji 2011). Fiji's four sugar mills are over a century old, making them inefficient and unreliable, with frequent breakdowns and stoppages. Inefficiency prevents sugar mills from extracting the maximum amount of sugar from raw cane. Once technical problems are addressed, the government hopes that farmer confidence will recover over time, leading to renewed investment. The government and industry stakeholders have also initiated a reform program that includes funding for new cane planting. A 2010 government grant of $6 million led to 6,000 ha of new cane being planted, representing 12% of the total 2011 harvest (Government of Fiji 2011). On this basis, the government has allocated a further $6 million grant for 2011.

19 EU sugar policy reform entailed a cumulative 36% price cut that was progressively implemented between 2006 and 2009 (Fiji Sugar Corporation Annual report 2009).

With the removal of the EU's preferential prices, Fiji can no longer depend on export earnings from sugar. The industry must now be driven by production volume in order to realize the necessary economies of scale (Andersson and Jenshagen 2010). Upon completion of upgrades to the mills, 4.2 million tons of cane will be required for a 25-week crushing season, compared with existing levels of around 2.4 million tons (The Fiji Sugar Corporation, Annual report 2009). According to Fiji Sugar Corporation, it will undertake a number of strategies to ensure the adequate supply of cane, including strengthening extension services to farmers, institutionalizing the involvement of landowners in cane farming through cooperatives and other management structures, and mechanizing cane farming. The EU's suspension of financial and technical assistance will make this more difficult to achieve. Overall, the industry will remain under considerable pressure, given the combination of the 36% EU price cut, declining cane production, and extreme weather events.

Taro Production in Fiji

Although at a slower pace than in the previous decade, taro production increased at a rate of 10.35% per year during 2000–2009, and with increased demand, area harvested also grew by 12.97% per year. Concerted efforts by the Ministry of Agriculture expanded the number of farmers growing taro under the Flatland Development Program, which provided them with planting materials, agrochemicals, and tractors for land preparation (Government of Fiji 2005a). Taro yields declined at a rate of 1.94% per year during that period, however, so the main source of production growth was expansion in harvested area.

Rice Production in Fiji

Rice production in Fiji followed a declining trend of 0.92% per year during 2000–2009. Although yields grew by 0.88% per year, area harvested declined by 1.71% per year. The country's rice self-sufficiency averaged only 28% during this time frame. The industry's poor performance has been attributed to the high cost of production, lack of access to credit in rural areas, changes in the country's economic policies, and new lifestyle preferences for semiurban farmers—most opting for life in urban areas (Rao et al. 2007; Fiji Department of Agriculture 2011a). The pressing need for white-collar jobs in urban centers was a response to farmers' children receiving a better education and prevailing deregulation policies that have contributed to an overall decline in rice production.

These factors prompted the government to take steps to revive the local rice industry by enhancing domestic capacity to produce rice for local consumption. Prasad and Narayan (2005), however, suggested that the economy-wide impact of the initiative would be minimal, and that even if rice production were restored to the production levels of the late-1980s, its impacts on national welfare and GDP would be insignificant. If rice production were increased by 40%, real GDP and government savings would only increase by 0.03% and 0.24% respectively. The study noted that support to the rice industry goes against the government's policy of moving toward trade liberalization and promoting crop sectors. The authors suggested that the government should focus on investing in rural infrastructure, such as roads, water supply, electricity, marketing institutions, and extension services, in support of the production of agricultural products.

Rice Production in Papua New Guinea

Increasing domestic rice production to replace rice imports in PNG has been promoted since the 1950s. Various government administrations have commissioned a number of feasibility studies to examine the potential for large-scale rice production to reduce the import bill (Powell et al. 2001). The Central Province, Morobe, East New Britain, and Madang have been ranked as having medium to high potential for semimechanized or fully mechanized small- to large-scale wetland rice production. Although potentials have been identified, previous attempts to introduce local rice production have largely been unsuccessful. Initiatives have included government-subsidized schemes to encourage rice growing in Central, East Sepik, and Sandaun provinces; five separate schemes in Central Province since 1921 to encourage the development of semimechanized upland rainfed rice growing; and three schemes in East Sepik Province since the 1960s purely based on non-mechanized production (Powell et al. 2001). Several studies have been undertaken to examine why efforts to increase PNG's domestic rice production have had limited success (the results of which are discussed further below). On the whole it was concluded that there is little potential for expanding rice production in PNG, and that the resources would be better used elsewhere.

Despite such findings, the government continues to pursue an import-substitution policy for rice, aiming to establish a sustainable domestic rice industry to enhance food security, generate income for smallholders, and reduce rice imports. The goal is to achieve domestic rice production of 60,000 metric tons by 2016. The government seeks to ensure that rice farmers have access to appropriate resources, technologies, skills, and support services to empower them to engage in sustainable rice production. Specific strategies involve (i) facilitating rice farmers' access to micro-credit services, adequate land resources, and inputs (i.e. good-quality rice seed, milling and other machines, and tools and other essential materials); (ii) facilitating the establishment of a suitable marketing system; and (iii) providing suitable training, extension, and information. The government also seeks to promote rice production by developing courses to be taught in primary and secondary schools, vocational centers, and tertiary institutions and correctional institutions. This includes facilitating access to credit, land resources, and inputs by these institutions, and providing suitable training, extension, and information support to the institutions, as well as assisting them in marketing the rice produced.

The NADP suggests that smallholder rice production for household consumption and local sale may be preferable, based on the high transportation, production, and other costs associated with large-scale production. Nevertheless, NADP's Rice Development Plan still seeks to promote and assist commercial rice production. Strategies include encouraging local and foreign investors to participate; identifying and mobilizing suitable lands for commercial production; and establishing a mechanism for the government to partner with landowners and investors. The PNG government has allocated K46.6 million to the Rice Development Plan for the period 2007–2016. Of this, K16.1 million is earmarked for commercial rice development, and

K16.5 million for smallholder rice development. About K14 million has been allocated to institutional rice development. Rice import substitution is also emphasized in the government's Strategic Development Plan of 2010–2030, which underscores the need to strengthen the bargaining power of local rice growers and encourage local processing by 2030.

Three main constraints—the environment, cost efficiencies, and returns to farmers' labor—were identified by Bourke et al. (2009) to explain the unsustainability of PNG's rice industry:

- PNG's environment is generally not conducive to growing grain. Rainfall is too unreliable in some areas for perennial, non-irrigated rice cultivation. Rainfall variation within a given year, across years, and in terms of the start of the wet season is not reliable enough to support large-scale non-irrigated rice. And in areas where irrigated rice has been grown, pests, weeds, and diseases reduced yields (although in cases where fields were shifted every year, pests and diseases were not a major problem; Bourke et al. 2009). In many areas, soil has poor water-holding capacity and is unsuitable for irrigated rice.
- Cost efficiency, mainly in terms of the high capital costs of establishing irrigated paddy fields and the high production costs per metric ton, hinders rice development in PNG. Studies have shown that developing large enough areas of irrigated rice for import replacement would distort the economy, require large subsidies, and result in a significant increase in the country's retail price of rice. FAO/NARI/World Bank (2002) even suggested that PNG would be much better off diverting the resources that had been invested in attempting to grow rice to promoting and improving traditional root crops, and identifying methods for storing them. Similarly, in analyzing the long-run trend in the terms of trade between rice and PNG's export tree crops, Gibson (1992) concluded that rice self-sufficiency would not represent a sensible allocation of resources and that it would be more efficient to focus on expanding exports, particularly of cocoa and coffee. Gibson (1992) contended that if households were forced to eat local rice based on the government's goal of rice self-sufficiency, the majority would be worse off because rice would actually cost more than it needed to. Resources allocated to promoting domestic rice production would be wasted because they could have been used more efficiently for much-needed agricultural research or road infrastructure.
- Domestic rice production has not become significant in PNG due to its low returns to farmer labor (K5/person/day) compared with returns to the production of sweet potato (K32/person/day), cocoa (K20/person/day), Arabica coffee (K18/person/day), and copra (K10/person/day) (Allen et al. 2009). As a result, some of the farmers who have experimented with rice production have later determined they are better off growing root crops and export cash crops (Bourke et al 2009). Blakeney and Clough (2001) also noted that, although most coastal areas of PNG can support rice production, rarely has it been economically sustainable compared with other agricultural activities. Cultivating rice can be highly labor intensive, and the timing of certain production activities is far more critical than with other crops.

Bourke et al. 2009 recommend that village smallholders should not be discouraged by the above-mentioned constraints to rice development, but that import-substitution levels are unlikely in the future.

Rice Production in Solomon Islands

Rice production in the Solomon Islands did not recover until Taipei,China targeted aid for the sector in the 1990s, providing technical and financial support to the Ministry of Agriculture and Livestock (MAL). The Chinese Agriculture Technical Mission (CATM) [of Taipei,China] was established between the two countries to focus on rice development. Unlike the large-scale rice plantation style operations of the 1960s and 1980s, CATM promoted smallholder upland rice cultivation, heavily subsidized with aid from Taipei, China. Subsidies included transporting rice to mills established with selected farmers or run by MAL, and providing mills, fertilizer, training, and other incentives (Bourke et al 2006). When ethnic tensions erupted, leading to the collapse of the rice program, almost all smallholder farmers abandoned their farms (MAL 2010). Dependence on subsidized chemical, mechanical, and technical inputs made it difficult for most smallholder growers to sustain production in the absence of the CATM.

The CATM was restored in 2003, but at that time shifted its focus from smallholders to semicommercial (5-hectare) production on a communal basis (MAL 2010). Aside from the problem of farmer dependence on subsidized external inputs, this approach encountered challenges including a limited land area for planting, lack of labor, and lack of cooperation from members due to mismanagement by local leaders. From 2006, CATM suspended assistance to extension services and reduced its support to smallholders and semi-commercial farms. As such, farmers continued to find it difficult to access inputs for rice farming.

In 2006, the National Rural Rice Development Program (NRRDP) was initiated by the Solomon Islands government to enhance food security and reduce the costs of importing rice. Under the NRRDP, 10-hectare projects received financial assistance for labor, tools, and equipment (TARD 2006). Subsequently, the government further strengthened the NRRDP, allocating S$15 million in 2009 and S$10 million in 2010 for establishing 38 semicommercial and fully commercial (i.e., 5- and 10-hectare) rice projects throughout the country. In 2010, the Solomon Islands government devised the National Rice Sector Policy for 2010–2015, endorsing continued support for the NRRDP, while also recognizing the significant input requirements of conventional methods of rice farming.

The National Rice Sector Policy recommended introduction of low-input methods of farming, such as the system of rice intensification (SRI), with particular emphasis on rainfed rice, given that the country has limited irrigated or irrigable area. The SRI is envisioned to be a useful system for the country because it uses little or no water (rainfall would provide sufficient water), only organic fertilizers, few if any synthetic pesticides, and fewer seeds (only one per seedling planting per hole). Nevertheless, the benefits in terms of higher yields, returns to farm labor, and reduced production costs are greater than those attained with conventional methods (MAL 2010). The National Rice Sector Policy outlines plans to implement the SRI during 2010–2015.

The above notwithstanding, a recent study noted that rice production is unlikely to become a commercial success in Solomon Islands (ADB 2010). This study noted that commercial rice production in the country does not have a history of success, and recommended that resources allocated to rice production be transferred to commercial crops that have proved successful. The study also recommended that such resources also be used to improve productivity in the production of traditional crops that increase food security and offer opportunities for earning cash income. The study further suggested that land reserved for rice should be returned to landowners for use in other enterprises such as palm oil. Meanwhile, World Bank (2007) suggested that the prospects for development of rice cultivation in Solomon Islands for purposes of import substitution were uncertain, pending the results of further research. Thus, conducting suitable agroeconomic and socioeconomic research relating to rice production prior to further investment in rice cultivation was deemed necessary by the World Bank study.

Recommendations for Agriculture Sector Policies in Fiji, Papua New Guinea, and Solomon Islands

In all three study countries, growth in agricultural output has been limited due to vulnerability to natural disasters, minimal private investment, inadequate infrastructure; marketing inefficiencies, high input costs, complicated land tenure systems with insecure land rights, weak research-extension-farmer linkages, and social and political instability. Notably, in all three countries, the agriculture sector depends heavily on a small number of primary export commodities, the prices of which are set in the world market. To address uncertainty caused by price fluctuations and global competition relating to these products, development of nontraditional agricultural exports, value-adding products, and cash crops are recommended as a means of diversifying the economic base of the agriculture sector in all three study countries.

Broad-based investments in agriculture are required if sustainable improvement in agricultural growth is to be achieved in these countries, along with the ability to adapt to climate change. Such investments should target improving governance; continuing development of fair, competitive, and efficient markets; revitalizing the private sector; and devising broad policy and institutional measures that create an environment within which restructuring can occur.

Greater public investment in rural infrastructure is necessary to increase consumer demand, provide farmers with access to input and output markets, stimulate the rural nonfarm economy and rural towns, and more fully integrate the poorest regions into the national economy. Increased investment in rural infrastructure and policies is also important for closing the gap between actual and potential yields in predominantly rainfed areas, the development issues in such areas being complex due to weaknesses in markets, credit, input supplies, and variable agroclimatic environments.

Overall, the use of fertilizer and other agro inputs is quite limited in all three study countries, yet increased fertilizer use would have substantial benefits in terms of raising yields for the major crops. However, increased use of fertilizer should be combined with other approaches to improving soil fertility, including sustainable agriculture based on low usage of external inputs, and integrated soil fertility management. No single approach is likely to succeed, given the region's diversity; nonetheless, a substantial increase in the use of inorganic fertilizer is essential.

Fertilizer use can be promoted through subsidies and vouchers, public investment in soil-fertility enhancement technologies, locally tailored fertilizer recommendations, and coordinated service provision, including output markets and the use of public–private partnerships. The affordability of fertilizers is a major challenge. Subsidies can compensate farmers in remote areas for the high transport costs involved in supplying their inputs and purchasing their outputs, but many of the benefits of subsidies are often captured by wealthier farmers who have the most effective demand for fertilizer. Subsidies also distort markets and inhibit efforts to develop effective private fertilizer markets and distribution systems. The use of small fertilizer packs of 1–5 kg can enhance the affordability of fertilizer for very poor households and reduce the risks of experimenting with new types of fertilizer.

Vouchers are a variation on subsidies that could be employed for targeted distribution of fertilizer to food-insecure households, in that they allow poor households to obtain access to fertilizer, while at the same time boosting development of the fertilizer market. Fertilizer voucher schemes linked to public works programs also have the potential to create employment through infrastructure and eco-rehabilitation programs during the off-farm season. Despite these benefits, questions remain as to why fertilizer vouchers would be distributed instead of cash under public works programs. Vouchers also pose some of the same tradeoffs as subsidies in terms of (short-term) expenditure on welfare and investment in enhancing (long-term) fertilizer market efficiency through investments in road, railways, ports, and communications infrastructure.

A more appropriate role for the government in increase use of fertilizer would be to provide public goods, including extension services that advise farmers on the appropriate quantity, quality, and timing of fertilizer applications. More aggressive public sector participation in the development of fertilizer markets could be enhanced by effective public–private partnerships.

Promoting application of inorganic fertilizer is a critical part of improving agricultural output and hence food security. Given the high costs and inefficiency of subsidies, the best approach is to establish an enabling policy environment for farmers and private sector fertilizer supply. This includes maintaining macroeconomic stability, avoiding free or highly subsidized fertilizer distribution except in cases of extreme emergency, and maintaining a predictable policy approach to the fertilizer industry. Moreover, as noted above, governments must upgrade the infrastructure that serves fertilizer supply and distribution networks such as roads and ports, and assist importers in gaining access to financing so that they can benefit from scale economies.

Finally, improved fertilizer policy should be accompanied by enhanced natural resource management that encourages the integrated expansion if soil fertility and productivity. Adoption of organic and low-external-input methods of soil fertility replenishment can be an important aspect of improved nutrient management. Technologies are being tested and promoted, including incorporating leguminous trees and shrubs into improved fallow systems, planting leguminous cover crops, applying manure and compost, and transferring nutrients through biomass transfer. The full potential of these technologies is still to be determined, because they often require significant knowledge, labor, land, and transport resources, the latter being required for moving bulky nutrients from supply depots to farmers' fields.

Agricultural Research, Extension, and Training

Overview

Agricultural research, extension, and training are important aspects of improving the speed and extent of adoption of farm-level practices for climate change adaptation. Improved extension services for agriculture and fisheries can help improve communication of adaptation strategies, conduct needs and vulnerability assessments, and develop applied research projects that support climate change adaptation, including the adoption of improved crop management practices and cultivars adapted to climate change. Research-extension-farmer linkages have been weak, limiting the ability of farmers to increase crop yields. In sum, research findings relating to agricultural innovations, proper farm practices, and production technologies that can increase crop yields are not being effectively transferred to farmers (MAL 2007).

Downsizing, corporatization, and decentralization of government services relating to the agriculture sector have been closely correlated with disintegration of extension services provided to farmers by government, particularly in the case of smallholders and subsistence farmers in remote areas. Given limited political and financial support for agriculture at the national and provincial level, minimal resources are generally available for providing extension services at the local level.

Lack of market information has also hindered agricultural development. Farmers often lack information regarding markets, prices, supply, and consumer preferences. This places them at a disadvantage in making appropriate decisions regarding which agriculture activities or enterprises they should invest in. As a result, farmers run the risk of cultivating and selling crops for which there is little demand, cultivating and selling them at an inappropriate time, or cultivating and selling them in suboptimal quantities.

Perhaps most critically, expenditures on agricultural research have been limited in all three study countries. While complete data to 2002 are only available for PNG, Stads, Omot, and Beintema (2005) have identified 10 agencies involved in agricultural research and development in PNG. That study estimated that 115 full-time equivalent researchers were employed by nine agencies, and that an estimated K21 million was spent on agricultural research and development in 2000, which was equivalent to 28 million 2000 international dollars (Table 4.1) (Stads, Omot, and Beintema 2005).

Another way of evaluating a country's agricultural research and development (R&D) commitment within an international context is to compare its agricultural research expenditures with the size of its agriculture

Table 4.1 Summary of Agricultural Research and Development Agencies, Researchers, and Expenditures in Papua New Guinea in 2002

Type of Agency	Spending (million)		Number of Researchers[a] (full-time equivalent [fte])	Share (%)		Agencies in Sample[b] (number)
	2000 PNG Kina	2000 International Dollars		Spending	Researchers	
Public agencies						
NARI	5.7	7.4	37.0	26.4	32.1	1
PNGFRI	1.9	2.4	28.0	8.6	24.3	1
Nonprofit[c]	11.4	14.8	38.2	52.9	33.1	3
Higher education[d]	0.5	0.6	4.2	2.3	3.6	2
Subtotal	19.5	25.2	107.4	91.4	93.1	7
Private enterprises	2.8	2.4	8.0	8.6	6.9	2
Total	21.4	27.6	115.4	100	100	9

[a] Includes national and expatriate staff.
[b] See note 2 for a list of the nine agencies included in the sample. Vudal Agriculture University was excluded from this table and further data analysis in this brief because data were unavailable.
[c] fte researcher and expenditure data for OPRA were estimated using 1998/99 data from Ghodake (1999).
[d] Expenditures for higher education in the sample are estimates based on average expenditures per researcher at NARI and PNGFRI. The 14 faculty staff employed in the two higher education agencies spent 30% of their time on research, resulting in 4.2 fte researchers.
Source: Compiled by authors from ASTI survey data (IFPRI-APAARI 2003–04).

sector, measured in terms of agricultural GDP, to calculate what is known as a research intensity ratio. PNG's 2002 intensity ratio was only 0.5%, down from 1% in 1991. The country's total agricultural research expenditures had also declined at that time (Beintema and Stads 2008).

Agricultural Research and Development in Fiji

The Secretariat of the Pacific Community (2011) developed a joint country strategy program with Fiji Government for 2010–2014 on major sectoral programs (e.g. agriculture, health, marine resources, human development, transport among others). The Secretariat has been providing assistance to Fiji in various sectors, including agriculture. Table 4.2 provides a partial list of agricultural research undertaken in Fiji, mainly through crop breeding, by the Research Division, Koronivia Station, Department of Agriculture, Ministry of Agriculture and Primary Industries in Fiji with technical and financial assistance from SPC.

The Australian Centre for International Agricultural Research (ACIAR 2009) pointed out the opportunities for economic and technical research for developing crop and agricultural industries in cooperation with government institutions that can eventually reach regional and international export markets. These can be papaya, root crops, and ornamentals. Studies on the development, postharvest technologies, and marketing options of horticulture crops should likewise be carried out. Capacity-building in R&D, particularly in horticulture, should be taken into consideration.

Table 4.2 Partial List of Crop Technologies Tested in Fiji

Crop	Variety/Technology Development	Description
Taro		Germplasm conservation; development of taro varieties for niche markets and different uses (e.g., chips)
	Hybrids	Early maturity, high-yielding, easy to sell, good eating quality even if harvested before maturity, tolerant of many growing conditions, good suckering ability (Rewa, Naitasiri, Bua provinces, Fiji)
	Tissue culture – DNA fingerprinting	TaroGen: conservation and use of genetic resources funded by the Australian government; provides a model of how biotechnology is used in the region, and how overseas institutes provide inputs from technologies; more demanding of resources
	Virus indexing	Diagnosis and detection of taro viruses in PNG and other Pacific Island countries to facilitate the safe international movement of taro germplasm. PCR-based diagnostics have been developed for several of the taro viruses, (taro bacilliform badnavirus, dasheen mosaic potyvirus, and taro reovirus)
	Cryopreservation	Practical and efficient technique for long-term storage of vegetatively propagated plants, requiring minimum space and relatively low cost
	Biological control of taro beetle using *Metarhizium anisopliae*; potential extract of *Pangium edule* under evaluation	Large-scale field trials and investigations into methods of low-cost mass production
	Breeding	Genetic diversity studies; gap-filling (Viti Levu)
Sweetpotatoes	Recommended: Vulatolu, Honiara, Papua, TIS 3030, and Carrot Other varieties: Navuso local; Funafuti; R.B. Lau; Turaga Red; Talei; Naqia; Ului Namai; White Timala; Black Rock; Drividrivi; Niue; Kasai loa; Gisborn red; Red timala; Coseni vula; Hong Kong, China; CA Dobuilevu; CN (yellow); V-52	Expected yield 15–20 tons/ha with good management
Yams	Recommended: Early season for all zones – Vurai Balavu, Vurai Dra Late season for wet zones – Kivi, Uvi ni Futuna Late season for dry and intermediate zones – Uvi ni Futuna, Murupoi, Beka, Taniela Vulaleka, Kivi	Expected yield 20–24 tons/ha Genetic diversity studies, gap-filling (western Viti Levu)
Cassava	Recommended: Merelesita, Sokobale, Beqa, Vulatolu, Yabia Damu, New Hebrides	Expected yield 20–25 tons/ha for all varieties
Sugarcane (including chewing cane)	Drought, sugar content	Germplasm conservation
Rice	For saline soils	Germplasm conservation
Re-building collection		Germplasm collection for R&D
Mango		Germplasm conservation
Coconut	Hybrids	4,000 ha produced 1 million nuts in the past 15 years, of which 60% are hybrids in Fiji

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Table 4.2 *continued*

Crop	Variety/Technology Development	Description
	Biofuels	SPC Rural energy program worked with CIRAD, the Ministry of Agriculture, and Pacific Power Association with funding from the French Embassy for the development and implementation of coconut biofuel projects in Fiji Decreasing prices of coconuts and the high price of fossil fuels is creating considerable interest Results have been encouraging; however, these have been pilot activities and the long-term sustainability is still being studied
	Cyclone resistance	Monasavu area, Yasawa
Cocoyam	Disease and moisture stress resistance, nutritional quality, medicinal value, genetic erosion (i.e., rescue collecting), gap-filling and replacement of lost collections, and the need for planting material for natural disaster rehabilitation	Germplasm collection for R&D
Kava		Harvesting of material from the wild for biochemical analysis and commercialization (Ministry of Agriculture, Sugar and Land Resettlement [MASLR]); Kadavu, Taveuni, Viti Levu and Vanua Levu
Traditional fruits (ivi, uto, dawa)		To support developing export activities (MASLR); Viti Levu
Traditional vegetables (ota, karisi, bele, moca, duruka)	Disease and moisture stress resistance, nutritional quality, medicinal value, genetic erosion (i.e., rescue collecting), gap-filling and replacement of lost collections, and the need for planting material for natural disaster rehabilitation	Germplasm collection for R&D
Exotic vegetables	Disease and moisture stress resistance; nutritional quality, medicinal value, genetic erosion (i.e., rescue collecting), gap-filling and replacement of lost collections, and the need for planting material for natural disaster rehabilitation	Germplasm collection for R&D
Voivoi (Pandanus caricosus)	Disease and moisture stress resistance, nutritional quality, medicinal value, genetic erosion (i.e., rescue collecting), gap-filling and replacement of lost collections, and the need for planting material for natural disaster rehabilitation	Germplasm collection for R&D
Medicinal plants	Disease and moisture stress resistance, nutritional quality, medicinal value, genetic erosion (i.e., rescue collecting), gap-filling and replacement of lost collections, and the need for planting material for natural disaster rehabilitation	Germplasm collection for R&D
Tapa (Broussonetia papyrifera)	Disease and moisture stress resistance; nutritional quality; medicinal value; genetic erosion (i.e., rescue collecting), gap-filling and replacement of lost collections, and the need for planting material for natural disaster rehabilitation	Germplasm collection for R&D

Sources: COGENT 2002. *Strengthening the South Pacific Sub-Network of COGENT*. 11th COGENT Steering Committee Meeting, 25–28 June 2002, Bangkok, Thailand. Department of Agriculture, Ministry of Primary Industries, Koronivia Station, Fiji; Masibalavu, V.T., D. Hunter, M. Taylor and P. Mathur. 2002. *Survey to Determine the Extent of Genetic Erosion of Taro Landraces in Fiji.* Journal of South Pacific; Taylor, M. 2002. *Agricultural Biotechnology in the South Pacific Region*.

Agricultural Research and Development in Papua New Guinea

The National Agricultural Research Institute (NARI) in PNG is responsible for research and research-related technical development for agriculture and agricultural systems improvement, information and knowledge, providing an enabling environment, and institutional management and development. Table 4.3 provides a partial list of the agricultural technologies released by NARI; Table 4.4 lists ongoing R&D projects in PNG.

Agricultural Research and Development in Solomon Islands

The Department of Agriculture and Livestock (DAL) Research Division is responsible for agricultural research and development in Solomon Islands. The Division is structured around seven specializations: tree crops, field crops, soils and plant nutrition, entomology, plant pathology, farming systems, and library and management services (Evans 2006). To date, only tree crops, plant pathology, and library services are operational, and even then, at limited capacity. Because of the absence of key staff, lack of facilities, or both, the other sections are inactive. DAL's Research Division preserves a large collection of cultivars and evaluated taro, sweet potato, yam, and *pana* varieties, as well as maintaining a vegetable and seed production program (Evans 2006). The Division also carried out applied research and development on spices such as cardamom, pepper, and vanilla. Tenaru field experimental stations provided the bulk of the planting materials for the current vanilla boom (Evans 2006).

There are opportunities for improving the agricultural output in Solomon Islands. Evans (2006) pointed out that the earlier collections of sweet potatoes and yams by the Research Division and the current collections of taro and bananas by nongovernment organizations (NGOs) have illustrated the country's diversity of cultivated field crops and the high probability that farmers' networks could manage these crops. Significant potential exists for collaborative agreements between NGOs, farmers, and DAL in continuing to carry out field crop collections and enrich their use through technical support and encouragement of qualified, yet underutilized DAL staff (Evans 2006).

Agricultural Training and Extension Services

Fiji has a large and dispersed extension system focusing on training; improving farming methods and techniques; and improving production efficiency, incomes, and the overall standard of living in rural areas (Prakash 2003). The extension system aims to teach communities to improve their circumstances with minimum assistance from the government. The Government of the Republic of Fiji determines the country's extension strategies, encouraging the participation of industry, NGOs, donors, and other stakeholders. Agricultural extension is administered by the Ministry of Primary Industries (Crop Extension and Research Divisions). The government has adopted a system of land-use surveys whereby crops are identified and intensive extension programs developed. Crop specialists and extension and training experts are involved in implementing extension services in farm communities. Farmer Field Days are organized to facilitate information exchange among farmers, trainers, and specialists. Farmers are also encouraged to establish cooperatives, particularly for marketing and processing their products (Prakash 2003).

In PNG, the Department of Agriculture and Livestock administers

Table 4.3 Crop Technologies Released by the National Agricultural Research Institute, Papua New Guinea

Crop Specifics	Variety/Technology	Description
Bananas	FHIA 02 AAAA	Extremely resistant to Black Sigatoka, medium maturity, dessert type; Yield: 22.5 t/ha. Released by NARI for farmer evaluation
	FHIA 17 AAAA	Highly resistant to Black Sigatoka; late maturity, desert type Yield: 27.6 t/ha. Released by NARI for farmer evaluation
	PISANG CEYLAN AAB	Highly resistant to Black Sigatoka; early maturing, dessert type Yield: 22.9 t/ha. Released by NARI for farmer evaluation
	SH 3436 AAAA	Highly resistant to Black Sigatoka; medium maturity, dessert type Yield: 26.0 t/ha. Released by NARI for farmer evaluation
	FHIA 23	Highly resistant to Black Sigatoka; late maturity, dessert type Yield: 21.3 t/ha. Released by NARI for farmer evaluation
	Banana pest control technology package	Pest control technique. Provides details on how to effectively control banana scab moth and banana fruit fly. Use of locally made pole injector reduces banana scab moth damage by 80%. Using fruit bags to control banana fruit flies (if done correctly and at the correct timing) will reduce fruit fly damage by nearly 100%.
Rice for upland cultivation	NR1	IRRI accession designated IR 19661-23-3-2-2, highly tolerant to drought; tolerant to leaf folders, rice bug, and brown planthopper; grain yield is 19.7% higher than TCS 10 over 5 sites
	NR9	Grain yield is 14.7% higher than TCS 10 over 4 sites; tolerant to leaf folders and brown planthopper
	NR15	Originally the Philippines variety Salumpikit obtained from IRRI; grain yield 47.1% higher than TCS 10 over five sites; early maturity at 100–110 days after sowing, highly tolerant to brown planthopper and rice bugs
	NR 16	Originally the variety Azucena from IRRI, grain yield 8.7% higher than TCS 10 over 5 sites, early maturing, highly tolerant to drought and acid soils
Taro hybrid varieties	NT01	Resistant to taro blight disease; produces stable yield in different agro-ecological zones of PNG; average number of suckers (3–4); average corm weight (525 g); released by NARI in 2001
	NT 02	Resistant to taro leaf blight; corm yield 7.7 t/ha; released by NARI in 2001
	NT 03	Highly resistant to taro leaf blight; ave. corm yield: 7.6 t/ha; released by NARI in 2001
	NT 04	Highly resistant to taro leaf blight; ave. corm yield: 11.1 t/ha; released by NARI in 2003
Drought tolerant sweet potato varieties for the lowlands	NARI Nambis Kaukau 1, NARI Nambis Kaukau 2, NARI Nambis Kaukau 3, NARI Nambis Kaukau 4	Drought tolerant High yielding Yields of 11–16 t/ha or 1.1–1.6 kg/m^2 NARI Nambis Kaukau 1, 2 and 3 are early maturing Dry conditions = planting during dry season at Laloki and withholding irrigation for 6 weeks
Drought tolerant sweet potato varieties for the highlands	NARI Hailans Kaukau 1, NARI Hailans Kaukau 2, NARI Hailans Kaukau 3, NARI Kaukau 4, NARI Hailans Kaukau 5	All varieties are drought tolerant All mature early Yields of 12–22 t/ha Dry conditions = covering plots with plastic sheet to keep moisture out for nine weeks

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Table 4.3 *continued*

Crop Specifics	Variety/Technology	Description
Cassava varieties for the dry lowlands	NARI Nambis Tapiok 1, NARI Nambis Tapiok 2, NARI Nambis Tapiok 3, NARI Nambis Tapiok 4	Yield ranged from 20–29 t/ha or 2–2.9 kg/m^2 Cyanide contents were low at 1.2–1.5 mg of HCN/100 g of fresh tuber Cyanide content < 5 mg/100 kg fresh tuber is safe/harmless
Kava plant	Madang short	Yield 3.2–4.8 tons dry roots per ha over a 5 year growing period
Lowland sweet potato varieties	NARI has released 79 sweet potato varieties suitable for the normal lowland conditions of PNG. (NOTE: Name of the varieties were not mentioned.)	All cultivars have acceptable yields with good market and consumer appeal. (no mention of how much yield was).
Nutmeg and mace clones	Technology: clones and information package on nutmeg (NARI info bulletin and NARI Toktok on marcotting)	Release of clones. Clones will come into production earlier than seedlings. Average yield of the selected clones is 618 kg/ha nutmeg and 176 kg/ha mace which is approx. 2.7 times more than the average yield of all of the female trees combines
African yam (Dioscorea rotundata)	NARI released two varieties (specific varieties were not mentioned)	Yields up to 50% more than common local varieties of native yam species
Early maturing sweet potato varieties for high altitude highland areas (traditional varieties takes 9–12 months to mature)	PRAP 546	Yield: 5.86 tons/ha (6 months); 12.10 tons/ha (8 months); 13.80 tons/ha (10 months)
	WHCK 005	Yield: 6.57 tons/ha (6 months); 10.28 tons/ha (8 months); 12.78tons/ha (10 months)
	WBS 010	Yield: 5.85 tons/ha (6 months); 9.88 tons/ha (8 months); 9.48 tons/ha (10 months)
	LIPULIPU	Yield: 4.72 tons/ha (6 months); 8.44 tons/ha (8 months); 2.35 tons/ha (10 months)
	BARU	Yield: 6.58 tons/ha (6 months); 10.19 tons/ha (8 months); 12.60 tons/ha (10 months)
	PRAP 506	Yield: 7.30 tons/ha (6 months); 10.32 tons/ha (8 months); 11.91 tons/ha (10 months)
	BAIM	Yield: 7.45 tons/ha (6 months); 12.23 tons/ha (8 months); 14.42 tons/ha (10 months)
	WHCK 007	Yield: 4.88 tons/ha (6 months); 8.65 tons/ha (8 months); 10.82 tons/ha (10 months)
	PRAP 469	Yield: 5.34 tons/ha (6 months); 8.12 tons/ha (8 months); 12.07 tons/ha (10 months)
	NAGAMAPU	Yield: 8.89 tons/ha (6 months); 12.81 tons/ha (8 months); 14.95 tons/ha (10 months)
	SIMB	Yield: 5.40 tons/ha (6 months); 9.45 tons/ha (8 months); 12.72 tons/ha (10 months)
	ARGO	Yield: 6.54 tons/ha (6 months); 9.49 tons/ha (8 months); 12.03 tons/ha (10 months)
Peanuts (note: current pod yield 0.5–1.0 mt/ha)	Recommendation of production practices and release of HYV 5 High-yielding short duration varieties for highlands: ICGV 93143, ICGV 94049, ICGV 93058, ICGV 96466, ICGV 95179	3–4 tons/ha

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Table 4.3 *continued*

Crop Specifics	Variety/Technology	Description
	9 High-yielding short duration varieties for lowlands: ICGV 96466, ICGV 94341, ICGV 95256, ICGV 94299, ICGV 95319, ICGV 95245, ICGV 95322, ICGV 95271, ICGV 95299 4 High-yielding medium duration varieties for highlands: ICGV 93043, ICGV 93115, ICGV 94113, ICGV 96073 6 High-yielding medium duration varieties for lowlands: ICGV 96110, ICGV 93139, ICGV 92160, ICGV 93123, ICGV 95172, ICGV 93058	
For Brassicas and other green leafy vegetables	Plant derived pesticide (PDP) technology package	Pesticides obtained from derris, chili, and neem which can give similar control of pests as the commercially available insecticides. Percentage of cabbage heads damaged by insect pests was reduced from 50% to around 5% by using PDPs
No specific crop	Introduction of two biological control agents of chromolaena weed	*Pareuchaetes pseudoinsulata* (moth) has been observed to cause severe damage to chromolaena weed by defoliation thus effectively controlling the weed. *Cecidochares connexa* (gallfly) larvae feeds on stems of the chromolaena weed, causing galls (or swellings) which stunt the plant and reduce seed production
	Rope and washer pump	Provides water for irrigation and household use. Keep crops growing even during drought. Cheap and easy to manufacture using local materials. Manual pump, no fuel or lubricants needed.
Cabbages	Use of diadegma as bio control agent in IPM of cabbages	Diadegma to control Diamondback Moth (DBM). Diadegma is a parasitic wasp of the DBM larvae. Rate of parasitism on DBM is very high (60%–100%).

Source: National Agricultural Research Institute (NARI). 2010. *Recently Released Technologies for Papua New Guinea Farmers.* NARI, Papua New Guinea.

agricultural extension activities. In practice, agricultural extension functions were decentralized to the provinces through a reform process (MAL 2007a). Agricultural extension and training programs are currently undertaken in 19 provinces and 89 districts (MAL 2007a). Expected outcomes outlined in the NADP include (i) at least 25% of provincial agricultural staff to be trained to upgrade their technical skills; (ii) at least 50% increase contact with farmers by extension officers by 2016; (iii) at least 50% improvement in networking with smallholder farmers; (iv) at least 60% improvement in farmers' skills in various agricultural enterprises in each district; (v) increased income-earning opportunities for rural families through the development of agricultural enterprises; (vi) understanding of food security and poverty alleviation issues by rural and village communities and agreement to address these two issues; (vii) reduction in social problems and urban drift as income-generation activities increase in the districts; (viii) increased internal revenues for provincial government derived from agriculture projects; (ix) innovative agricultural extension and market services provided to smallholder farmers; and (x) innovative extension services prompt a 10%-20% increase in the output of coffee, cocoa, and coconut commodities.

Table 4.4 Partial List of Current Agricultural Research and Development Projects Undertaken by the National Agricultural Research Institute, Papua New Guinea

Project	Description
Evaluation and Adaptation of Open-Pollinated Maize Varieties	Objective is to introduce, evaluate, and recommend open-pollinated maize varieties suitable for subsistence and smallholder farmers in both highland and lowland environments.
Improving Yields and Economic Viability in Peanut Production	Objectives are to generate information on peanut production, postharvest storage, utilization, marketing systems, and extent of aflatoxin contamination in the major peanut production regions; crop-modeling approach and field experiments are used to develop and implement improved choice of variety and management approaches for economically sustainable peanut production
Taro Improvement Program	Aim is to create new improved varieties for PNG farmers using a conventional method that involves a cyclic approach in a system of recurrent selection; these new varieties are bred for three important agronomic traits: taro leaf blight (TLB) resistance, good eating quality, and high yield, along with consistent performance
High-Yielding Legume (Pulse) Varieties for PNG	Objectives are to introduce and evaluate germplasm of legume pulses (cowpeas, peanuts, mung beans, and soybeans) for yield and suitability, develop suitable production practices for adapting, and develop standard protocols and extension materials for seed multiplication and variety maintenance.
Rice varieties for the Lowlands and Highlands of PNG	Major objectives are to provide technical information on the production, mechanization, and marketing of rice and other grain crops by conducting relevant applied research on the feasibility of various technologies; these technologies include production methodologies, selection of suitable varieties, pest and disease management, farm mechanization, postharvest handling and storage, marketing and economics, and consumer demand and preference; current activities include continuation of evaluation for improved varieties for agronomic traits, research on village milling and postharvest, quality of seed production, germplasm conservation, information sharing and farmer training in both lowland and highland areas
Use of pathogen tested in planting materials to improve sustainable sweet potato production in the Solomon Islands and PNG	Objectives are to describe and evaluate sweet potato seed supply systems in both countries, to introduce and evaluate improved sweet potato varieties, and to introduce, refine, and disseminate technologies for improved sweet potato seed supply systems for smallholder practicing low-input agriculture.
Management of potato blight disease	Current project activities include selecting potato varieties resistant or tolerant to potato late blight, developing cost-effective and safe fungicide spray technologies for late blight management, continuing to streamline PNG's seed production programs to incorporate resistant clones, developing integrated management strategies for late blight, and developing a training and extension program
Mitigating the threat of Banana Fusarium Wilt	Main outputs of the project will be a manual of farmer-evaluated tactics for disease management, national strategies, and improved capacity for disease exclusion, containment, and control
Fruit fly management in PNG	Present activities are conducting trials and implementing various technologies for fruit fly control on a Participatory Technology Development (PTD) approach; these technologies will include protein baits, physical barriers, bagging, Male Annihilation Technology (MAT), Control, Confidor, and MAT & Protein Bait combination
Reducing Pest and Disease Impact on Yield of Sweet potatoes in the Highlands	Objectives are to develop and test strategies to control sweet potato weevil and diseases and to disseminate adoption of "Pathogen tested" clean planting materials in an Integrated Pest Management Strategy
Evaluation of International Banana Varieties and Hybrids Resistant to Sigatoka Leaf Diseases	Objectives are to assess yield and growth performance of five international banana hybrids and varieties resistant to Sigatoka Leaf Disease against local varieties, observe the re-infection rate of Sigatoka leaf disease in the fields, and assess consumer preferences for both dessert and cooking bananas
Domestication and Commercialization of Galip Nut (Canarium Spp.)	Activities of the project include: development of various propagation methods for galip propagation; nationwide prospecting, characterizing, selecting and multiplying individual trees that have superior commercial traits for cultivar development and field tests; and improving market prospects for nut products in Melanesia
Andean root and tuber crops as alternative food in frost vulnerable areas	The project involves on-station evaluation for yield and consumer acceptability of three Andean root crops: Oca, Mashua, and Ulluco; on-farm evaluations will follow to assess yield at various high altitude sites and consumer acceptability
Cassava Starch Project	Aims to select high-yielding suitable cassava varieties for ethanol production

Source: National Agricultural Research Institute (NARI). 2010. *Recently Released Technologies for Papua New Guinea Farmers.* NARI, Papua New Guinea.

Outsourcing of extension services through private and donor projects due to weaknesses in the public extension system has been utilized in the past (MAL 2007a). Weak extension has led the government to promote commodity-based extension services through the semi-independent coffee and oil palm agencies, such as the Oil Palm Industry Corporation and Cocoa Coconut Institute of PNG. Some extension services are provided by organizations affiliated with churches (e.g. the Lutheran Development Service and the Salvation Army) (Bourke and Harwood 2009). Other public agencies involved in extension include the Fresh Produce Development Agency, National Agricultural Research Institute, Coffee Industry Corporation, and University of Natural Resources and Environment (formerly the University of Vudal). There are numerous locally based NGOs that offer only minor agricultural extension activities, given that most are under-resourced and have limited technical skills (Bourke and Harwood 2009). The lack of a national coordinating NGO body allows inefficiencies, such as duplication of effort (Bourke and Harwood 2009).

In Solomon Islands, the Ministry of Agriculture and Livestock's administers agricultural extension services through its Department of Extension and Training (DET). The country's extension officers are mainly involved in donor-funded activities (Bourke et al. 2006). Evans (2006) reported an estimated 150 extension workers in Solomon Islands. Three major projects have provided technical assistance to the agriculture extension:

1. *The Rural Services Project in 1984–1991*. This project was funded by ADB and the International Development Association (part of the World Bank) to a value of $12 million, with 15% of the budget contributed by the Solomon Islands government. The major extension activities included the National Agricultural Training Institute at Fote Field Experiment Station, north Malaita, which was amalgamated into the Solomon Island College of Higher Education in 1991 (although ethnic tensions left this college inoperative). The project provided support for extension services in the form of salaries, housing, and travel. In addition, seven rural development centers were built in the provinces to provide training, extension, and demonstrations (which were not successful). An assessment of this project indicated that it set overly ambitious targets, left too little time for initiatives to be integrated into the DET framework; and that the government was unable to provide sustainable financial assistance to maintain infrastructure. As a result, the project was deemed a failure and follow-up proposals were not implemented.
2. *Smallholder Development Program, 1989–1993* (funded by EU Stabex funds). This project focused on improving production and productivity of smallholder copra and cocoa. Similar to the previous project, however, it was deemed unsuccessful based on misguided policy, insufficient participation by rural smallholder farmers, and what was considered wasteful use of resources (through large-scale delivery of free inputs through a centrally administered system).
3. *Farmers Support Program, 1994–2000* (funded by EU Stabex at S$11 million per year). This project emphasized farmers' needs and supporting extension delivery mechanisms. Unfortunately, the ethnic tensions of the late-1990s prematurely put an end to this project.

The lack of integration of the above three projects into DET deterred the continuity of support for project assets and activities when donor support was terminated (AgriSystems 1993; Morgan and Lokay 2000; Evans 2006).

In 1997–2000, New Zealand Official Development Assistance (NZODA) funded the Women's Agricultural Extension Services Project in Solomon Islands (Evans 2006). The project was designed to increase rural women's ability to produce food crops for subsistence and income generation by providing support for female agricultural extension officers within DET. Significant progress had been made in the training of women when ethnic tensions prematurely put an end to the project.

Other projects, such as the FAO's "Capacity Building for Farming Systems Development in Support of the Special Program for Food Security," which eventually ran from 2004 until 2006, were delayed because of the ethnic tensions. The major activities of this project included improving food production through participatory on-farm demonstrations, and by reinforcing extension and research capacities (Evans 2006). Agricultural extension was to be a major part of the reform process of the late-1990s, but once again ethnic tensions prevented this. MAL's current extension plan emphasizes support for copra and cocoa production (mostly financed by Australian Aid's Community Peace and Restoration Fund), and rice production (financed by Taipei,China).

Several national and provincial NGOs have capacity in agricultural production and development. Kastom Gaden Association (KGA) is the best-known NGO providing technical assistance to farmers. Additionally, the Melanesian Farmers' Network was created with KGA assistance for the purpose of facilitating cooperation and peer-to-peer extension between the Solomon Islands, Bougainville, and PNG farmers (Evans 2006).

Recommendations for Agricultural Research, Extension, and Training

The trend toward inadequate and declining public investment in agricultural research needs to be reversed. A useful approach would be to target growth in agricultural research to an appropriate level of intensity, as is being encouraged in Africa under the Comprehensive Africa Agriculture Development program. Agricultural research funding should increase by at least 10% per year in real terms in the three countries in order to triple the existing agricultural research investment intensity to at least 1.5% of agricultural gross domestic product (GDP). Advancement in productivity and profits from improved agricultural research and extension and market liberalization can contribute to substantial increases in rural income and poverty alleviation. Input from farmers, local farmer groups, and NGOs can stimulate innovation and adaptation and then promote their impact. Increased research funding should also be accompanied by reform of technology support policies and regulatory systems. Intellectual property rights must be addressed to ensure that the benefits of modern science and technology reach smallholder farmers. Resource-poor farmers will be excluded from the benefits of modern science, including biotechnology, if measures are not taken to avoid social exclusion in the dissemination of new agricultural technologies.

In addition to increasing investments at the national level, it is essential to improve regional cooperation for agricultural research. The individual countries do not have the critical mass of scientists needed to meet the complex breeding challenges associated with yield growth and breeding for resistance to biotic stresses such as pests and disease, and abiotic stresses like drought and heat that will be exacerbated by climate change. Efforts at regionalization of agricultural research can build on the current programs with the Secretariat of the Pacific Community. In addition, more advanced techniques could help at the regional level. Investments in conventional breeding and tools of biotechnology, such as marker-assisted selection and cell and tissue culture techniques, could boost crop yield growth in both irrigated and rainfed environments.

Biotechnology, in the form of molecular breeding approaches has rapidly changed programs to improve a number of economically important crops in developed, and increasingly in developing, countries. Molecular marker approaches have provided tools to select for root architecture and virus resistance. The application of these tools has not yet become central to public sector breeding programs. High-throughput marker platforms are not currently in use and are a clear opportunity to improve crops for poor farmers across a range of objectives. Significant benefits would be provided by international donor investments in a regional center of excellence that would launch a major program to improve the efficiency and effectiveness of public crop-breeding programs of importance to poor farmers.

Agricultural training and extension need to be implemented as a multi-institutional network of knowledge and information support for agriculture and rural development. Two approaches that should be extended and integrated are demand-driven and pluralistic extension approaches. Demand-driven services suggest that extension packages given to farmers, women, and more marginalized members of the communities are more responsive to their needs, thus making these participants more accountable with higher degree of effectiveness (Birner and Anderson 2007). Pluralistic extension services make use of a wide range of institutions, where the advisory service delivery and funding are provided by both the public and private sectors (Alex et al. 2004). This approach assumes (i) that the private sector, including NGOs, can provide extension services more efficiently and effectively than can public agencies, thereby increasing the likelihood of long-term and sustainable services; (ii) that transferring funding for extension to private end-users provides them with greater ownership and thereby enhances a demand-driven service; (iii) that each type of private provider has its own niche and comparative advantage, allowing for complementarity of providers; and (iv) that it is vital for the public sector to continue to be a major player, both in funding and coordinating operations (Alex et al. 2004). In some cases, commercial farmers pay for extension advice, while the government provides extension services to smallholder producers free of charge.

It is essential to begin the reform of extension policy with an inventory of the actors, in terms of who provides what to whom, and an assessment of the quality of the services rendered before deciding on any reform, regardless of the approach applied (World Bank 2004). It is likewise necessary to have extension strategies that identify the overall objectives of public sector involvement in extension, and define the role and responsibilities expected of various service providers and of public funding (Alex et al. 2004). Coordination and regulation among extension service providers are also needed, especially to prevent conflicting technical recommendations.

Decentralized, demand-driven, and participatory programs are more democratic in design and more successful in implementation (Alex et al. 2004). This approach transfers power from central government to institutions or participatory systems at lower levels to ensure that public services meet the preferences and demands of local people. Decentralization increases community participation and ownership of programs. Since producer organizations are involved in extension activities, it helps to engage them in programs that coincide with their own goals. The main constraint under this approach is the lack of an operating budget.

Private companies are most likely to be effective in providing extension for commercial crops, such as palm oil, coconut, and sugarcane. But even for these commercial crops, there is a need to define an appropriate role for public institutions in agriculture, based on available funding and capacity to provide reasonable coverage to dispersed rural communities (Anderson and Parker 2004). For subsistence crops, the government and NGOs will need to take a stronger role because there is little incentive for private companies to participate in extension for these crops. The decline in public extension services therefore needs to be reversed. For example, in PNG, the provincial and local governments need to rebuild and play an important role in through the provision of extension services. There is an urgent need to build the capacity of the provincial and local governments in order for them to build linkages and facilitate partnerships, provide natural resource management and economic information, and develop mechanisms for joint policy development and priority setting in their respective areas.

Fisheries Policies

Subsistence and Coastal Fisheries

Challenges Facing Subsistence and Coastal Fisheries

Significant proportions of the populations of Pacific island countries depend on subsistence and coastal fisheries for food and livelihood security (e.g., around 80% in Solomon Islands). Despite this, activities often lead to the abuse and misuse of this important resource. The absent or uncontrolled waste disposal system is a key example, whereby sewage and garbage are directly dumped into the sea. Coastal development is excessive, and siltation and sand mining are further harming both freshwater and marine resources. In addition, uncontrolled logging activities in Fiji, PNG, and Solomon Islands trigger soil erosion (Kajiura 2010) affecting river systems and inshore waters, eventually increasing the silt load of the oceans and thus harming coral reefs. Another human-induced activity is the improper disposal of goldmine tailings in PNG that not only harm the river and ocean systems, but also the health of the immediate and surrounding communities (Kajiura 2010). These activities degrade the fish habitat, and thus negatively impact fisheries resources.

Rising population and incomes in the three countries under study have increased local fish demand and promoted the tendency to overexploit resources through increased fishing pressure—a problem not only in Pacific islands, but also in other developing and developed countries. Extensive illegal fishing methods, such as fishing without a permit, using dynamite (in the western province of Fiji), and applying cyanide, are some of the practices used by fishers to harvest more of the coastal fisheries resources (Hand, Davis, and

Gillett 2005). Excessive harvesting of inshore resources particularly occurs in areas close to urban markets (Gillett 2011). Further, growing export demand for sea cucumber and shell products promotes uncontrolled harvesting in rural areas and outer islands (Preston 2005). The lack of awareness of coastal communities on the consequences of overexploitation and lack of alternative livelihood opportunities result in continuous, unsustainable harvesting of coastal fisheries resources.

Coastal fisheries resources have often been overexploited by rural and adjacent communities because small-scale fishers have difficulty accessing offshore fishery resources. In addition, the rising cost of inputs such as fuel has had detrimental effects on small-scale motorized fisheries.

The increasing shift from subsistence to a cash economy is another issue affecting coastal fisheries (Kajiura 2010). Related to overharvesting of the resources is the emergence of fish as a cash commodity, in turn gearing the society toward a cash economy. Unlike crops that take time to mature and be harvested, fish are readily available and can immediately be converted into cash. This scenario transforms subsistence fisheries into commercial or semicommercial operations, providing rural communities with opportunities to earn cash and satisfy their food, nutrition, and other needs (Kajiura 2010).

Pacific island countries have developed management plans for their fisheries sectors, but the limited capacity and resources available to national and provincial fisheries agencies hamper the full implementation of policies and regulations. This is further aggravated by recurrent ethnic tensions that have led to deterioration in the quality of governance, and reduced domestic and foreign direct investment and foreign aid.

Current Performance and Policies in Subsistence and Coastal Fisheries in Fiji

Fiji is endowed with 1.29 million km^2 of water area and 5,010 km of continental coastline (FAO 2009). As mentioned in Chapter II, almost half of the population of Fiji lives in rural areas and relies on subsistence fishing (including fish farming) for food and livelihood. Subsistence fisheries contributed F$38.35 million of the country's F$5.26 billion GDP in 2007, at current market prices (Gillett 2009).

The Department of Fisheries (DOF) under the Ministry of Fisheries and Forest in Fiji is responsible for managing the country's fisheries resources. It supports the expansion of fisheries production into more remote areas through the use of rural service centers;[20] the development of small-scale aquaculture operations; the use of fish aggregating devices (FADs) and boat subsidies; and the emerging role of fisheries management, in terms of benefits, preservation, and sustainable management of the resources. The Fisheries Act 1942, Chapter 158, created the Native Fisheries Commission to ensure the protection of the *qoliqoli*, which are communally owned and managed in each province, similar to customary land ownership.

20 These centers, located in remote villages in Fiji, provide an ice plant, fish storage facilities, a slipway, jetty, fish grading/processing facilities, collection vessels, pick-up trucks, and office facilities. The centers were created through a policy directive of the national government in an effort to support resource owners in fully benefiting from their fishing grounds, and to support economic growth and livelihood security (Singh 2005).

Under the Fisheries Act, management objectives for the 406 traditional management areas in subsistence fisheries do not exist in Fiji. Rather, subsistence fisheries are administered for the protection and assurance of the availability of food supplies for the villages (FAO 2009). A traditional authority, normally the single hereditary chief of the village, develops and enforces management decisions in consultation with resident stakeholders (FAO 2009). Some of these measures include limiting outsider access to fishing areas and restricting fishing activities, such as banning the use of gillnets, commercial fishing on Sundays, and use of diving compressors by the local residents. But traditional management systems have not consistently performed well in maintaining sustainable fish stocks and generating income for the communities. Procedures for obtaining fishing licenses have not been systematized, and the prices of licenses have varied and been arbitrary relative to their financial returns.

Similar to traditional fisheries, formal objectives have not been specified in the legislation or management plans for coastal fisheries (FAO 2009). Based on various programs, however, DOF's main goals are to promote the sustainable use of resources, maximize economic returns, and ensure that commercial fisheries do not negatively affect subsistence fisheries (FAO 2009).

In order to improve the performance of traditional fishery systems, Fiji implemented a program of locally managed marine areas (LMMA), a novel form of management under which ocean resources are managed through a combination of traditional and modern methods of biological monitoring and assessment (LMMAN 2008). LMMA are areas of traditional fishing grounds within which restricted access is enforced to allow the recovery of marine resources. As marine resources are left to recover in these restricted areas, stocks gradually increase in nearby parts of the LMMA where fishing is allowed. This "spillover effect" offers substantial benefits to communities. Experts from the Fiji' Island's LMMA partner organizations, such as the University of the South Pacific and the Fijian Fisheries Ministry, provide technical information and advice to support community decision making. The LMMA model also offers some solutions to emerging climate-related problems by reviving traditional knowledge and combining it with modern tools. This strategy aims to provide food security for local populations that are dependent upon fish stocks and other marine resources for their livelihoods and employment. The LMMA strategy of replanting mangroves and coastal trees to reduce coastal and riverside erosion will combat effects of climatic change.

The first LMMA was established in 1997 in the small village of *Ucunivanua* on the eastern coast of the country's largest island (LMMAN 2008). Thereafter, the system was extended to other areas of Fiji. LMMA can be established based on the needs of the community to ensure clarity, transparency, and bottom-up approaches. Furthermore, involving the community is an effective method of managing the natural resource base and is arguably more effective than centralized, top-down approaches (Watts and Bourne 2009).

The LMMA approach has been successfully applied to Fiji clam fishery (Watts and Bourne 2009). Given declining capture fisheries resources, restricted areas were established in consultation with the local fishers, DOF, Fijian Affairs, and other experts. A mid-term review showed a 250%–300% increase in the productivity of the clam fishery, and a 10% increase in household incomes (Watts and Bourne 2009). These impressive improvements indicated the effectiveness and efficiency of community-based adaptive management. The recognition of the need of the community, the involvement of the community members, and the training provided (through community workshops) are important steps in ensuring the success of this type of management scheme for subsistence and coastal fisheries.

It should be noted, however, that while the LMMA approach has had considerable success, DOF has limited resources with which to fully implement the government's policies and regulations in the fishing industry. As with land policy reform, governance of the sector presents a major constraint.

Current Performance and Policies in Subsistence and Coastal Fisheries in Papua New Guinea.

Subsistence fisheries are a valuable component of PNG's fishing industry (Allen, Bourke, and McGregor 2009). As discussed in Chapter II, an estimated 500,000 people engage in inland and coastal subsistence fisheries, resulting in a catch of around 25,000–50,000 tons of harvested fish products annually (Allen, Bourke and McGregor 2009). Yet, despite this, PNG's subsistence fisheries sector is not well documented. The National Fisheries Authority (NFA) manages all fisheries in PNG as specified by the National Fisheries Management Act 1998. Other relevant legislation relates to the environment, maritime zones, shipping and maritime safety, and laws governing the management of private businesses.

The majority of PNG's population (87%) live inland, without any direct access to marine resources, making them more dependent on freshwater resources (Coates 1996). Around 50% of the people living in highland areas engage in traditional fishing activities, such as harvesting eels and exotic species (FAO 2010). Because fishing activities are limited, commercial use of freshwater fisheries is not a major issue in PNG. Sepik/Ramu and Fly/Purari are the two major river systems in PNG that provide freshwater fish resources. Barramundi and some commercial sales of tilapia are the main marketable fishing activities. Freshwater fishery resources are not well developed for commercial purposes, so they are mostly used for subsistence fishing (FAO 2010).

With the exception of the Fly River barramundi fishery, which is managed by NFA, management interventions for inland fisheries resources are carried out—on an informal basis—by the local communities mainly to support and protect the flow of food from freshwater fisheries to the villages (FAO 2010).

Current Performance and Policies in Subsistence and Coastal Fisheries in Solomon Islands

Solomon Islands is estimated to have around 1.34 million km^2 of water area, offering rich marine resources (FAO 2009; Gillett 2009). Subsistence fisheries are an important source of food, nutrition, and, to some extent, income given that more than 80% of Solomon Islanders live in rural areas (Gillett 2009). The Solomon Islands Fisheries Act 1998 outlines the country's objectives for fisheries development and management. It upholds the assurance of long-term conservation and sustainable use of resources for the benefit of Solomon Islanders (FAO 2009).

Traditional management arrangements are applied to coastal subsistence fisheries. FAO (2009) reported that almost 85% of inshore marine areas are customarily owned and managed by local villages, tribal groups, and communities. Similar to Fiji, traditional authorities, such as the hereditary chief of the village, form and implement management decisions in consultation with resident stakeholders (FAO 2009). Interventions limit outsider access to fishing areas and inputs introduced into fishing activities by local residents. Some of these restrictions involve periodic bans on harvesting in specific areas, as well as bans on the types of fishing gear that can be used (FAO 2009).

Similar to PNG, large inland populations have no direct access to marine food resources, so most Solomon Islanders depend on freshwater subsistence fishery resources even though they are far more limited than marine fishery resources (FAO 2009). Little information is available on interventions for managing inland fisheries in Solomon Islands. As already stated, management is geared toward protecting and ensuring the availability of village food supplies (FAO 2009). In addition, temporary and long-term bans are enforced, mostly in export areas (FAO 2009). Examples of the bans include the temporary national ban on the sea cucumber fishery in 2006 and the long-term ban on gold-lip pearl shell, turtle shell, and crocodiles (FAO 2009). The Solomon Islands' Ministry of Fisheries and Marine Resources develops the interventions, and enforcement is implemented by (nonfishery) government officials at the point of export. Note, however, that other coastal communities have their own management approaches to coastal commercial fisheries, including the residents of Ontong Java atoll, who implement alternating year-long bans of sea cucumber and trochus fishing to allow stocks to be replenished (FAO 2009).

Recommendations for Subsistence and Coastal Fisheries Policy in Fiji, Papua New Guinea, and Solomon Islands

Conservation, preservation, and sustainable management and use of natural resources require active partnerships among all stakeholders, including urban and rural communities, government institutions, the private sector, and donor agencies. The recommendations that follow are valid not only for subsistence and coastal fisheries, but also for the fisheries resources of inland and marine ecosystems.

Pollution entering aquatic systems from the land can be minimized through community awareness programs, integrated actions by the responsible ministries, and strict monitoring to ensure compliance by various parties. Environmental impact assessments should be mandatory for industries that run the risk of causing water pollution—as is the case with goldmine tailings in Fiji, PNG, and Solomon Islands—that will eventually affect the harvests of subsistence and inland and coastal small-scale fishers. Mitigation measures should be clearly provided and acted upon by the responsible parties. Appropriate preventive measures should be rigorously followed, and fines should be high for all those polluting/harming parties to ensure compliance with policies. Regular monitoring, control, and surveillance must be implemented by the responsible government agencies.

The creation of alternative livelihood options and employment would also contribute to preventing the overexploitation of coastal fisheries. Developing networks using low-cost inshore fish aggregating devices (FADs) would enable subsistence fishers to access tuna fishery resources, thereby improving their livelihoods. Fish aggregating devices are floating objects made of ropes, floats, and other materials intended to attract tuna and make them easy for fishers to find. In 2009, Prange, Oengpepa and Rhodes conducted a study on nearshore fish aggregating devices as a way of protecting habitats, while ensuring food security, particularly during postdisaster events in Solomon Islands. These low-cost devices draw tuna to nearshore areas, allowing subsistence fishers to catch them, thereby supplementing both their food and income needs. The government and private sector can provide much-needed assistance to coastal communities to lessen pressures on fisheries resources, but this would requires private sector business investment, e.g. in tuna canneries (similar to Soltai in the Solomon Islands) and hotels and restaurants that will create local jobs and other means of generating income.

Current fisheries management policies need to be examined, and policy enacted to convey the government's priority of protecting, conserving, and supporting the sustainable use of inshore fisheries as opposed to promoting increased production and harvesting of these resources (Hand, David, and Gillett 2005). In addition, management plans need to be instituted for important resources like sea cucumber and trochus, and for commercial fishing methods, such as gillnetting, spearfishing, and aquarium fisheries. Management plans can address a number of fisheries issues but they need to be implemented and enforced, and they also need to be regularly reassessed to ensure their applicability and success in achieving targeted objectives.

Improved enforcement of LMMA regulations is a key issue. Other issues include ensuring that the needs of women and children are represented in management committees and that alternative income-generating activities are available to reduce the incidence of poaching and overharvesting (LMMAN 2008). Hand, David, and Gillett (2005) suggest, although *qoliqolis* are primarily managed by the local communities, they could be more effectively utilized through the addition of the following government initiatives: (i) developing policy to define and protect village fishery supplies; (ii) creating community awareness of the need for and benefits of environmental protection, disaster and risk management, and formal fisheries management plans, including the provision of support and assistance in preparing the plans; (iii) building support for a more active government role in operating LMMAs; and (iv) revitalizing the system of fish wardens to address extensive problems on illegal fishing.

Additional management measures and research opportunities for subsistence and coastal fisheries include decentralizing and devolving responsibilities from national to local government officials; identifying fishing seasonality and fishing areas; assessing stocks through studies in support of fisheries management plans; determining workable license renewal schemes and restrictions; examining limits on the size of fish in catch; establishing fishing gear restrictions; verifying the total allowable catch; developing marketing standards; and determining the potentials of commercial exploitation of freshwater resources. Research on sustainable fisheries management to determine and strengthen the role of protected areas and customary resource management regimes would also be helpful. Once these strategies have been trialed and proved successful they can be scaled-up to other areas.

The above recommendations point to the crucial need for improving the effectiveness of the fisheries departments in the three study countries. There is a need to reinforce government initiatives on reducing the exploitation of coastal fisheries resources. Moreover, it is vital to enhance the capacity of staff to manage, oversee, and enforce management plans at the national, provincial, and local levels.

Aquaculture

Challenges Facing Aquaculture

Aquaculture creates employment, increases fish supply, and lessens pressure on capture fisheries, making it a viable alternative source of fish for developing countries, such as those included under the present study. Nonetheless, aquaculture also has inherent problems that need to be studied before initiatives are fully implemented or scaled-up. Issues relating to aquaculture in the three study countries include the geographic distances between fish farms and seed/fingerling hatcheries; lack of infrastructure, including the availability of materials required to construct and operate an aquaculture plant; availability, accessibility, and quality of seed or fingerlings; and lack of financing to operate and sustain aquaculture operations. Other significant issues include fish farmers' lack of technical knowledge in terms of seed production techniques, ocean rearing and restocking (e.g. as required for sea cucumber), and the availability of technical assistance/extension workers to address fish farmers' concerns or problems.

The absence of environmental controls and monitoring is a serious concern that urgently needs to be addressed. The responsible government agencies have little or no capacity to address environmental issues, provide fish farmers with environmental management techniques for aquaculture, and ensure compliance (Hand, Davis, and Gillett 2005). The absence of an appropriate legal environment in aquaculture development in the three study countries needs to be addressed (Hand, Davis, and Gillett 2005). Related management objectives, legislation, and policies are not clearly defined in Fiji (FAO 2009), PNG (FAO 2010), and Solomon Islands (FAO 2009). The following areas need to be defined through policy, legislation, and management plans: (i) the distinction between aquaculture and capture fisheries; (ii) provisions on licensing schemes for aquaculture; (iii) environmental protection mechanisms; (iv) the establishment and recognition of property rights in marine and coastal areas, and the right to exclusively take fish in the farm area; (v) land tenure in terms of feasible lease periods (the current 15 years is too short and may impede growth of the industry); and (vi) the need to introduce water leases—i.e., leases below the high water mark in Fiji (Hand, Davis, and Gillett 2005). A recent concern in aquaculture farming is the need for a clearer regional biosecurity framework to protect biodiversity and prevent the entrance of invasive species.

The lack of adequate human resource capacity is another urgent issue. Capacity is needed in collecting and collating data, and in instituting proper data-keeping and reporting procedures. Accurate data records are also important for assessing aquaculture's contribution to GDP (Hand, Davis, and Gillett 2005). In addition, the implementation of national aquaculture programs is impeded by the lack of skilled staff and facilities, as well as the high turnover of trained technicians. Lack of technical and business knowledge in fish farming operations compromises the feasibility and sustainability of aquaculture.

Other challenges outlined by Ellis (2010) include issues relating to marketing, such as distance from many major markets, poor understanding of international markets, lack of transportation and/or communications, the need for niche marketing and lack of a profitable market. Price and competitiveness of aquaculture are major challenges to small island nations such as those in the Pacific. It is difficult for these developing countries to compete in a globalized world; the comparatively high cost of aquaculture business; the inability to produce sufficiently to meet the demands, and thus scaling-up of operations may be difficult and not feasible (Ellis 2010).

Faced with low levels of financing and unavailability of resources, aquaculture suffers from perceptions of a poor track record, insufficient government support, and absence of or uncooperative lending from banks, which consider aquaculture operations to be high-risk ventures. Similar to subsistence and coastal fisheries, ethnic tensions in Fiji, PNG, and Solomon Islands have sometimes resulted in an unstable political environment that harms potential investments in the three study countries, with detrimental effects on availability of food, employment opportunities, improvement and availability of alternative livelihoods, and on nutrition among the rural poor.

Current Performance of, and Policies Relating to Aquaculture in Fiji

The Government of the Republic of Fiji developed the Freshwater Aquaculture Sector Plan 2005–2010 to promote aquaculture to improve the nutritional status of rural populations as well as to reduce the flow of migration from rural to urban areas (Billings 2011). Other new initiatives in 2011 include the development of a commercially vibrant and economically significant pearl farming industry, the development of biosecurity policy, aquaculture legislation approved and adopted, and a cluster farms model for prawn farming for trial (Billings 2011).

Despite the financial support provided by the government and other external donor agencies, aquaculture remains poorly developed in Fiji (Hand, Davis, and Gillett 2005). Aquaculture operations in Fiji include the following:

1. The seaweed industry in 2000 (ADB 2005; Hand, Davis, and Gillett 2005; and Gillett 2009). There are around 658 farms developed in 47 villages/settlements around the coast and maritime zone with an average annual production of 300 metric tons valued at F$275,000. The government has provided over F$1.8 million since 1998 in direct seaweed assistance to farmers with total production of 1,413.8 tons and an export value of F$1.5 million. This indicated the high total subsidy of F$1.8 million against value of exports at F$1.5 million.
2. Shrimp farming (Hand, Davis, and Gillett 2005; and Gillett 2009). More than F$4 million assistance spent for the past 10 years but production remains low (currently about 1 metric ton).

3. Tilapia and freshwater prawn (SPC 2004; Hand, Davis, and Gillett 2005; and Gillett 2009). The Fiji government provided F$ 2.02 million since 1997 to support the development of infrastructure and extension services; currently at 300 fish farms of different sizes, covering 48.22 has of land, but only17 farms are commercial; and
4. Pearl farm development (Hand, Davis, and Gillett 2005). An allocation of F$0.42 million was provided by the Government of the Republic of Fiji since its inception in late 1990s. This industry has successfully produced over 30,000 pearls in 2004.

The aquaculture sector has received substantial financial assistance from the government. Despite this assistance, the economic performance of aquaculture has been poor. The issues discussed under challenges, such as poor assessment of opportunities, inadequate development support, and governance issues, may be the reasons behind its weak economic ability. Prior to providing financial support to these aquaculture operations, there is a need for an objective marketing and feasibility studies on farmed species and fish farm operations conducted in different areas in the country. The DOF can improve the business environment of Fiji through analyzing features related to tax structure, administrative blockages, investment and land and marine tenure (Hand, Davis, and Gillett 2005). Hand, Davis, and Gillett (2005) suggested that the potential and opportunities of aquaculture have been overestimated and past aquaculture development work was inappropriate; governance issues that negatively affect aquaculture and the need to remove impediments to growth may be some of the reasons behind the weak performance of the sector.

DOF needs to meticulously analyze and assess the costs and benefits of the different aquaculture programs implemented in the country and receiving substantive support and assistance from the government. Operations that are unlikely to succeed must not receive support. According to Hand, Davis, and Gillett (2005), if government funding will be provided to fish farmers it should be proportionate with the expected future returns. At the same time, there is a need to consider the high level of uncertainty of fish farming such as declining fish prices, risk of diseases, problems in producing fingerlings, and other difficulties in maintaining the farm, the yield, and even those related to source of feed at reasonable costs.

Current Performance of, and Policies Relating to Aquaculture in Papua New Guinea

Since 1954, freshwater aquaculture has been promoted and carried out in PNG (FAO 2010). Fish culture operations include carp, eels, catfish, gourami, perch, tilapia, and trout. The national government program focused on freshwater aquaculture involving common carp and rainbow trout hatcheries in highland and inland areas, restocking of natural water bodies with introduced species and promotion of small-scale commercial aquaculture operations until the mid-1990s (FAO 2010). This national program was handed over to the provincial governments in late 1995.

The Highlands Aquaculture Development Center (HADC) was established in Ayura, Eastern Highland Province (Mufuafe et al. 2007). The center is nationally important because of its production of common carp seeds for distribution to farmers in PNG and production of rainbow trout seeds supplied to farmers from the private sector (Mufuape et al. 2007; FAO 2010). In 2006, an estimated 8,000 small-scale fish farmers had active ponds, while around 2,000 fish farmers had ponds without any seeds for stocking (FAO 2010).

Several externally funded research projects given to HADC have improved hatchery capacity as well as availability of training courses for fish farmers. These projects also served as quarantine facilities and trial farms for several exotic fish species introduced through some projects in an effort to boost inland fish farming and stock enhancement in open water bodies (FAO 2010).

In 2002, genetically improved farmed tilapia (GIFT) was introduced and fingerlings distributed to farmers (FAO 2010). GIFT farming considerably relieved the chronic bottleneck of seed shortages in developing fish farming in PNG. In addition, the fast growth of GIFT fish enabled the farmers to produce fingerlings in their own ponds. Farming of tilapia boomed in PNG resulting in a dramatic increase in aquaculture production in 2005 (FAO 2010).

According to FAO (2010), recent aquaculture development in PNG involves

1. Coral Sea mariculture on Samurai Island, where cultivation of silver-lip pearl oyster (*Pinctada maxima*) is undertaken;
2. Coconut Product Limited, Rabaul, where prawn culture is done in earthen ponds;
3. Western Province Sustainable Aquaculture, Daru, which is a company focusing on setting up a barramundi hatchery to produce barramundi fingerlings for restocking and conservation, especially in the areas affected by the Ok Tedi mine; and
4. Nago Island Mariculture and Research Station.

As mentioned in the discussion of subsistence fisheries, the National Fisheries Agency (NFA) is the government entity responsible for fisheries management in PNG. A National Aquaculture Development Policy was developed which defines several areas of aquaculture and its management (FAO 2010). For example, aquaculture conducted by the private sector uses economic profit as the motive while subsistence aquaculture is more to enhance food security and provide some alternative sources of income. A National Aquaculture Development and Management Advisory Committee was also established to serve as medium for aquaculture stakeholders to collaborate and develop aquaculture. The NFA Aquaculture and Inland Fisheries Unit is newly created to undertake research and development of aquaculture and its main role includes addressing constraints; research and collaboration; luring investors; research and development activities; and assistance and funding where necessary (FAO 2010).

The NFA Corporate Plan 2008–2012 provides a list of priority actions for aquaculture encompassing (i) regular consultation with stakeholders to promote sustainable fisheries and identify opportunities for potential new fishery and aquaculture development; (ii) a consultative review of the NFA aquaculture policies; (iii) research projects in collaboration with international and national stakeholders; and (iv) collaboration with stakeholders to develop and facilitate training and skill development opportunities to increase human resource capacity in relation to aquaculture development demands (FAO 2010).

Current Performance of, and Policies Relating to Aquaculture in Solomon Islands

FAO (2009) reported the limited aquaculture activities in Solomon Islands. These are culture of *Acropora* coral and soft corals; postlarval capture and culture of lobsters, shrimp and fish, with coral shrimp (*Stenopus* spp.) and spiny lobsters (*Panulirus* spp.); and seaweed culture using *Kappaphycus alvarezii* (FAO 2009).

Lindsay (2007) provides a summary of aquaculture in Solomon Islands. Cultured species in the country include giant clams, penaeid shrimps, freshwater prawns, pearl oysters, seaweed, sea cucumbers, hard and soft corals, milkfish, sponges, and the capture/culture of postlarval animals. Currently, the aquaculture sector makes a minimal contribution to livelihoods in the rural sector. The ethnic tension that led to political instability from the late 1990s to 2003 severely impacted commercial aquaculture operations leading to its closure, and little private sector interest in restarting operations (Lindsay 2007). Further, hard and soft coral culture extended small-scale sustained economic benefits through successful development of community-based farms that address the needs of private sector aquarium companies. Although the seaweed industry is only in its developmental stage, it looks promising and may become viable in the long term (Lindsay 2007).

The establishment of the Coastal Aquaculture Center (CAC) by the Government of Solomon Islands and the International Center for Living Aquatic Resource Management (ICLARM, now WorldFish Center) was the most significant step done by the government in promoting aquaculture in the country. It housed cultured juvenile giant clams for the live aquarium trade as well as for giant clam sashimi markets in Taipei,China and Hong Kong, China in the 1990s. These juveniles were grown out by small-scale farmers after which matured stages were sold to exporters (Lindsay 2007).

Aside from giant clams, CAC started a black-lip pearl oyster collection program to study pearl culture, experimental culture of *beche-de-mer,* and analysis of green snail and *trochus* resources (Lindsay 2007). It is unfortunate that the ethnic tension of early 2000 led to an early termination of operations and closure of CAC. Other aquaculture efforts implemented by other agencies include the Coral Gardens program of the Foundation of the Peoples of the South Pacific International. Its main objective is to alleviate poverty and reverse ecological damage by mariculture initiatives, such as coral culture in Marau Sound, the Nggela Islands, and Langalanga Lagoon in Malaita (FAO 2009). Aside from the initiatives to promote aquaculture development, there is no active management of the aquaculture subsector in the Solomon Islands (FAO 2009).

Recommendations for Aquaculture Policy in Fiji, Papua New Guinea, and Solomon Islands

Several policies need to be improved if efficient aquaculture operations in Fiji, PNG, and Solomon Islands are to be properly supported. Of utmost importance is promotion of objective marketing and feasibility studies for determining the economic viability of aquaculture operations in the three study countries (Hand, Davis, and Gillett 2005). The benefits and costs of programs that support aquaculture must be rigorously assessed in order to ensure that aquaculture projects are likely to succeed, and that any financial assistance provided is commensurate with expected returns (FAO 2010). Regular monitoring and performance reviews carried out within an appropriate time frame are likewise essential in cases in which financial assistance is to be provided to fledgling aquaculture operations. In this regard, the capacity of the government agencies concerned in assessing the environmental impacts of aquaculture operations needs to be strengthened.

Once the feasibility of aquaculture operations has been established, infrastructure development should follow. This includes establishment of ponds, hatcheries, and provision of seeds and fingerlings, fish feed, and other inputs. There is also a need to improve the business environment, including its features relating to tax structure, administrative blockages, investment, and land and marine tenure. Government assistance in key support services such as insurance of availability and quality of fry through funding of public freshwater fish hatcheries is important in the early stages of development. Such programs have been successful in Cambodia, Indonesia, Malaysia, and the Philippines. Viet Nam utilizes its government marine seed center to provide broodstock and conducts research on diagnostic services, new strains, certification, and production standards. Assistance in identifying affordable and reliable supplies of fishfeed using local rather than imported ingredients has also proven effective in Malaysia and Indonesia (Hishamunda et al. 2009).

A transparent legal context relating to aquaculture also needs to be provided. Legislation should clearly define aquaculture itself, as well as its operations, licensing needs, and property rights relating to land, marine, and coastal areas, as well as any exclusive rights to fishing in aquaculture areas (Hand, Davis, and Gillett 2005).

For the government agencies, recommendations regarding aquaculture operations include:

1. undertaking rigorous economic evaluations of aquaculture programs both during the design phase and evaluation phase to determine their viability;
2. establishing an effective and cost-efficient quarantine facility;
3. encouraging active participation by, and strengthening the role of the private sector, particularly regarding the location, configuration, and size of aquaculture farms, unless there is some firm environmental or disease risk or management basis for imposing restrictions on the participation of the private sector; and
4. introducing subsidies for aquaculture programs.

Billings (2011) enumerates the advantages of aquaculture as follows. Aquaculture encourages partnerships and collaboration among the various actors such as national and local fisheries agencies, the private sector, research institutes, community-based fish farmers, conservation NGOs, and funding agencies. It also invites engagement of the private sector, including businesses with expertise in assessing the financial viability of aquaculture operations.

Depending on the size of the aquaculture operations concerned, there may be a need to involve a broker agency, usually a government agency, NGO, or not-for-profit organization (Hand, Davis, and Gillett 2005). Such agencies help harmonize the expectations of sellers and buyers, provide assistance in liaising with community farmers, and often serve as conduits for communication for all parties concerned.

Conservation agencies should be engaged in aquaculture development and operations if possible, since members of local communities better understand conservation measures when such agencies participate. Ultimately, aquaculture can ease environmental pressures on open-water fishing areas, and help minimize loss of income from closure of protected areas.

There is also a need to reduce subsidies. Heavily subsidized projects typically cease operations, when subsidies are removed. Thus, plans for removing subsidies should be phased, with the schedule for their removal being announced well in advance. If possible, projects should be designed in a manner that requires minimal subsidies, if any. This is particularly true since in macroeconomic terms, subsidizing a single industry distorts resource allocation decisions, as providing a subsidy to a single industry is tantamount to imposing a tax on all others.

Tuna Fisheries

Challenges Facing Tuna Fisheries

The contribution of tuna to total fisheries exports is about 60% in Fiji, 87% in PNG, and 90% in Solomon Islands (FAO 2010). Although tuna processing plants offer low wages due to the highly competitive international environment in which they operate, these plants and the fleets that supply them are essential to the national economy, as well as to the welfare of the people they employ. In all, direct and indirect employment in the tuna industry accounts for 5%–8% of total national employment in the Pacific region (Gillett et al. 2001).

While offshore fisheries—particularly tuna fisheries—are abundant in the Pacific, costly equipment such as modern fishing boats and gear are required to access these resources. Subsistence and small-scale fishers thus have little access to the rich tuna fishing areas of the three study countries, and as a consequence are unable to compete with commercial large-scale fishing operations in offshore areas. The issue of access to tuna resources by subsistence and small-scale fishers is thus an important one, if for no other reason than equity considerations.

The issue of by-catch and discards from offshore fisheries also needs to be addressed if the abundance of all fish species and biodiversity in general are to be preserved. Further, the large numbers of offshore vessels currently licensed has resulted in overcapacity in the regional purse-seine tuna fleet, this latter factor putting significant pressure on tuna fisheries in the Pacific. Although some restrictions on tuna fisheries are stated in the management plans of Fiji, PNG, and Solomon Islands, enforcing limits is expensive, and frequently beyond the capacity of the governments concerned. Further, proper postharvest handling of the tuna catch of offshore fishing vessels is often constrained by limited onshore processing facilities.

Scarcity of trained staff and crew also discourages national operators from entering the tuna fishing market. Lack of credit for tuna operators is a further constraint, particularly since loanable funds are required for maintaining larger-scale fishing boats and related facilities. Finally, lack of coordination among government agencies has led to misunderstanding of management policies and, as a result, poor implementation of them. Thus, national and regional management plans, including partnerships among agencies and stakeholders, need greater integration if the potential benefits of such plans are to be captured by individual countries. This is particularly true since at present, Pacific island countries collectively reap only $200 million annually from their tuna fisheries, whereas the value reaped by foreign nations fishing in Pacific waters exceeds $1 billion each year (DEVFISH 2011). As a result, since local fishing industries offer few jobs and low wages, they currently have a minimal impact on ensuring food security and alleviating poverty.

Overall, three challenges constrain the contribution of the fisheries sectors to national economic development in the three study countries. These are (i) the effects of ethnic tensions, which impede all fishing operations and negatively impact the national economy at all levels, (ii) the withdrawal of foreign assistance, and (iii) the weak capacity of government agencies in implementing plans relating to fisheries resources.

Current Performance of, and Policies Relating to Fiji's Tuna Fisheries

Kitolelei, Torii, and Bideshi (2009) show that offshore fisheries are the major contributor to revenue in the fishing industry in Pacific island countries. The main commercial target species are albacore (*Thunnus alalunga*), skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacores*) and big eye (*Thunnus obesus*). Other by-catch fish species are sailfish, opah, sharks, dolphin fish, wahoo, and barracuda. Target markets of Fiji's fish harvest are Australia, the People's Republic of China, the European Union, Japan, New Zealand, and the US.

The management objectives of Fiji tuna fisheries are presented in the Fiji Tuna Development and Management Plan which was adopted in 2002, these objectives still remaining in force (FAO 2009). The major objective stated in the Management Plan is to provide maximum sustainable benefits to Fiji from its fisheries resources. The plan indicated target harvest levels deemed to not damage the size of the fish stock over the long term, and put into practice a licensing policy for ensuring maximum financial benefits from fishing (FAO 2009). The plan also helped reduce the degree of preferential treatment given to indigenous Fijians in accessing licenses (FAO 2009).

The majority of the tuna harvested in Fiji waters are caught on the high seas and in neighboring exclusive economic zones (EEZs), where several vessels were licensed to catch fish in 2004–2006 (Amoe 2010). Interestingly, the catch of Fiji fleets in waters outside the Fiji's EEZ rose from 10% to 55% during the period 2001–2004 (Amoe 2010).

Current Performance of, and Policies Relating to Tuna Fisheries in Papua New Guinea

Because of the large volume of tuna caught in PNG waters, the country has become increasingly assertive in Pacific islands regional fisheries affairs (FAO 2010). PNG also has a large number of tuna processing plants, and thus a large number of people employed in the sector. However, jobs created in tuna processing plants are low-wage cannery jobs. The volume of tuna catch from foreign fishing vessels in PNG waters was 278,459 tons valued at $226 million in 2006 (FAO 2010).

To some degree, tuna processing in PNG is leveraged by PNG's preferential access to European markets. However, that preferential access is increasingly being eroded. Further, the low wages paid in tuna processing plants appear to be insufficient to meet the future expectations of the workforce (FAO 2009; Gillett 2011).

Current Performance of, and Policies Relating to Tuna Fisheries in Solomon Islands

Offshore fisheries open opportunities for formal jobs in the Solomon Islands, particularly, since processed and raw tuna are major export commodities. Further, license fees paid by foreign vessels are a substantial source of government revenue.

Prior to the ethnic tensions in late-1990s to early 2000s, Solomon Islands had the most vibrant domestic tuna industry in the Pacific region. The Solomon Taiyo Fishing Company based in Noro was established in 1973 by the Solomon Islands Government (Investment Corporation of Solomon Islands that held 51% shareholding in the mid-1980s) and the large Japanese fishing multinational Taiyo Gyogyo (changed to Maruha Corporation in 1993) (Barclay 2008). The company had a fleet of 21 pole and line vessels that employed about 900 Solomon Islanders. In addition, about 2,200 permanent staff and 800 casual laborers were employed by Solomon Taiyo. The base at Noro included a large cannery, an arabushi smoking factory, and a fishmeal plant. However, ethnic tensions led to its closure.

The Solomon Islands National Tuna Management and Development Plan of June 1999 states the country's offshore fisheries management objectives. The major purpose of the plan is to ensure that the country's tuna resource is not exploited beyond its sustainable yield. The plan thus sets catch limits, and suggests harvesting the resource in a way that maximizes the economic and social benefits accruing to Solomon Islanders (FAO 2009).

The plan likewise lays out management measures that include a limit on the number of licenses issued, and restrictions relating to access by certain vessels to some areas (FAO 2009). However, during the period of ethnic tensions, problems were encountered in restricting the number of licenses issued. Licensing procedures have since been tightened, and further tightening is anticipated under the new tuna management plan that is currently under preparation (FAO 2009).

Recommendations for Tuna Fisheries Policy in Fiji, Papua New Guinea, and Solomon Islands

A review of the national tuna management and development plan should be conducted by the three countries to accommodate changes in provisions of offshore fishing practices, costs, and the overall impacts of the tuna industry. It is necessary for government officials to ensure greater transparency of rules, policies, and other changes concerning the offshore fisheries of all three study countries. The extent and validity of fishing licenses need to be reviewed to avoid investment uncertainties. A monitoring scheme, particularly with new regional management regimes by the WCOFC, must be taken into consideration. Other items that need to be looked into include fisheries taxation, a transferable quota system, and share management of offshore fisheries resources.

SPC (2012) recommended management initiatives for the four tuna species: (i) reducing fishing for bigeye tuna by at least 32% compared with 2006–2009 average levels to ensure long-term sustainability of the resource; (ii) maintaining harvests of yellowfin tuna in the western equatorial Pacific at current levels; and (iii) limiting skipjack tuna harvests to sustainability levels, since it is a critically important stock with maximum economic returns that provides food security to Pacific islanders.

Given the need for sustainable management of tuna fisheries, the Parties to the Nauru Agreement (PNA) brings together eight Pacific Island countries—the Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands, and Tuvalu—to discuss sustainable management of tuna fisheries. PNA members are global leaders in conservation and fisheries management. Currently, 25% of the global supply of tuna is controlled by PNA. Some conservation measures pioneered by PNA include high-seas closures, controls on FADs and 100% coverage of purse seine fishing vessels with observers. One proposed scheme of PNA to sustainably manage tuna is the Vessel Day Scheme, under which PNA members agree on a limited number of fishing days for the year, based on scientific advice about the status of the tuna stocks.

DEVFISH (2011) points out the need for policy analysis, consultations, and training at the regional level and sharing of information on tuna development and management. Potential activities involve strengthening fish producers associations, improving consultations among stakeholders and interested parties—such as the private sector, government, and seafood industries—and developing strategies and national plans for tuna industries.

V. Conclusions and Policy Recommendations

Conclusions

The results of the study indicate that climate change will likely have significant negative impacts on agricultural output in Fiji, Papua New Guinea, and Solomon Islands. While the evidence relating to fisheries is mixed, even relatively positive projections of the medium-term impacts of climate change on fisheries suggest that the fisheries sectors of the three study countries cannot be relied upon to counterbalance the food security challenges these countries face as a result of the negative impacts of climate change on agricultural output.

While food security to the year 2050 in Papua New Guinea and to a lesser extent Fiji already faces significant challenges, slowing growth in agricultural output and falling income growth rates resulting from climate change would only further exacerbate these challenges. Given the agriculture sector's significant role in both employment and gross domestic product in the three study countries, adverse climate change-driven impacts on the agriculture sector are a particular concern. Maintaining "business-as-usual" in the agriculture sector would thus be a costly long-term policy response.

Beyond the negative impacts on crop yields and agricultural output projected by the quantitative analysis under the study, climate change will likely negatively impact incomes in the agriculture sector, food consumption levels, calorie availability, and the severity of child malnutrition in all three study countries. Since the poor will no doubt be the most adversely affected by these changes, an increase in the number of people at risk of hunger is a likely outcome in all three study countries unless adaptation to climate change is undertaken.

In this regard, the study results indicate that climate change adaptation investments in the agriculture sector including improved crop management, efficient increases in fertilizer use, and increased investment in agricultural research and extension services hold the potential to effectively eliminate the negative impacts of climate change on food security. As shown in the results of the DREAM analysis included under the study, the projected returns to increased fertilizer use as a climate change adaptation option are particularly impressive for all crops with the exception of sugarcane, which already benefits from significant fertilizer use. Similarly, improved crop management is likewise projected to result in significant benefits to the production of several crops. The corresponding benefits from expanding the use of irrigation in crop production are likewise projected to be significant for sugarcane production, but somewhat limited or nonexistent for taro, cassava, and sweet potato.

As expected, the manner in which climate change impacts crop yields varies greatly from region to region within individual countries, the projected benefits from adopting adaptation technologies thus ranging from a few hundred dollars in one province of Fiji to a few million dollars in another. While it is important to evaluate the overall financial benefit likely to accrue from adoption of climate change adaptation technologies, policy design should pay particular attention to the distribution effects of adoption of these technologies, particular with respect to their impacts on small farmers.

With regard to the above, education and extension services are essential if climate change adaptation technologies are to be fully adopted by all farmers. Education, capacity-building, and effective agricultural research and extension services are all thus critical in achieving the potential benefits from adaptation to climate change, both in Pacific island countries such as those analyzed under the present study, and elsewhere. Further, developing or importing a wide range of climate change adaptation crop production technologies is likely to increase the potential benefit achievable from adaptation to climate change.

Finally, aquaculture has significant potential to improve food security and incomes in all three study countries. However, aquaculture feasibility studies are necessary to ensure the practicality and cost-effectiveness of investment in this alternative source of food production. Further, aquaculture is directly and indirectly vulnerable to climate change. Direct impacts include the effects of rising temperatures in the open ocean, which is the source of the wild fingerlings that form the basis of some aquaculture operations. The indirect effects of climate change on aquaculture include the rising cost of fish feed due to drought, and damage to production facilities due to extreme weather events.

Policy Recommendations

The negative impacts of climate change on crop yields projected by the present study suggest that additional investment in the agriculture sector is required to prevent current levels of output and production efficiency from declining over the coming decades. Particularly important in this regard are investment in research, rural roads, strengthening of markets, information technology, education, extension services, and irrigation. Further, the negative impact of climate change on output in both the agriculture and fisheries sectors projected by the study suggests that improvements are required in communicating market information, that land tenure must be made more secure, and that research regarding adaptation to the negative impacts of climate change on sectoral output be increased. Specific policy recommendations for each sector are presented below.

Agriculture

Overall Recommendations

Overall, appropriate strategies for adapting to climate change in the agriculture sector of all three study countries include the following.

1. Developing nontraditional agricultural exports and value-adding products, and promoting other cash crops so as to diversify the agricultural base.
2. Reducing the risk of climate change through the use of high-yielding cultivars that are resilient to multiple types of climate shocks, improved farming system strategies, soil-fertility options, and selective expansion of the use of irrigation.

3. Investing in agricultural research, including establishing regional centers of excellence; testing varieties for adaptation to local conditions; undertaking cost-benefit analyses of evaluated technologies; building national and regional research capacity; and strengthening linkages with international agricultural research centers in order to access broader genetic diversity, advanced bioinformatics, and gene sequencing.
4. Developing and promoting extension services that provide market support to farmers, and disseminating agricultural technologies and appropriate agricultural practices.
5. Promoting improved varieties of rice adapted to local conditions.
6. Undertaking marketing, technical, and financial prefeasibility appraisals with pilot testing of new technologies and management arrangements prior to scaling-up.
7. Further developing climate models and projections that focus on crops relevant to the three study countries.

Land Policy

Reform of land tenure policy is an essential climate change adaptation strategy insofar as it creates the flexibility required for agriculture to nimbly respond to climate change. The goal of such land policy reform should thus be to facilitate climate change adaptation by providing security of land tenure that, in turn, provides incentives for producers to invest in new crop varieties, improved crop management, and increased rates of fertilizer use. Specific measures for removing current barriers to expansion of agricultural output caused by inefficient land tenure policy include the following.

1. Improving land tenure systems and land-use policies in a way that increases availability of land for agricultural and aquaculture production.
2. Utilizing land under customary ownership in a way that ensures security of traditional land ownership, while at the same time tapping the economic potential of the land.
3. Ensuring an efficiently functioning system of land administration.
4. Creating land banks that act as intermediaries in leasing use rights to customary land, while at the same time protecting the communal ownership of lands.

Finally, reform of customary land tenure and ownership systems should be treated with care and sensitivity. Each country must design a land tenure regime suited to its particular circumstances.

Fertilizer Use

The use of fertilizer and other agro inputs is notably limited in all three study countries. Increased use of fertilizer, combined with other approaches for improving soil fertility including low-external-input sustainable agriculture and integrated soil fertility management, would have substantial benefits in increasing the output of major staple crops.

The most appropriate role for the government in enhancing fertilizer use would be to provide public goods, including extension services that advise farmers on the appropriate quantity, quality, and timing of fertilizer applications. Moreover, in order to achieve increased rates of fertilizer use, governments must upgrade the infrastructure that affects the supply and distribution of fertilizer such as that relating to roads and ports, and must assist importers in gaining access to financing so that they can benefit from scale economies.

Agricultural Research and Extension

The trend toward inadequate and declining public investment in agricultural research needs to be reversed. To accomplish this, agricultural research funding should increase in real terms by at least 10% per year in the three study countries to achieve a tripling of agricultural research investment to a level of at least 1.5% of agricultural GDP. In addition to increasing national-level investments, it is essential to improve regional cooperation for agricultural research.

Fisheries

Overall Recommendations

Overall, appropriate adaptation policies for counteracting the negative impacts of climate change on the fisheries sector are to significantly improve the management of tuna fisheries; to sustain production of coastal fish and invertebrates; to develop an effective aquaculture industry that will diversify the supply of fish and replace the potential losses of fish production due to climate change; and to improve postharvest methods, utilization, and marketing of fishery and aquaculture products.

Tuna Industry

Given the high costs, high risks, and high skill requirements of the industry, direct government investments in the tuna industry have not fared well. Government policy in the three study countries should thus instead focus on the following strategies. An improved national catch from inshore tuna fisheries should be linked with the provision of networks of low-cost inshore fish-aggregating devices and development of fishing technologies for small-scale fishers. At the same time, the government should continue to work together within a regional framework to negotiate higher access fees from other nations.

Coastal and Inland Fisheries

Improved governance is essential for adaptation to climate change in coastal and inland fisheries. Creation of national coastal fishery development plans that include adaptation and climate change mitigation strategies is a critical development measure for coastal communities and villages. A promising public–private management approach in this regard is locally managed marine areas, under which marine resources are managed through a combination of traditional and modern methods of biological monitoring and assessment.

Aquaculture

Aquaculture remains an undeveloped industry in the three countries, but the technical potential is high. However, implementation of aquaculture projects has met with difficulties. Several policies thus need to be strengthened to support aquaculture in the three study countries.

Objective marketing and feasibility studies must be undertaken to determine the economic viability of aquaculture operations. Once the feasibility of aquaculture operations has been established, infrastructure development should follow. The business and trade environment must also be improved, including its features relating to the tax structure, administrative blockages, investment, land and marine tenure, and quality control. Government assistance in key support services such as ensuring the availability and quality of fry through the funding of public freshwater-species fish hatcheries is important in the early stages of development.

In sum, strategies for adapting to climate change in the fisheries sector include the following.

1. Improving and encouraging a higher inshore national tuna catch, using networks of low-cost inshore fish-aggregating devices and developing technologies for small-scale fishers.
2. Negotiating increased access fees from both distant-water fishing nations and local fishing nations, and reorienting government spending of revenue thus collected into indirect support of the domestic market.
3. Diversifying existing diets and encouraging the production of freshwater aquaculture (e.g., species such as tilapia and carp).
4. Investing both in technical research (e.g., developing local supplies of feed and feed formulations, exploring consumer preferences, assessing fish stocks, and analyzing the value chain), and in socioeconomic and policy research (e.g., ensuring economic and market feasibility and sustainability), given that most of the research is performed by regional and national institutions primarily focusing on technical evaluation.
5. Improving and promoting extension services that support markets for fishers and fish farmers, building community awareness regarding the importance of environmental protection, and disseminating fishery and aquaculture technologies.
6. Further developing climate models and associated tools for projecting climate change impacts and formulating responses to them.
7. Improving and supporting fisheries and aquaculture management, incorporating local participation and community management, and introducing necessary regulations (e.g., regulations that prevent downstream pollution from excessive feeding of fish in aquaculture operations).
8. Improving regional mechanisms for protecting biodiversity and preventing entrance of invasive species.
9. Improving technology and extension support to inland and coastal aquaculture (e.g., seeding and hatcheries).
10. Creating an enabling policy environment for the development of aquaculture (e.g., through provision of incentives, credit, and marketing support), and encouraging rural residents to enter the industry.

Prioritizing policy recommendations is always difficult. However, based on the results of the present study, the six areas of policy change summarized immediately below are the most pressing, since their implementation would lead to major advances in development of the agriculture and fisheries in the face of climate change:

1. Rationalizing land tenure policy in a way that retains indigenous land ownership, but that puts commercial land-use rights into place.
2. Increasing investment in agriculture and fisheries research, and harmonizing research at the regional level by establishing centers of excellence that link national research institutions and access services from international research centers.
3. Revitalizing extension systems in a way that incorporates effective local participation, and coordination of public and private sector, as well as nongovernmental organization providers.
4. Increasing rural infrastructure investment that links directly to market development.
5. Promoting expansion of aquaculture and coastal fisheries by providing technology, institutional and management support at the local and community levels, and by promoting adoption of, and adherence to best aquaculture and fisheries management practices.
6. Developing and implementing integrated data management, monitoring, and evaluation systems for the agriculture and fisheries sectors from the community level to the national level.

References

Asian Development Bank (ADB). 2005. Republic of the Fiji Islands: Fisheries Sector Review. Manila: ADB.

_______. 2008. Solomon Islands Country Performance Assessment. Manila: ADB.

_______. 2010. Solomon Islands 2010 Economic Report. *Pacific Studies Series*. Manila: ADB.

_______. 2011a. *Key Indicators for Asia and the Pacific*. Manila: ADB.

_______. 2011b. *Asian Development Outlook 2011*. South–South Economic Links. Manila: ADB.

ADB and Australian Agency for International Development (Australian Aid). 2010. *Solomon Islands 2010 Economic Report*. Manila: ADB.

ADB and International Food Policy Research Institute (IFPRI). 2009. *Building Climate Resilience in the Agriculture Sector*. Manila: ADB. http://www.adb.org/Documents/Books/Building-Climate-Resilience-Agriculture-Sector/default.asp

Alex, G., D. Byerlee, M. Helene-Collion, and W. Rivera. 2004. Extension and Rural Development Converging Views on Institutional Approaches?. ARD Discussion Paper 4. World Bank, Washington DC, US.

Agricultural Commodities Committee/Coconut Advisory Council (ACC/CAC). 1985. Commodity Profile: Coconut A Programme for the Future Development of the Coconut Areas. Suva.

AgriSystems.1993. Smallholder Development Programme: Monitoring and Evaluation Final Report. Solomon Island Ministry of Agriculture and Lands and Delegation of the European Community in the Solomon Islands.

Ahmed, M., J. Maclean, R.V. Gerpacio, and M.A. Sombilla. 2011. Food Security and Climate Change in the Pacific: Rethinking the Options. *Pacific Studies Series*. Manila: ADB.

Ahmed, S. 2002. Agriculture-Fertilizer Interface in the Asian and Pacific Region: Issues of Growth, Sustainability, and Vulnerability. http://fftc.imita.org/htmlarea_file/library/20110721163620/eb387.pdf

Allen, M., and R. M. Bourke. 2009. People and Environment. In R.M. Bourke and T. Harwood, eds. *Food and Agriculture in Papua New Guinea.* Canberra: ANU E Press, The Australian National University.

Allen, M., R. M. Bourke, and A. McGregor. 2009. Part 5 Cash Income from Agriculture. In Bourke, R.M. and Harwood, T. eds. *Food and Agriculture in Papua New Guinea*. Canberra: ANU E Press, The Australian National University.

Alston, J. M., P.G. Pardey, S. Wood, and L. You. 2000. Strategic technology investments for LAC agriculture: a framework for evaluating the local and spillover effects of R&D. Washington: IFPRI.

Alston, J.M., G.W. Norton, and P.G. Pardey. 1998. Science Under Scarcity: Principles and Practices for Agricultural Research Evaluation and Priority Setting. Wallingford: CAB International (CABI).

Amoe, J. 2010. *Annual Report to the Western and Central Pacific Fisheries Commission*. Part 1: Information on Fisheries, Research and Statistics 2009. Suva: Fisheries Department, Ministry of Primary Industries.

Anderson, J., and A. Parker. 2004. Towards Agricultural Growth in Papua New Guinea. *Pacific Economic Bulletin*. 19 (1): pp. 94–100.

Anderson, S., and H. Jenshagen. 2010. An Analysis of the Sugar Industry and Its Global Competitiveness—The case of Fiji. Bachelor Thesis. Linnaeus University School of Business and Economics, Sweden.

Aryeetey, E., and C. Udry. 2010. Creating Property Rights: Land Banks in Ghana. *American Economic Review*. 100 (2): pp, 130–134.

Asafu-Adjaye, J., R. Mahadevan, Y. Kim, B. Prasad, K. Prasad, and S. Tubuna. 2009. Trade Liberalisation, Agriculture and Land Degradation. In *Fiji: Implications For Sustainable Development Policies*. ACIAR Final Report No. FR2009-37.

Australian Aid. 2006a. *Smallholder for Agriculture Report*. Canberra: ANU E Press, The Australian National University.

_______. 2006b. Pacific 2020. Background papers on Land, Fisheries and Forestry. Canberra: ANU E Press The Australian National University.

Barnett, J. 2007. Food Security and climate change in the South Pacific. *Pacific Ecologist*. 14. pp. 32–36. http://www.pacificecologist.org/archive/14/food-security-climate-change.pdf

Barnett, J., and J. Campbell. 2010. *Climate change and Small Island States: Power, knowledge and the South Pacific*. London: Earthscan Publications.

Bartholome, E., and A.S. Belward. 2005. GLC2000: A new approach to global land cover mapping from Earth observation data. *International Journal of Remote Sensing*. 26. pp. 1959–1977.

Batjes, N., K. Dijkshoorn, V. Van Engelen, G. Fischer, A. Jones, L. Montanarella, M. Petri, et al. 2009. *Harmonized world soil database*. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Beintema, N.M., and G-J. Stads. 2008. Agricultural R&D Capacity and Investments in the Asia–Pacific Region. Research Brief No. 11. http://www.ifpri.org/sites/default/files/publications/rb11.pdf

Bell, J. 2010. Climate Change, Fisheries and Aquaculture in the Pacific: Adaptations for Food Security, Livelihoods and Economic Growth. Based on a presentation made at ICES/PICES/FAO Symposium of the 'Climate change effects on fish and fisheries', Sendai, Japan, April 2010.

Bell, J.D., M. Kronen, A. Vunisea, W.J. Nash, G. Keeble, A. Demmkea, S. Pontifex, and S. Andre. 2009. Planning the use of fish for food security in the Pacific. *Marine Policy*. 33. pp. 64–76.

Bell, J. D., J. E. Johnson, and A. J. Hobday, eds. 2011. *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*. Noumea, New Caledonia: Secretariat of the Pacific Community.

Bell, J. D., J. E. Johnson, A. S. Ganachaud, P. C. Gehrke, A. J. Hobday, O. Hoegh-Guldberg, R. Le Borgne, P. Lehodey, J. M. Lough, T. Pickering, M. S. Pratchett, and M. Waycott. 2011. *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change: Summary for Pacific Island Countries and Territories.* Noumea, New Caledonia: Secretariat of the Pacific Community.

Benson, C. 1997. The Economic Impact of Natural Disasters in Fiji. Overseas Development Institute Working Paper 97. London, England.

Billings, G. 2010. Status of Aquaculture in Fiji. Powerpoint presented during the 2010 Sustainable Aquaculture on Tropical Islands Conference, Arue, Tahiti, December 6–10, 2010.

Billings, G., and T. Pickering. 2010. Fiji launches milkfish aquaculture project for food security. *SPC Fisheries Newsletter* #132: May/August 2010.

Birner, R., and J.R. Anderson. 2007. How to make agricultural extension demand-driven? The case of India's agricultural extension policy. IFPRI Discussion Paper 729. Washington, DC, US.

Blakeney, M., and R. Clough. 2001. An assessment of grain production and imports in PNG, 1975–2000. In Bourke, R.M., M.G. Allen, and J.G. Salisbury, eds. *Food Security for Papua New Guine*a. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. ACIAR Proceedings No. 99. Canberra: Australian Centre for International Agricultural Research. pp. 23–29.

Bourke, R., A. McGregor, M. Allen. et al. 2006. *Solomon Islands Smallholder Agriculture Study* Volume 1: Main Findings and Recommendations. Canberra: Australian Aid.

Bourke, R.M., J. Gibson, A. Quartermain, K. Barclay, B. Allen, and J. Kennedy. 2009. Food Production, Consumption and Imports. In R.M. Bourke. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea.* Canberra: ANU E Press, The Australian National University.

Bourke, R.M., and T. Harwood (eds). 2009. Food and Agriculture in Papua New Guinea. ANU E Press, The Australian National University, Canberra. http://press.anu.edu.au//wp-content/uploads/2011/05/whole_book_Part_1.pdf

Central Bank of Solomon Islands (CBSI). 2006. 2006 CBSI Annual Report. Honiara.

______. 2010. 2010 CBSI Annual Report. Honiara.

Chand, K. 2001. Fiji. http://www.apipnm.org/swlwpnr/reports/

Copra Millers Fiji Limited (CMFL). undated. Copra Millers Fiji Limited brochure. Balaga Bay, Savusavu, Fiji.

Daw, T., W.N. Adger, K. Brown, and M. C. Badjeck. 2009. Climate change and capture fisheries: potential impacts, adaptation and mitigation. In Cochrane, K., C. De Young, D. Soto, and T. Bahri (eds). *Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge.* Food and Agriculture (FAO) Fisheries and Aquaculture Technical Paper. No. 530. Rome: FAO. pp. 107–150.

Deininger, K. 2004. Land Policies for Growth and Poverty Reduction: Key Issues and Challenges Ahead. http://www.fig.net/pub/mexico/papers_eng/ts2_deininger_eng.pdf

Department of National Planning and Monitoring (DNPM). 2010. Papua New Guinea Development Strategic Plan 2010–2030. March. Port Moresby.

Dimes, J., and J. Koo. 2009. 27-Class World Soil Database. Washington: IFPRI.

Economic Planning and Statistics Division, Department of Agriculture (EPSD-DA). 2009. Report on the Fiji National Agricultural Census. Suva.

Ellis, S. 2010. Advantages and Constraints to Development of Sustainable Aquaculture in the Pacific Islands and its Role in Livelihoods, Development and Conservation. Marine and Environmental Research, Institute of Pohnpei. Hilo: University of Hawaii.

EM-DAT (Emergency Events Database [for floods, droughts and storms]). www.emdat.be/Database/CountryProfile/countryprofiles.php (accessed on 11 March 2011).

Ero, M., P. Navus, M. Liu, L. Werry, B. Kenny, J. Pitala, A. Judah, H. Hati, and A. Anas. 2011. Impacts of Climate Change on Agriculture and Fisheries: Case Study in Papua New Guinea. Draft country report.

European Space Agency (ESA). 2010. GlobCover 2009 land cover map, v2.3. http://ionia1.esrin.esa.int/

Evans, B. 2006. Solomon Islands Smallholder Agriculture Study Volume 5. Literature Review: A Brief National Assessment of the Agriculture Sector. ACIAR, Australia.

Evans, B.R. 2006. Solomon Islands Smallholder Agriculture Study Volume 5: Literature Review: A Brief National Assessment of the Agriculture Sector. Canberra: Australian Aid.

Fiji Islands Bureau of Statistics (FIBS). 2011. Fiji Islands Facts and Figures as of 1 July 2010. Fiji Islands Bureau of Statistics, Suva.

Fiji Islands Business (FIB). 2007. Putting Life Back Into Coconuts: CIDA Has Big Plans to Revive the Industry in Fiji. http://www.islandsbusiness.com/fiji_business/index_dynamic/containerNameToReplace=MiddleMiddle/focusModuleID=15861/overideSkinName=issueArticle-full.tpl

______. 2010. What's Next in Sugar? The inside story on a Sticky Business. *Island Business*, October Issue, 2010. http://www.islandsbusiness.com/archives/fiji_business/index_dynamic/containerNameToReplace=MiddleMiddle/focusModuleID=19417/overideSkinName=issueArticle-full.tpl

Fiji Islands Development Authority (FIDA). 2007. Taro/Dalo Beetle Management in Fiji. Technical Bulletin. Issue No 3. April.

______. 2010. Agriculture Programme Overview Briefing to Commissioner Central and Commissioner Eastern. 18 February 2010.

______. 2011a. National Agricultural Census 2009. Economic Planning and Statistics Division, Suva.

______. 2011b. Revitalization of Coconut Industry. 16 August 2011 Ministry. News & Updates. http://www.agriculture.org.fj/index.cfm?si=main.resources&cmd=forumview&uid=news&cid=1622

______. 2011c. Coconut Crop Farmers Guide. http://www.agriculture.org.fj/_resources/main/files/33.jpg (accessed on July 7, 2011).

______. 2011d. Department of Agriculture Annual Corporate Plan.

Fiji Sugar Corporation (FSC). 2009. Fiji Sugar Corporation Annual Report 2009.

______. 2002. The Fiji Industry. Fijian Studies Vol. 1 No. 2. Fiji Institute of Applied Studies.

Filer, C. 2007. Local Custom and the Art of Land Group Boundary Maintenance in Papua New Guinea. *In* Weiner, J. F., and K. Glaskin (eds) 2007. Customary Land Tenure and Registration in Australia and Papua New Guinea: Anthropological Perspectives, Australia National University E-Press, 135 p.

Food and Agriculture Organisation of the United Nations (FAO). 2007. *Selected Indicators of Food and Agricultural Development in the Asia-Pacific Region 1996–2006*. Rap Publication 2007/15. Bangkok: Food and Agriculture Organization of the United Nations. Regional Office for Asia and the Pacific.

______. 2009. *Climate Change and Food Security in the Pacific*. Rome: FAO. ftp://ftp.fao.org/docrep/fao/012/i1262e/i1262e00.pdf

______. 2010. FISHSTATJ database.

______. 2011. FAOSTAT. Statistical Database. Rome. http://faostat.fao.org/

FAO/IIASA/ISRIC/ISS-CAS/JRC. 2009. Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

FAO, National Agricultural Research Institute (NARI), and World Bank. 2002. Strategies for Agricultural and Rural Development in Papua New Guinea. Proceedings of the national consultative workshop on Agriculture and rural development: Issues and strategies, Volume II.

Forum Fisheries Agency (FFA). 2008. The Value of Western and Central Pacific Fisheries Commission (WCPFC) Tuna Fisheries. Unpublished report. Honiara.

Gbetibouo, G.A., and C. Ringler. 2009. Mapping South African Farming Sector Vulnerability to Climate Change and Variability. IFPRI Discussion Paper, 885. Washington: IFPRI.

GEF/UNDP/SPREP. undated. Pacific Adaptation to Climate Change Solomon Islands Report of In-Country Consultations.

GFDRR/World Bank/SOPAC. 2009. Reducing the Risk of Disasters and Climate Variability in the Pacific Islands. Solomon Islands Country Assessment.

Gibson, J. 1992. Rice Self-Sufficiency and the Terms of Trade (why rice is a good thing to import). Policy Working Paper No. 2. Programming, Planning and Budgeting Division, Department of Agriculture and Livestock, Port Moresby, Papua New Guinea.

_______. 2001a. The Nutritional Status of PNG's Population *In* Bourke, R.M., M.G. Allen, and J.G. Salisbury, eds. 2001. Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, PNG University of Technology, Lae, 26–30 June 2000. ACIAR Proceedings No. 99, xviii + 892p.

_______. 2001b. Food Demand in Rural and Urban Sectors of Papua New Guinea. In R.M. Bourke, M.G. Allen, and J.G. Salisbury, eds. 2001. Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, PNG University of Technology, Lae, 26–30 June 2000. ACIAR Proceedings No. 99.

_______. 2001c. The Economic and Nutritional Importance of Household Food Production in PNG. In R. M. Bourke, M. G. Allen, and J. G. Salisbury, eds. Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. University of Technology, Lae, 26–30 June 2000. ACIAR Proceedings No. 99. Canberra: Australian Centre for International Agricultural Research.

Gillett, R. 2009. *Fisheries in the Economies of the Pacific Island Countries and Territories*. Manila: ADB.

Gillett, R. 2011. Fisheries of the Pacific Islands: Regional and National Information. FAO Regional Office for Asia and the Pacific, Bangkok Thailand. RAP Publication 2011/01, 290 p.

Gilman, E., H. Van Lavieren, J. Ellison, V. Jungblut, L.Wilson, F. Ereki, G. Brighouse, J. Bungitak, E. Dus, M. Henry, I. Sauni, M. Kilman, E. Matthews, N.Teariki-Ruatu, S. Tukia, and K.Yuknavage. 2006. Pacific Island mangroves in a changing climate and rising sea. United Nations Environment Programme (UNEP) Regional Sea Reports and Studies 179. Nairobi: UNEP Regional Sea Programme. 58 pp.

Global Land One-kilometer Base Elevation (GLOBE) Task Team and others (Hastings, David A., Paula K. Dunbar, Gerald M. Elphingstone, Mark Bootz, Hiroshi Murakami, Hiroshi Maruyama, Hiroshi Masaharu, Peter Holland, John Payne, Nevin A. Bryant, Thomas L. Logan, J. P. Muller, Gunter Schreier, and John S. MacDonald, eds. 1999. The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center, 325 Broadway, Boulder. http://www.ngdc.noaa.gov/mgg/topo/globe.html

Government of Fiji (GOF). 2004. Preliminary Estimates of Flood Affected Areas. Press Release, April 17. Suva.

______. 2005a. Fiji Today 2004/2005. Ministry of Information, Communications and Media Relations.

______. 2005b. Climate Change The Fiji Islands Response. Fiji's First National Communication Under the Framework Convention on Climate Change 2005.

______. 2011. Case Story on Fiji's Sugar Industry. Aid-For-Trade Case Story Fiji.

Government of Solomon Islands (GSI). 2010. National Food Security, Food Safety and Nutrition Policy, 2010–2015.

Grieve, R.B. 1986. The Oil Palm Industry of Papua New Guinea. *Australian Geographer*. 17. pp. 72–76.

Hand, T., D. Davis, and R. Gillett. 2005. Republic of the Fiji Islands: Fisheries Sector Review. Project Number 34224. Asian Development Bank, Mandaluyong, Philippines.

Hartemink, A.E., S. Polomab, M. Maino, K.S. Powell, J. Egenae, and J.N. O'Sullivan. 2000. Yield decline of sweet potato in the humid lowlands of Papua New Guinea. Agriculture, Ecosystems and Environment 79 (2000). pp. 259–269.

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2007. The WorldClim interpolated global terrestrial climate surfaces. Version 1.4. http://biogeo.berkeley.edu/

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas". *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org

Hishamunda, N., P.B. Bueno, N. Ridler, and W.G. Yap. 2009. Analysis of aquaculture development in Southeast Asia: a policy perspective. FAO Fisheries and Aquaculture Technical Paper. No. 509. Rome: FAO. 69 p.

Hone, P., and H. Haszler. 2006. Estimating the Size of the Fiji Islands Agricultural Sector. School working paper—economic series 2006. University of the South Pacific.

Hone, P., H. Haszler, and T. Natasiwai. 2008. Agricultural Supply Response in Fiji. Contributed Paper Presented to 52nd Annual Conference: Australian Agricultural and Resource Economics Society. Canberra. 6–8 February.

IFRC. 2009. Papua New Guinea: Cyclone Guba. Final Report. May 2009. http://www.ifrc.org/docs/appeals/07/MDRPG002FR.pdf

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC.

International Bank for Reconstruction and Development (IBRD). 1965. *The Economic Development of the Territory of Papua New Guinea*. John Hopkins Press, Baltimore

International Federation of Red Cross and Red Crescent Societies (IFRC). 2010. Solomon Islands: Tropical Cyclone Ului. DREF (International Federation's Disaster Relief Emergency Fund) Operation Update. 12 May 2010. www.ifrc.org/docs/appeals/10/MDRSB00202.pdf

International Global Change Institute (IGCI), South Pacific Regional Environment Programme (SPREP), and Pacific Islands Climate Change Assistance Programme (PICCAP). 2000. Climate Change Vulnerability and Adaptation Assessment for Fiji. IGCI Technical Report.

International Monetary Fund (IMF). 2004. Solomon Islands: Selected Issues and Statistical Appendix, Country Report No. 04/255, August. Washington: IMF.

_______. 2008. Solomon Islands: Tax Summary and Statistical Appendix. IMF Country Report No. 08/359. Washington: IMF.

_______. 2011. Republic of Fiji: Staff Report for the 2010 Article IV Consultation. IMF Country Report No. 11/85.

Jansen, T., B. Mullen, A. Pollard, R. Maemouri, C. Watotot et al. 2006. Solomon Islands Smallholder Agriculture Study: Vol 2. Subsistence Production, Livestock and Social Analysis, Canberra: Australian Government and Australian Aid. http://www.ausaid.gov.au/publications/pubout.cfm?ID=4088_5412_1071_6193_2813

Jones, J.W., G. Hoogenboom, C.H. Porter, K.J. Boote, W.D. Batchelor, L.A. Hunt, P.W. Wilkens, U. Singh, A.J. Gijsman, and J.T. Ritchie. 2003. The DSSAT cropping system model, *European Journal of Agronomy.* 18 (3–4). pp. 235–265.

Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3

Jones, R.N., K.L. Hennessy, C.M. Page, K.J.E. Walsh, and P.H. Whetton. 1999. An Analysis of the Effects of Kyoto Protocol on Pacific Island Countries, Part 2: Regional Climate Change Scenarios and Risk Assessment Methods. A research report prepared for the South Pacific Regional Environment Programme, Apia, Samoa and CSIRO Atmospheric Research, Canberra, Australia, 61 pp.

Jones, S., E.M. Fleming, and J.B. Hardaker. 1988. Smallholder Agriculture in Solomon Islands. Report of the South Pacific Smallholder Project in the Solomon Islands, 1985–86. South Pacific Smallholder Project. University of New England, New South Wales.

Kajiura, N. 2010. Coastal fisheries resource management in the Pacific Islands. http://www.un.org/staffdevelopment/pdf/Coastal%20Fisheries.pdf

Kaly, U.L., C.R. Pratt, and J. Mitchell. 2004. The Environmental Vulnerability Index (EVI) 2004. SOPAC Technical Report 384. SOPAC, Suva.

Kaly, U.L., C.R. Pratt, and R. Howorth. 2003. The Demonstration Environmental Vulnerability Index: Results for 235 countries. SOPAC Technical Report 356. SOPAC, Suva.

Kauhiona, H., and T. Masolo. 2011. Climate Change and Food Security: Adaptation Mechanisms and Policy Recommendations for Solomon Islanders. Unpublished report.

Koczberski, G., G.N. Curry, and K. Gibson. 2001. Improving Productivity of the Smallholder Oil Palm Sector in Papua New Guinea. RSPAS, Australian National University.

Koo, J. 2009. 27-Class World Soil Database. Washington: IFPRI.

Kumar, S., and J. Bhati. 2010. Challenges and Prospects for Sustainable Development of Agriculture and Agribusiness in Fiji Islands. University of the South Pacific, School of Economics Working Paper No. 2010/09. School of Economics, University of South Pacific.

Kumoru, L. 2008. Papua New Guinea. Working Paper 23. Fourth Regular Session of the Scientific Committee of the Western and Central Pacific Fisheries Commission, Port Moresby, Papua New Guinea, 11–22 August.

Lal, M. 2004. Climate change and small island developing countries of the South Pacific. Fijian Studies. 2. pp. 15–31.

Lal, M., H. Harasawa, and K. Takahashi. 2002. Future climate change and its impacts over small island states. *Climate Research*. 19. pp. 188–189.

Lal, P.N., Rita, R., and Khatri, N. 2009. Economic Costs of the 2009 Floods in the Fiji Sugar Belt and Policy Implications. Gland: IUCN.

Landell Mills Ltd. 1991. Smallholder Oil Palm Productivity Study, Volume 1: Main Report, Bath, United Kingdom.

Lawrence, D., and M. Allen. 2006. Community Sector Program. Report of the CSP Community Snapshot. Volume 2—Analysis of the Data. CSP Milestone 13.

Lindsay, S. 2007. Aquaculture Sector Assessment, Solomon Islands. Lincoln International Pty Ltd., Marine Resource Organizational Strengthening Project Solomon Islands.

Long, S.P., E.A. Ainsworth, A.D.B. Leakey, J. Nosberger, and D.R. Ort. 2006. Food for thought: Lower-than-expected crop yield stimulation with rising CO2 concentrations. *Science*. 312 (5782). pp. 1918–1921.

MA. 2005. Millennium Ecosystem Assessment—Ecosystems and Human Well-being: Synthesis, Island Press, Washington.

Macfadyen, G., and E. Allison. 2009. Climate Change, Fisheries, Trade and Competitiveness: Understanding Impacts and Formulating Responses for Commonwealth Small States. International Trade and Regional Co-operation Section Economic Affairs Division Commonwealth Secretariat Marlborough House Pall Mall London.

McGregor, A. 2006. Solomon Islands Smallholder Agriculture Study Volume 3: Markets and Marketing Issues, Australian Aid, Canberra.

McGregor, A., P. Afeaki, J.A., A. Hamilton, J. Hollyer, R. Masamdu, and K. Nalder. 2011. Pacific Island Taro Market Access Scoping Study. Facilitating Agricultural Commodity Trade (FACT) Project and Secretariat of the Pacific Community (SPC).

McGregor, A., W. Gonemaituba, and K. Stice. 2009. Natures Way Cooperative (Fiji) Ltd : A Case Study of Agriculture for Growth in the Pacific. UN-Food and Agriculture Organization, Rome: FAO. http://www.faopacific.ws/Portals/167/publications/AG%20for%20Growth%20Reports/Natures_Way_Cooperative_(Fiji)Ltd%20final.pdf

Meehl, G.A., T.F. Stocker, W. Collins, P. Friedlingstein, A.T. Gaye, J. Gregory, A. Kitoh, R. Knutti, J. Murphy, A. Noda, S. Raper, I.G. Watterson, A. Weaver, and Z.-C. Zhao. 2007. Global climate projections. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, Eds. Cambridge: Cambridge University Press. pp. 747–846.

Mimura, N., Nurse, L., McLean, R.F., Agard, J., Briguglio, P., Payet, R., and Sern, G. 2007. Small Islands. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E.Hanson, Eds. Cambridge, UK: Cambridge University Press. pp. 687–716.

Ministry of Agriculture and Livestock (MAL). 2007a. National Agriculture Development Plan 2007–2016. Policies and Strategies. Volume 1, Growing the Economy through Agriculture. Independent State of Papua New Guinea.

_______. 2007b. National Agriculture Development Plan 2007–2016. Implementation Plan. Volume 2, Growing the Economy through Agriculture. Independent State of Papua New Guinea.

_______. 2008. Ministry of Agriculture and Livestock Annual Report 2008. Honiara.

_______. 2009a. National Agriculture and Livestock Sector Policy 2009–2014. Honiara.

_______. 2009b. Ministry of Agriculture and Livestock Annual Report 2009. Honiara.

_______. 2010. National Rice Sector Policy (2010–2015). Honiara.

Ministry of Finance and National Planning (MFNP). 2002. 20-Year Development Plan (2001–2020) for the Enhancement of Participation of Indigenous Fijians and Rotumans in the Socio-Economic Development of Fiji. Parliament of Fiji. Parliamentary Paper No. 73 of 2002.

_______. 2004. Strategic Development Plan 2007–2011. Millennium Development Goals, Fiji National Report. National Planning Office, Ministry of Finance and National Planning, Fiji.

Ministry of Health. 2002. Fiji Non-Communicable Diseases (NCD) STEPs Survey 2002.

Moore, Clive. 2004. *Happy Isles in Crisis: The Historical Causes for a Failing State in Solomon Islands, 1998–2004*. Canberra: Asia Pacific Press.

Morgan, M., and P. Lokay. 2000. Mid-term Review of the Farmers Support Programme: Final Report. Report prepared for European Development Fund. Honiara, Solomon Islands.

Mueller, I. 2001. The Spatial Pattern of Child Growth in PNG. In Bourke, R.M., Allen, M.G., and Salisbury, J.G., eds. 2001. Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, PNG University of Technology, Lae, 26–30 June 2000. ACIAR Proceedings No. 99. xviii + 892p.

Mufuape, K., J. Soranzie, H. Simon, T. Yasang, and P.T. Smith. 2007. Chapter 4 Fingerling production and distribution in Papua New Guinea. In Smith P.T. (ed.) 2007. Aquaculture in Papua New Guinea: status of freshwater fish farming. ACIAR Monograph No. 125. 124p.

Naidu, V., and M. Reddy. 2002. ALTA and expiring land leases: Fijian farmers' perceptions of their future. A Ford Foundation funded project. http://piasdgserver.usp.ac.fj/apmrn1/fileadmin/files/projects/fiji_alta.pdf

Narayan, P.K. 2004. *An Empirical Analysis of Sugarcane Production in Fiji, 1970–2000. Economic Analysis & Policy*. 34 (1). March.

Narayan, P.K., and B. Prasad. 2004. Economic Importance of the Sugar Industry in Fiji: Simulating the Impact of a 30 Percent Decline in Sugar Production. University of the South Pacific, Department of Economics Working Paper No. 2004/12.

NASA Land Processes Distributed Active Archive Center (LP DAAC). 2009. MODIS MCD12Q1 Land Cover 2008 L3 Global 500m SIN Grid. USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota. 2001.

National Agricultural Research Institute (NARI). 2010. *Recently Released Technologies for Papua New Guinea Farmers*. Revised November 2010. NARI, Morobe, Papua New Guinea. http://www.hari.org.ng

National Food and Nutrition Center (NFNC) 2007. 2004 Fiji National Nutrition Survey. Main Report. National Food and Nutrition Center, Suva, Fiji.

_______. Various years. National Food and Nutrition Centre Report of Fiji Islands. Various annual reports.

National Statistical Office of Papua New Guinea 2002. Papua New Guinea 2000 Census: Final Figures. National Statistical Office of Papua New Guinea, Port Moresby.

Nature Fiji–Mareqeti Viti. 2011. http://www.naturefiji.org/endspecies.php?info=Taro

Neitsch, S.L., J.G. Arnold, J.R. Kiniry, R. Srinivasan, and J.R. Williams. 2005. Soil and Water Assessment Tool Input/Output File Documentation, Version 2005. Temple, Tex.: USDA-ARS Grassland, Soil and Water Research Laboratory. www.brc.tamus.edu/swat/doc.html

Nelson, J., M. W. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz, T. Zhu, T. B. Sulser, C. Ringler, S. Msangi, and L. You. 2010. Food Security, Farming and Climate Change to 2050: Scenarios, Results, Policy Options, IFPRI Research Monograph. Washington: IFPRI.

Nurse, L.A., Graham, S.E.M., Hay, J.E., Suarez, A.G., Wong, P.P., Briguglio, L., and Ragoonaden, S. 2001. Small Island States, in Climate Change 2001: Impacts, Adaptation and Vulnerability, contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (Eds.), GRID Arendal. http://www.grida.no/publications/other/ipcc_tar/

O'Sullivan, J.N., C.J. Asher, and F.P.C. Blamey. 1997. Nutrient Disorders of Sweet Potato. ACIAR Monograph No. 48, Canberra.

Office for the Coordination of Humanitarian Affairs of the United Nations (OCHA). 2010. Fiji: Tropical Cyclone Tomas Situation Report No. 6. 12 April.

Pacific Islands Climate Change Assistance Programme (PICCAP) Fiji Islands. 2005. Climate Change The Fiji Islands Response. Fiji's First National Communication Under the Framework Convention on Climate Change 2005.

Papua New Guinea Ministry of Agriculture and Livestock (PNG MAL). 2007a. National Agriculture Development Plan 2007–2016. Policies and Strategies. Volume 1. Growing The Economy Through Agriculture. Independent State of Papua New Guinea.

_______. 2007b. National Agriculture Development Plan 2007–2016. Implementation Plan. Volume 2 Growing The Economy Through Agriculture. Independent State of Papua New Guinea.

Powell, K.S., A. Saleu, S. Poloma, and J. Engenae. 2001. Influence of Management Practices in Rainfed Rice Ecosystems on the Incidence of Rice Brown Planthopper (*Nilaparvata lugens*) in PNG. In M. Bourke, M.G. Allen, and J.G. Salisbury, eds. 2001. Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, PNG University of Technology, Lae, 26–30 June 2000, ACIAR Proceedings No. 99.

Prakash, K.S. 2003. ICTs – transforming agricultural extension? A case study of Fiji. Conference Paper presented during the 6th Consultative Experts Meeting, Wageningen, Netherlands, September 23–25, 2003. http://www.cta.int/en/content/download/2809/20510/version/1/file/Case_study_Fiji.pdf

Prasad, B. 2010. Global Crisis, Domestic Crises and Crisis of Confidence: Which way forward for Fiji? *Pacific Economic Bulletin.* 25 (2). pp. 1–24.

Prasad, B.C., and P. K. Narayan. 2005. Contribution of the Rice Industry to Fiji's Economy: Implication of a Plan to Increase Rice Production. No. 2005/7. Dept. of Economics. Suva: University of the South Pacific.

Preston, G. 2000. Managing the Ocean. Report prepared for the World Bank, Washington, DC.

Preston, G.L. 2005. Review of fisheries management issues and regimes in the Pacific Islands Region. IWP-Pacific Technical Report (International Waters Project) No. 17. SPREP, Apia, Samoa. 80 p.

Rao, S.K., S.V. Subbaiah, M. Nacola, K. Puran, R. Pratap, B.D. Lal, E.T. Delai, and R. Reddy. 2007. Cultivation Techniques to Enhance Rice Production in Fiji. Rice Production Technology Bulletin. Research Division, Ministry of Agriculture, Fisheries and Forests, Republic of Fiji Islands.

Rashid, H. 2010. Land Rights and the Millennium Development Goals: How the Legal Empowerment Approach Can Make a Difference. Legal Empowerment Working Papers, No. 15. Rome: International Development Law Organization (IDLO).

Rosegrant, M.W., G. Yohe, M. Ewing, R. Valmonte-Santos, T. Zhu, I. Burton, and S. Huq. 2010. Climate change and Asian agriculture. *Asian Journal of Agriculture and Developmen*t. 7 (1). pp. 1–42. http://beta.searca.org/searca/index.php/knowledge-management/knowledge-resources/publications/244-asian-journal-of-agriculture-and-development-vol-7-no-1

Rosegrant, M. W., M. Pasiner, S. Meijer, and J. Witcover. 2001. Global food projections to 2020: Emerging trends and alternative futures. IFPRI 2020 Vision Report. Washington: IFPRI.

Rosegrant, M.W., S. Msangi, C. Ringler, T.B. Sulser, T. Zhu, and S.A. Cline. 2008. International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model description. Washington: IFPRI.

Ruosteenoja, K., T. Carter, K. Jylha, and H. Tuomenvirta. 2003. Future climate in world regions: an intercomparison of model-based projections for the new IPCC emissions scenarios. The Finnish Environment 644. Finnish Environment Institute, Helsinki.

Saweri, W. 2004. Papua New Guinea: Nutrition Overview. http://www.wpro.who.int/internet/resources.ashx/NUT/png.pdf

Secretariat of the Pacific Community (SPC). 2002. Obesity in the Pacific: Too Large to Ignore.

_______. 2006. Climate and tuna fisheries. Oceanic Fisheries Programme. SPC, Noumea. http://www.spc.int/oceanfish

_______. 2007. Solomon Islands 2007 Demographic and Health Survey. Facts and Figures at your fingertips. SPC.

_______. 2008. Fish for Food Security in the Pacific. Working Paper 5. Marine Resources Division, Secretariat of the Pacific Community, Noumea, New Caledonia.

_______. 2011a. SPC Assists Biosecurity Authority of Fiji on Taro Export. http://www.spc.int/en/component/content/article/216-about-spc-news/676-spc-assists-biosecurity-authority-of-fiji-on-taro-export.html

_______. 2011b. Fiji and the Secretariat of the Pacific Community Joint Country Strategy 2010–2014. Jointly compiled by the Secretariat of the Pacific Community and the Fijian Government. Secretariat of the Pacific Community Noumea, New Caledonia.

_______. 2011c. Aquaculture and food security in Solomon Islands. SPC Fisheries Newsletter 134 (January–April 2011)

Simpson, M.C., Scott, D., New, M., Sim, R., Smith, D., Harrison, M., Eakin, C.M., Warrick, R., Strong, A.E.,4 Kouwenhoven, P., Harrison, S., Wilson, M., Nelson, G.C., Donner, S., Kay, R., Geldhill, D.K., Liu, G., Morgan, J.A., Kleypas, J.A., Mumby, P.J., Christensen, T.R.L., Baskett, M.L., Skirving, W.J., Elrick, C., Taylor, M., Bell, J., Rutty, M., Burnett, J.B., Overmas, M., Robertson, R., and Stager, H. 2009. An Overview of Modeling Climate Change Impacts in the Caribbean Region with contribution from the Pacific Islands. United Nations Development Programme (UNDP), Barbados, West Indies.

Singh, J. 2008. Fixing the copra industry. In *Fiji Times*. December 04, 2008. http://www.fijitimes.com/story.aspx?id=107923

Smith, P., A. Mobiha, J. Wani, K. Mufuape, U. Kolkolo, P. Minimulu and J. Soranzie. 2007. Chapter 1 Summary in Smith, P.T. (ed.) 2007. Aquaculture in Papua New Guinea: status of freshwater fish farming. ACIAR Monograph No. 125, 124p.

Solomon Islands Coastal Marine Resources Consultancy Services (SICFCS). 2002. Synopsis of Issues, Activities, Needs, and Constraints: Sustainable Development 1992–2002. Solomon Islands. Prepared by SICFCS in close collaboration with the National Steering Committee, World Summit for Sustainable Development (WSSD Working Group). Solomon Islands National Assessment World Summit on Sustainable Development Johannesburg, June 2002; GEF/UNDP/SPREP. undated. Pacific Adaptation to Climate Change Solomon Islands Report of In-Country Consultations.

Solomon Islands Government Ministry of Development Planning and Aid Coordination (SIG MDPAC). 2007. Solomon Islands Agriculture and Rural Development Strategy: Building local foundations for rural development. http://siteresources.worldbank.org/INTPACIFICISLANDS/Resources/442114-1180930407961/ARDS_Full_Report.pdf

Stads, G-J., N. Omot, and N.M. Beintema. 2005. Papua New Guinea. ASTI Country Brief No. 28. http://www.asti.cgiar.org/pdf/PNG_CB28.pdf

Sugar Research Institute of Fiji (SRIF). 2011. http://www.srif.tk/1_13_History.html

To'abaita Authority for Research and Development (TARD). 2006. Government launches national rural rice development programme. MAY 23, 2006 HTTP://TOABAITA-AUTHORITY.BLOGSPOT.COM/2006/05/GOVERNMENT-LAUNCHES-NATIONAL-RURAL.HTML

Trukai Industries. 1998. *The Rice Relay International*. 3 (6). Lae, PNG.

United Nations Development Programme (UNDP). 1997. Human Development Report 1997. New York: Oxford University Press.

United Nations Department of Humanitarian Affairs (DHA). 1993. Fiji—Cyclone Kina. January 1993. UN DHA Situation Reports 1–6.

University of Berkeley, Museum of Vertebrate Zoology and the International Rice Research Institute. 2010. Global Administrative Areas (GADM), v1.0. http://www.gadm.org

Vilsoni, F. 1993. Sustainable taro culture: Fiji situation. *In* Ferentinos, L., (ed) 1993. Proceedings of the Sustainable Taro Culture for the Pacific Conference. Sustainable Taro Culture for the Pacific Conference; 1992 Sept 24–25; Honolulu, Hawaii. Honolulu (HI): University of Hawaii. pp. 84–87.

Volau, N. 2011. Moves underway to boost dalo export. *Fiji Sun*. February 26. http://www.fijisun.co/2011/02/25/moves-underway-to-boost-dalo-export/

Watts, N., and R. Bourne. 2009. Establishing the Context for Enhanced Commonwealth Support of Small Fisheries. In Bourne, R., and M. Collins (eds) 2009. From Hook to Plate: The State of Marine Fisheries. A Commonwealth Perspective. London: Commonwealth Foundation. xii + 244 pp.

Webster, P.J., G.J. Holland, J.A. Curry, and H.R. Chang. 2005. Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment. *Science*. 309. pp. 1844–1846.

Wood, S., L. You, and W. Baitx. 2000. Dynamic Research Evaluation for Management (DREAM). Washington: IFPRI. http://www.ifpri.org/dataset/dream-dynamic-research-evaluation-management

Woodward, A., S. Hales, N. Litidamu, D. Phillips, and J. Martin. 2000. Protecting human health in a changing world: the role of social and economic development. Bulletin of the World Health Organization. 78 (9).

World Bank (WB). 2000. Cities, Seas and Storms. Managing Change in Pacific Island Economies. Volume IV. Adapting to Climate Change. Washington, DC: The World Bank. http://siteresources.worldbank.org/INTPACIFICISLANDS/Resources/4-TOC.pdf

_______. 2007. Solomon Islands Agriculture and Rural Development Strategy—Building local foundations for rural development. Washington, DC: The World Bank.

_______. 2008. Reducing the Risk of Disasters and Climate Variability in the Pacific Islands. Washington, DC: The World Bank.

_______. 2011a. World Development Indicators. Washington, DC: The World Bank. http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

_______. 2011b. Data on Papua New Guinea. http://data.worldbank.org/country/papua-new-guinea

World Bank and International Finance Corporation (WB-IFC) 2010. Improving the Livelihoods of Palm Oil Smallholders: the Role of the Private Sector. Prepared by FSG Social Impact Advisors (commissioned by the World Bank Group). http://www.ifc.org/ifcext/agriconsultation.nsf/AttachmentsByTitle/FSG+Report/$FILE/FSG+report_formatted.pdf

World Health Organization (WHO). 2005. Papua New Guinea. Country Cooperation Strategy at a Glance. http://www.who.int/countryfocus/cooperation_strategy/ccsbrief_png_en.pdf

World Meteorological Organization (WMO). 1999. The 1997–1998 El Niño Event: A Scientific and Technical Retrospective. Geneva: WMO.

WorldFish Center (WFC). 2011. Aquaculture and food security in Solomon Islands. Policy Brief 2011–08.

Yala, C. (ed). 2010. The Genesis of the Papua New Guinea Land Reform Program. Selected Papers from the 2005 National Land Summit. The National Research Institute Monograph No. 2. NRI, Papua New Guinea. http://www.nri.org.pg/publications/Recent%20Publications/National_Land_Summit_CRC_200910.pdf

Yala, C., and K. Lyons. 2010. The National Land Research Framework for the Papua New Guinea National Land Development Program. The National Research Institute, Papua New Guinea. http://www.nri.org.pg/publications/Recent%20Publications/2012%20Publications/png_landresearch_framework.pdf

You, L. and S. Wood. 2006. An entropy approach to spatial disaggregation of agricultural production. Agricultural Systems 90(1–3): 329–347.

Yu, Winston, Mozaharul Alam, Ahmadul Hassan, Abu Saleh Khan, Alex C. Ruane, Cynthia Rosenzweig, David C. Major, and James Thurlow. 2010. Climate change risks and food security in Bangladesh. Washington: Earthscan.

Zavala, Jorge A., Clare L. Casteel, Evan H. DeLucia, and May R. Berenbaum. 2008. Anthropogenic increase in carbon dioxide compromises plant defense against invasive insects. Proceedings of the National Academy of Sciences. 105 (13). pp. 5129–5133.

APPENDIX 1
Description of Models

International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)

The IMPACT model was originally developed by the International Food Policy Research Institute (IFPRI) for projecting global food supply, food demand, and food security to 2020 and beyond (Rosegrant et al. 2008). It analyzes 32 crop and livestock commodities for 115 countries and regions of the world, further divided into 281 food producing units (grouped according to political boundaries and major river basins). These regions of the world together cover the earth's land surface (with the exception of Antarctica). These regions are called food production units (FPUs). Each country or region is represented by supply and demand equations.

Production and demand relationships in countries are linked through international trade flows. The 2009 version of the model includes a hydrology model and links to the Decision Support System for Agrotechnology Transfer (DSSAT) crop-simulation model, with yield effects of climate change at 0.5-degree intervals aggregated up to the food-production-unit level.

The model simulates growth in crop production, which is determined by crop and input prices, externally determined rates of productivity growth and area expansion, investment in irrigation, and water availability. Demand is a function of prices, income, and population growth and contains four categories of commodity demand—food, feed, biofuels, and other uses. Fiji and Solomon Islands are not in the full IMPACT model due to data limitations for these countries. Therefore, country models were developed for these two countries following IMPACT supply/demand equations systems and were linked to the full model. Supply and demand relationships in the countries are linked through international trade flows and equilibrium world prices.

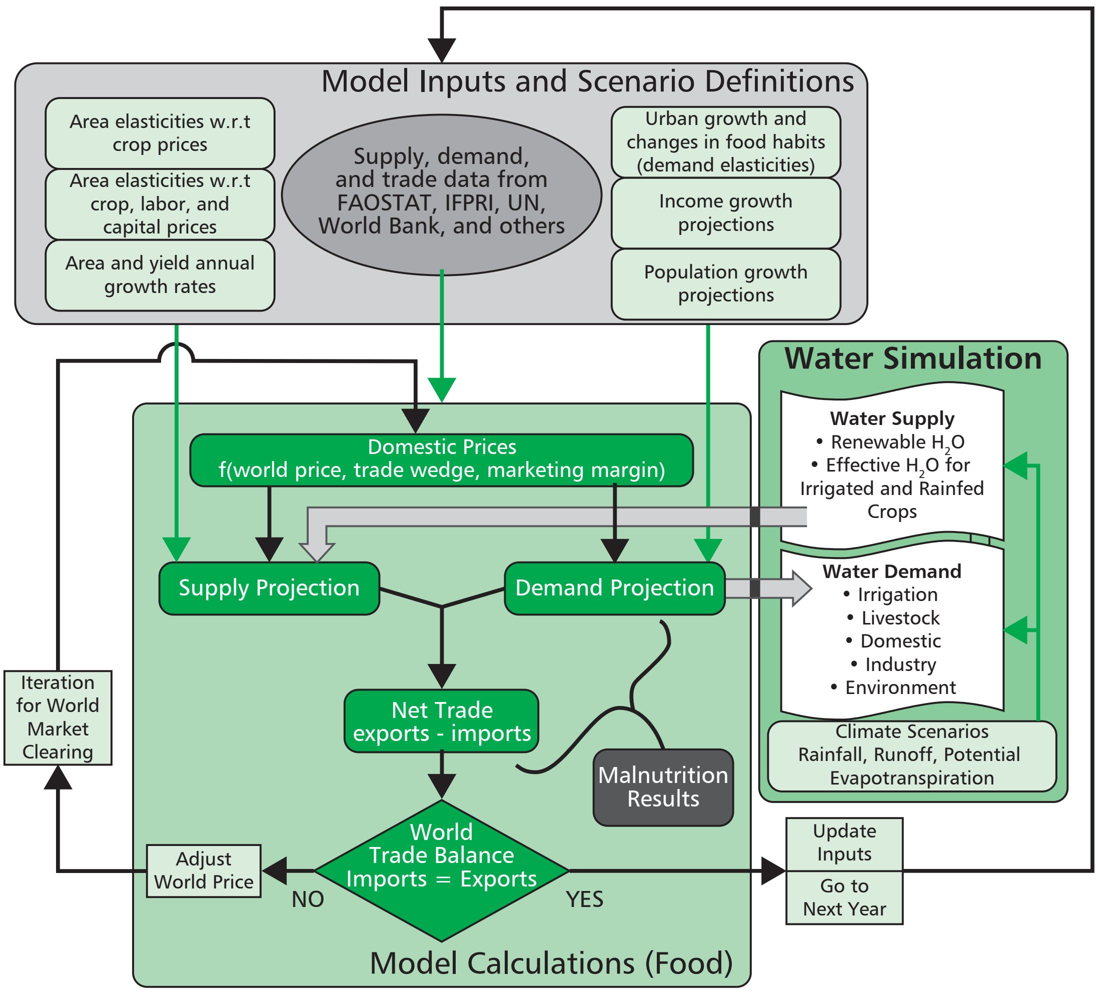
An illustrative schematic diagram of the linkage between the global agricultural policy and trade modeling of the partial agriculture equilibrium model with the hydrology and agronomic potential modeling is shown in Figure A1.

The IMPACT model also generates projections of two food security indicators, based on projected calorie consumption from the model and other factors. The methodology for these food security indicators is described in the following sections.

Malnourished Children

The percentage of malnourished children under the age of five is estimated from the average per capita calorie consumption, female access to secondary education, the quality of maternal and child care, and health and sanitation

Figure A1 The IMPACT Modeling Framework



FAOSTAT = FAO Statistical Database, IFPRI = International Food Policy Research Institute, IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade, UN = United Nations, w.r.t = with respect to.
Source: ???.

(Rosegrant 2001). Observed relationships between all of these factors were used to create the semi-log functional mathematical model, allowing an accurate estimate of the number of malnourished children to be derived from data describing the average per capita calorie consumption, female access to secondary education, the quality of maternal and child care, and health and sanitation. The precise relationship used to project the percentage of malnourished children is based on a cross-country regression relationship of Smith and Haddad (2000).

$$\Delta MAL_{t,t2000} = -25.24 \times \ln\frac{KCAL_t}{KCAL_{2000}} - \left(71.76 \times \Delta LFEXPRAT_{t,t2000}\right) - \left(0.22 \times \Delta SCH_{t,t2000}\right) - \left(0.08 \cdot \Delta WATER_{t,t2000}\right)$$

where

MAL	=	percentage of malnourished children
KCAL	=	per capita kilocalorie availability
LFEXPRAT	=	ratio of female to male life expectancy at birth
SCH	=	the gross female secondary school enrollment rate[1]
WATER	=	percentage of population with access to safe water
$\Delta_{t,t2000}$	=	the difference between the variable values at time t and the base year t2000

The data used in this calculation comes from a variety of sources. The base values for malnourished children originally come from the World Health Organization's *Global Database on Child Growth Malnutrition* (WHO 1997), and have been adjusted to reflect changes reported in the World Bank's *World Development Indicators* (WDI) (World Bank 2010). The base values for the female–male life expectancy ratio, female secondary school enrollment, and access to safe water come from the WDI (World Bank 2010, 1998, 1997). The projections of changes in the female–male life expectancy come from the *United Nations Populations Prospects* medium variant (UN 2006). The projections of changes in female secondary school enrollment and access to clean water come from the Technogarden Baseline Scenario (MA 2005). Per capita kilocalorie availability is derived from two sources: (i) the amount of calories obtained from commodities included in the IMPACT–Food model, and (ii) the calories from commodities outside the model (FAO 2011).

After calculating the percentage of malnourished children, the total number of malnourished children is calculated using the following equation, with the child (0–5 year old) population coming from the medium variant of the UN population projections (UN 2010).

$$NMAL = MAL_t \times POP_t$$

where

MAL	=	Percent of malnourished children
POP	=	number of children 0–60 months old in the population

Share at Risk of Hunger

The share at risk of hunger is the percent of the total population that is at risk of suffering food insecurity. This calculation is based on a strong empirical correlation between the share of malnourished within the total population and the relative availability of food, and is adapted from the work done by Fischer et al. (2005) in the IIASA World Food System used by International Institute for Applied Systems Analysis (IIASA) and Food and Agriculture Organization (FAO) (Fischer et al. 2005).

$$ShareAtRisk = \alpha RelativeKCal^2 + \beta RelativeKCal + int + \varepsilon$$

1 Total female enrollment in secondary education (any age group) as a percentage of the female age-group corresponding to national regulations for secondary education.

where

RelativeKCal	=	the ratio of average food supply to minimum food requirement
int[2]	=	the share at risk of hunger intercept, estimated to be 314.84
A	=	the x^2 parameter, estimated at 106.97
B	=	the x parameter, estimated at –364.54
ε	=	the estimation error

It should be noted that due to the quadratic nature of this equation, it is necessary to bound the share at risk. The lower bound is defined as zero, and the upper bound is 100. Developed countries unsurprisingly have a low share at risk. To save time, we treat all countries below four-percent share at risk of hunger as if they had zero-percent share at risk of hunger. The relative availability of food has been bounded to ensure realistic results, and is calculated using the formula below. When the ratio of calories available to calories required, RelativeKCal, is greater than 1.7, we assume that the share at risk of hunger is below four percent.

$$\text{RelativeKCal} = \frac{\text{KCal}}{\text{MinKCal}}$$

where

Kcal	=	the per capita kilocalorie consumption calculated by the IMPACT model
MinKCal	=	the minimum calories from food requirement, adjusted by the rate of change estimated by FAO (2010)

As noted above, the IMPACT model includes a hydrology model and links to the Decision Support System for Agrotechnology Transfer (DSSAT) crop-simulation model, with yield effects of climate change at 0.5-degree intervals aggregated up to the food-production-unit level.

The DSSAT model is used to assess climate change effects and carbon dioxide (CO_2) fertilization for five crops: groundnuts, maize, rice, soybeans, and wheat. For the remaining crops in IMPACT, the primary assumption is that plants with similar photosynthetic metabolic pathways will react similarly to any given climate change effect in a particular geographic region. Maize, millet, sorghum, and sugarcane all follow the same (C4) metabolic pathway, and are assumed to follow the DSSAT results for maize in the respective geographic regions. The other crops in IMPACT follow a different pathway (C3), so the climate effects are assumed to follow the average for groundnuts, rice, soy, and wheat from the same geographic region with two exceptions. The IMPACT commodities of "other grains" and dryland legumes are directly mapped to the DSSAT results for wheat and groundnuts, respectively. A detailed description of the DSSAT model is provided in the following section.

2 The estimated values of the parameter and intercept values are not the same as the ones used by Fischer et al. These parameters have been adjusted to better fit data from IMPACT. Nevertheless, the parameters are similar.

Decision Support System for Agrotechnology Transfer (DSSAT)

The Decision Support System for Agrotechnology Transfer (DSSAT) is a software package developed by Jones et al. (2003) which integrates the effects of soil, crop phenotype, weather, and management options, and combines crop, soil, and weather databases into standard formats for access by crop models and application programs. The user can simulate multi-year outcomes of crop management strategies for different crops at any location in the world. The DSSAT software incorporates models of 26 different crops with tools that facilitate the creation and management of experimental, soil, and weather data files. DSSAT includes improved application programs for seasonal and sequential analyses that assess the economic risks and environmental impacts associated with irrigation, fertilizer and nutrient management, climate change, soil carbon sequestration, climate variability, and precision management.

We use DSSAT in this research in a number of ways. First, for crops available in DSSAT that are currently grown, we compute a baseline yield using climate data for the year 2000. We recompute yield for these same crops for the climate as anticipated by four global climate models (GCMs) and three climate scenarios for 2050 (though we focus on only one of the scenarios, the A1B scenario). We then look at the differences in yield between these results to get potential losses or gains due to climate change, considering that no other changes are made in the production system.

For DSSAT to be able to compute yield, a collection of detailed information about soil and weather characteristics and our choice of crop and cultivar is put into DSSAT. Weather data is available to us via downscaled climate models from the International Panel on Climate Change Fourt Assessment Report (IPCC AR4). These downscaled models, which were done by Jones, Thornton, and Heinke (2009), supply monthly weather data on solar radiation, the number of rainy days, total rainfall, and maximum and minimum temperatures, and are recorded at each pixel.

Because DSSAT requires detailed daily climate data, not all of which are readily available, we develop various approximation techniques. To simulate today's climate we use the WorldClim current conditions dataset (Hijmans et al. 2007), which is representative of 1950–2000 and reports monthly average minimum and maximum temperatures and monthly average precipitation. Site-specific daily weather data is generated stochastically using the SIMMETEO software built into the DSSAT software suite. At each location, 90 iterations of the DSSAT model are run, and the mean of the yield values are used to represent the effect of the climate variables (adapted from Nelson et al. 2010).

Soil data is available from many sources. The one we typically use is a simplified version (Koo 2009) of the *Harmonized World Soil Database* (FAO/IIASA/ISRIC/ISS-CAS/JRC 2009). Given that soil and weather conditions vary spatially, DSSAT is of great worth because it can compute potential yield at each point in space. We use a 5 arc-minute grid (about 10 kilometers at the equator) in which we compute a value for yield at each point (sometimes referred to as pixel or gridcell) for each technology that DSSAT is capable of evaluating. In our preliminary analysis that has already been completed at the global level, a pixel is 15 arc-minutes (approximately 30 kilometers at the equator). The preliminary analysis looks at groundnuts, maize, potatoes, rice, soybeans, and wheat.

We experiment with various cultivars to find the optimal one, and then use that for our baseline. Similarly, we experiment with all relevant months until we find the optimal month, and then use that as our baseline.

For our analysis, we measure yield at a relatively low level of nitrogen fertilizer use and at a relatively high level of nitrogen fertilizer use. In our analysis, we assume that rainfed crops receive water either from precipitation at the time it falls or from soil moisture. Soil characteristics influence the extent to which previous precipitation events provide water for growth in future periods. We also assume that irrigated crops receive water automatically in DSSAT as needed. Soil moisture is completely replenished at the beginning of each day in a model run (adapted from Nelson et al. 2010). For irrigated rice, however, we use a computer subroutine which calculates appropriate dates to apply water and appropriate levels of water to apply

The second way we use DSSAT is to vary the technologies associated with the crops that are already evaluated. That is, in the first use of DSSAT, we simply allow climate variables to change. Here, we allow other variables to change, such as cultivar, planting date, or fertilizer use. In our analysis, we also use DSSAT to examine other crops that are not currently grown in each country under study, to see if they might give large enough yields under climate change to make them worth considering for adoption. Overall, we produce maps showing spatial variation of the main DSSAT results. In addition, we tabulate the results, so that readers are able to see net changes in crops. Tabulating the results is a little problematic, however, because we do not have an indication where the crops are currently grown, and so do not know how to properly weight the cultivated area of each cell to get yield. The easiest way to address this would be to average the yields in all of the gridcells of the province. However, it is often the case that much of the land area is not currently under crops, and therefore the potential yield in those areas is not being realized. We use the simplifying assumption that for the purposes of aggregation, they will not be cultivated either. We therefore chose to aggregate yields by taking a weighted average based on the amount of cropland, according to our calculations, that must be in each gridcell.

We chose to use satellite land use and land cover datasets to guide us in determining how much land is in cropland. These datasets sometimes misclassify large amounts of land because they misinterpret the meaning of the image data. For example: savanna looks a lot like low-intensity cropland, seasonably flooded areas look like water, and fallowed areas often resemble secondary forest or bush. This last category is relevant for the three countries in this report, particularly Papua New Guinea. To avoid misclassification, we chose to use three different satellite datasets, computing agricultural land in each 5 arc-minute gridcell based on each of the satellite datasets, and then selecting the middle value of the three in each gridcell. The three datasets are the GLC2000 (Bartholome and Belward 2005), the MODIS MCD12Q1 Land Cover 2008 L3 Global 500m (NASA 2009), and GlobCover 2009 (ESA 2010).

GLC2000, the oldest of the three, but still a reliable tool, is at one-kilometer resolution. The MODIS Land Cover data is at 500-meter resolution.

The version we used was for land cover in 2008. Finally, GlobCover 2009 is at 300-meter resolution.

IFPRI's Dynamic Research Evaluation for Management (DREAM) Model

The DREAM model (Alston, Norton, and Pardey 1995) was designed to measure returns to commodity-oriented research in an open-economy setting, allowing for price and technology spillover effects between a country in which the research originates and the rest of the world. DREAM is a single-commodity model, so there is no explicit representation of cross-commodity substitution effects in production and consumption. But these aspects are represented implicitly by the elasticities of supply and demand.

The primary parameterization of the supply and demand equations is based on a set of prices and annual quantities in a defined primary parameterization of the supply and demand equations. The idea is that the linear approximation implied by these elasticities will be good for small equilibrium displacements, such as those implied by single-digit percentage shifts of supply or demand, regardless of the true (nonlinear) functional forms of supply and demand. Small shifts have the added virtue that the cross-commodity and general equilibrium effects are likely to be small, and that the *total* research benefits will not depend significantly on the particular elasticity values used (although the distribution of benefits between producers and consumers and internationally will depend on the elasticities).

DREAM parameterization defines the supply and demand curves in the base year so as to replicate observed market prices and quantities. The DREAM model also allows for underlying growth of supply and demand, to project a stream of shifting supply and demand curves into the future that generates a stream of equilibrium prices and quantities, in the "without research" scenario. These "without research" outcomes can be compared with "with research" outcomes, which are obtained by simulating a stream of displaced supply curves, incorporating research induced supply shifts. The research-induced supply shifts are defined by combining an assumption about a maximum percentage research-induced supply shift under 100% adoption of the technology, in the base year, with an adoption function, representing the pattern of adoption of the technology over time.

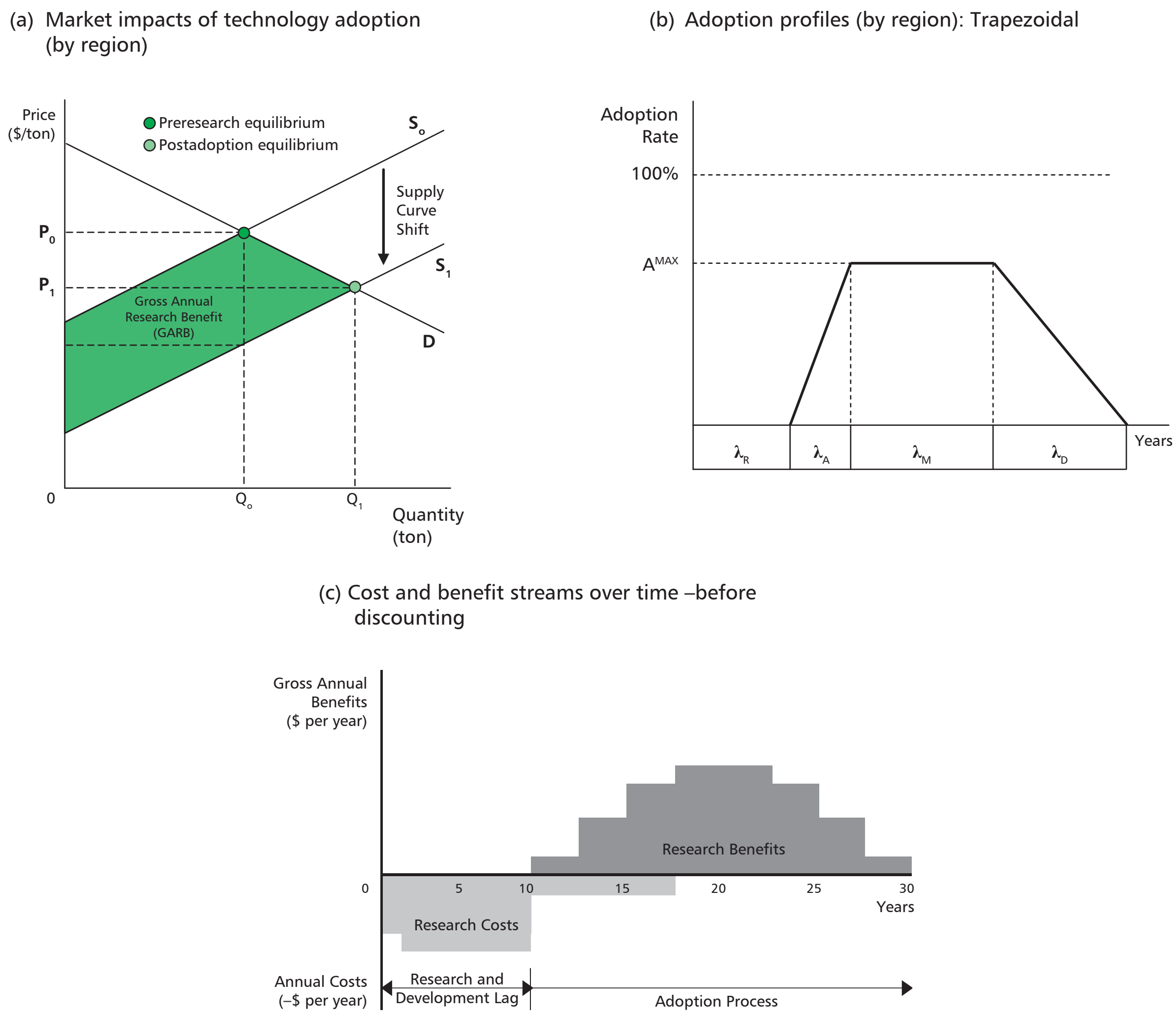
Finally, measures of producer and consumer surplus are computed and compared between the "with research" and "without research" scenarios, and these are discounted back to the base year to compute present values of benefits. In a situation where we know the costs of the research that is responsible for the supply shift being modeled, we can compute a net present value or internal rate of return, but that is not done in this study. The work here is limited to computing the present value of benefits from various climate change adaptation technologies.

The following sections provide descriptions and equations included in DREAM model (Figure A1.2).

DREAM assesses the present value of research benefits in the following cases:

(i) multiple regions, *i*
(ii) producing a homogeneous product
(iii) with linear supply and demand in each region
(iv) with exponential (parallel) exogenous growth of linear supply and demand

Figure A1.2 Key Analytical Components of DREAM



DREAM = Dynamic Research Evaluation for Management Model.
Source: Alston, J.M., G.W. Norton, and P.G. Pardey. 1995. *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. New York: Cornell University Press.

(v) with a parallel research-induced supply shift in one region (or multiple regions)
(vi) with a consequent parallel research-induced supply shift in other regions
(vii) with a range of market-distorting policies
(viii) with zero transport costs (at least initially)
(ix) with a research lag followed by a linear adoption curve up to a maximum
(x) with an eventual linear decline

The analytical model described in detail below is embedded within the DREAM computer program (Wood, You, and Baitx 2001), developed for research priority setting and evaluation.

General Form of Supply and Demand

For region i in year t, linear supply-and-demand equations for a particular commodity (subscript suppressed) are specified as

Supply: $Q_{i,t} = \alpha_{it} + \beta_i P_{i,t}$ (1a)
Demand: $C_{i,t} = \gamma_{it} + \delta_i PC_{i,t}$ (1b)

The first subscript, i, refers to a region, and the second subscript, t, refers to years from the initial starting point of the evaluation. The slopes are assumed to be constant for each region for all time periods. The intercepts may grow over time to reflect underlying growth in supply or demand due to factors other than research (i.e., growth in productivity or income).

Initial Parameterization

Supply and demand are defined by initial conditions (t = 0)

(i) quantity consumed in each region – $C_{i,0}$
(ii) quantity produced in each region – $Q_{i,0}$
(iii) producer price in each region – $PP_{i,0}$
(iv) consumer price in each region – $PC_{i,0}$
(v) elasticity of supply in each region – $\varepsilon_{i,0}$
(vi) elasticity of demand in each region – $\eta_{i,0}$ (<0)

In many cases, the initial values of elasticities would be assumed to be equal among regions (a convenient, but not necessary, assumption). These initial values are sufficient to allow us to compute the slope and intercept of supply and demand in each region for the initial year:

$\beta_{i0} = \varepsilon_{i0} Q_{i,0}/PP_{i,0}$ (2a)
$\alpha_{i0} = (1 - \varepsilon_{i0}) Q_{i,0}$ (2b)
$\delta_{i0} = \eta_{i0} C_{i,0}/PC_{i,0}$ (2c)
$\gamma_{i0} = (1 - \eta_{i0}) C_{i,0}$ (2d)

Exogenous Growth in Supply and Demand

We incorporate average exponential growth rates for demand (due to growth in population and income) and supply (due to growth in productivity or an increase in area cropped) growth expected to occur regardless of whether the research program is undertaken.

$\alpha_{it} = \alpha_{it-1} + \pi_i^Q Q_{i,t}$ for $t > 0$ (3a)
$\gamma_{it} = \gamma_{it-1} + \pi_i^C C_{i,t}$ for $t > 0$ (3b)

where
π_i^C = the growth rate of demand (e.g., population growth rate + income elasticity × income growth rate)
π_i^Q = is the growth rate of supply (e.g., area growth rate + yield growth rate not attributable to research)

Now we have sufficient information to parameterize the supply-and-demand equations for each region in each year under the no-research scenario.

Research-Induced Supply Shifts

Local Effect of Research

Let region *i* undertake a program of research with

(i) probability of success p_i, which, if the research is successful and the results are fully adopted, will yield

(ii) a cost saving per unit of output equal to c_i percent of the initial price, $PP_{i,0}$ in region *i*, while

(iii) a ceiling adoption rate of A_i^{MAX} percent holds in region *i*

Then it is *anticipated* that the supply function in region *i* will shift *down* (in the price direction), eventually, by an *amount per unit* equal to

$$k_i^{MAX} = p_i c_i A_i^{MAX} PP_{i,0} \qquad (4)$$

The *actual* supply shift in any particular year is some fraction of the eventual *maximum* supply shift, k_i^{MAX}, defined above. To define the actual supply shift, we can combine the maximum supply shift with other information about the shape of the time path of $k_{i,t}$ based on data about adoption and depreciation-cum-obsolescence factors. Assuming a trapezoidal shape for the adoption curve, to define the entire profile of supply shifts over time, we need to define the following parameters:

(i) research lag in years – λ_R

(ii) adoption lag (years from initial adoption to maximum adoption) – λ_A

(iii) maximum lag (years from maximum adoption to eventual decline) – λ_M

(iv) decline lag (years from the beginning to the end of the decline) – λ_D

Then we can define the supply shifts (in the price direction) for region *i* in each year *t* as follows:

$$k_{i,t} = 0 \qquad (\text{for } 0 \leq t \leq \lambda_R)$$
$$k_{i,t} = k_i^{MAX} (i - \lambda_R) / \lambda_A \qquad (\text{for } \lambda_R < t \leq \lambda_R + \lambda_A)$$
$$k_{i,t} = k_i^{MAX} \qquad (\text{for } \lambda_R < \lambda_A < t \leq \lambda_R + \lambda_A + \lambda_M)$$
$$k_{i,t} = k_i^{MAX} \frac{\lambda_R + \lambda_A + \lambda_M + \lambda_D}{\lambda_D} \qquad (\text{for } \lambda_R < \lambda_A < \lambda_M < t \leq \lambda_R + \lambda_A + \lambda_M < \lambda_D)$$
$$k_{i,t} = 0 \qquad (\text{for } t > \lambda_R + \lambda_A + \lambda_M < \lambda_D)$$

Figure A1(b) shows the trapezoidal adoption curve and shows how the parameters above ($\lambda_R + \lambda_A + \lambda_M$, and $< \lambda_D$) may be used to define the entire curve.

Spillover Effects of Research

The *spillover effects* from region *i* to other regions, *j*, are parameterized in relation to the supply shifts in region *i*, implicitly assuming the same adoption curve applies in every region.

$$k_{j,t} = \theta_{ji} k_{i,t} \text{ for all i and j} \qquad (5)$$

where

θ_{ji} = supply shift in j due to research-induced supply shift in i ($\theta_{ii} = 1$)

With-Research Supply and Demand

To model the with-research case (denoted by superscript R on all relevant variables and parameters), we take the intercepts from the without-research case (but include the effects of exogenous supply growth), add the effect of the supply shift to them, and include the result in the supply equation:

$$\alpha^R_{j,t} = \alpha_{jt} + k_{jt}\beta_j \quad (6)$$

Supply and demand models reflecting the local and spillover effects of research are

$$Q^R_{i,t} = \alpha^R_{it} + \beta_i PP^R_{i,t} \quad (7a)$$
$$C^R_{i,t} = \gamma_{it} + \delta_i PC^R_{i,t} \quad (7b)$$

The only substantive difference from the corresponding without-research equations (1a and 1b) is in the supply intercept, but as noted above, the prices and quantities are labeled differently (the R superscript) to distinguish them from the without-research values:

(i) quantity consumed in each region – $C^R_{i,t}$
(ii) quantity produced in each region – $Q^R_{i,t}$
(iii) producer price in each region – $PP^R_{i,t}$
(iv) consumer price in each region – $PC^R_{i,t}$

Market-Clearing Rules

For all of the scenarios to be considered, there is an overall quantity clearing rule to the effect that the sum of quantities supplied equals the sum of quantities demanded in each year. Considering n regions,

$$Q_t = (Q_{1,t} + Q_{2,t} + \ldots + Q_{n,t}) = C_t = (C_{1,t} + C_{2,t} + \ldots + C_{n,t}) \quad (8)$$

All of the market-clearing rules express policies in terms of price wedges that permit differences between consumer and producer prices within and among regions consistent with clearing quantities produced and consumed.[3]

Free Trade

The easiest case is that of free trade, where

(i) with-research prices: $PP^R_{i,t} = PC^R_{i,t} = PC^R_{j,t} = PP^R_{j,t} = PP^R_t$
(ii) without-research prices: $PP_{i,t} = PC_{i,t} = PC_{j,t} = PP_{j,t} = P_t$

are defined for all regions i and j and for any year t.

3 Transportation costs influence trade among countries and should theoretically be incorporated into the analysis if possible. However, accurate calculation of these costs is often difficult because it requires knowing the transportation differentials for each commodity between the home country being studied and each of its major trading partners, as well as the pattern of commodity flows.

Making this substitution into each of the n regional supply-and-demand equations and then substituting them into equation 8 yields a solution for the equilibrium price for each year. To simplify, let us define the following aggregated parameters for each year, t:

(i) $\gamma_t = \gamma_{1t} + \gamma_{2t} = \ldots + \gamma_{nt}$
(ii) $\alpha_t = \alpha_{1t} + \alpha_{2t} = \ldots + \alpha_{nt}$
(iii) $\alpha_t^R = \alpha_{1t}^R + \alpha_{2t}^R = \ldots + \alpha_{nt}^R$
(iv) $\delta_t = \delta = \delta_{10} + \delta_{20} + \ldots + \delta_{n0} < 0$
(v) $\beta_t = \beta = \beta_{10} + \beta_{20} + \ldots + \beta_{n0} > 0$

Then the without-research and the with-research market-clearing prices under free trade are given by

$$P_t = (\gamma_t - \alpha_t)/(\beta - \delta) \quad (9a)$$
$$P_t^R = (\gamma_t - \alpha_t^R)/(\beta - \delta) \quad (9b)$$

These are always positive numbers, with $P_t > P_t^R$, because the intercepts on the *quantity* axis satisfy $\gamma t > \alpha_t^R > \alpha_t$—unless we make a mistake such as letting supply grow too fast relative to demand.

We can substitute the results for prices from equations 9a and 9b into the regional supply-and-demand equations to compute regional quantities produced and consumed with and without research and, as we shall see later, then calculate the regional consumer and producer welfare effects.

Generalized Taxes and Subsidies

We can define a general solution for a large variety of tax or subsidy regimes by setting out a general model in which a *per unit* tax is collected from consumers in every region and from producers in every region.

(i) T_i^C = per unit consumer tax in region i
(ii) T_i^Q = per unit producer tax in region i

Different policies can be represented as different combinations of taxes and subsidies

(i) consumption tax in region i at T_i per unit:	$T_i^C = T_i$;	$T_i^Q = 0$
(ii) production tax in region i at T_i per unit:	$T_i^C = 0$;	$T_i^Q = T_i$
(iii) export tax in region i at T_i per unit:	$T_i^C = -T_i$;	$T_i^Q = T_i$
(iv) import tariff in region i at T_i per unit:	$T_i^C = T_i$;	$T_i^Q = -T_i$

A subsidy is a negative tax, so it is also possible to use these to represent subsidies on output, consumption, imports, or exports. One way to think about this is to imagine a region with no taxes or subsidies in which the prices to producers and consumers are $P_t = PC_t = PP_t$ and $P_t^R = PC_t^R = PP_i{}^R$. Thus, P_t (expressed in common currency units, either local currency or \$) is the border price for an exporter or an importer whose internal consumer or producer prices will be equal to that price in the absence of any domestic distortions. The arbitrage rules are that the prices in all regions are equal to

(i) $PP_{i,t} = P_t - T_i^Q$
(ii) $PC_{i,t} = P_t - T_i^C$
(iii) $PP_{i,t}^R = P_t^R - T_i^Q$
(iv) $PC_{i,t}^R = P_t^R - T_i^C$

for all regions i and j and for any year t.

Making this substitution into each of the n regional supply-and-demand equations and substituting them into equation 9 yields a solution for the equilibrium price for each year. As for the case of free trade, let us define the following aggregated parameters for each year:

(i) $\gamma_t = \gamma_{1t} + \gamma_{2t} + \ldots + \gamma_{nt}$
(ii) $\alpha_t = \alpha_{1t} + \alpha_{2t} + \ldots + \alpha_{nt}$
(iii) $\alpha_t^R = \alpha_{1t}^R + \alpha_{2t}^R + \ldots + \alpha_{nt}^R$
(iv) $\delta_t = \delta = \delta_{10} + \delta_{20} + \ldots + \delta_{n0} < 0$
(v) $\beta_t = \beta = \beta_{10} + \beta_{20} + \ldots + \beta_{n0} > 0$

In addition, we define the following aggregated demand-and supply shifts in the quantity direction because of consumer and producer taxes:

(i) $T_t^C = T_{1t}^C\delta_{10} = T_{2t}^C\delta_{20} + \ldots + T_{nt}^C\delta_{n0}$
(ii) $T_t^C = T_{1t}^C\delta_{10} = T_{2t}^C\delta_{20} + \ldots + T_{nt}^C\delta_{n0}$

$$P_t = (\gamma_t + T_t^Q + T_t^C - \alpha_t)/(\beta - \delta) \quad (10a)$$
$$P_t^R = (\gamma_t + T_t^Q + T_t^C - \alpha_t^R)/(\beta - \delta) \quad (10b)$$

To compute the actual consumer and producer prices in any region, the results of equations 10a and 10b are substituted into the arbitrage (market-clearing) rules given above (under the heading "generalized taxes and subsidies"). Individual prices can then be used in the individual supply-and-demand equations (equations 1 and 7) to compute quantities with and without research, and from there to compute surplus effects. Notice that this set of results includes the free-trade model as a special case (i.e., when all of the taxes and subsidies are zero).

Other Policies

Quantitative restrictions on production or trade can be treated approximately as tax/subsidy equivalents with a little care to distribute "tax revenue" as quota rents. The approximation is somewhat unreliable in a dynamic model, but it might suffice for our purposes. A target price, deficiency-payment scheme might involve more work. Conceptually, the approach is to define target price and allow it to determine output in regions where it applies. Then, with that supply as exogenous, supply equations in the other regions and demand equations in all regions would interact to determine price.

Welfare Effects

The following equations apply for assessing welfare effects.

$$\Delta PS_{j,t} = (k_{j,t} + PP^R_{j,t} - PP_{j,t})[Q_{j,t} + 0.5(Q^R_{j,t} - Q_{j,t})] \quad (11a)$$
$$\Delta CS_{j,t} = (PC_{j,t} - PC^R_{j,t})[C_{j,t} + 0.5(C^R_{j,t} - C_{j,t})] \quad (11b)$$
$$\Delta GS_{j,t} = T^C_{jt}\,(C^R_{j,t} - C_{j,t}) + T^Q_{jt}\,[Q^R_{j,t} - Q_{j,t})] \quad (11c)$$

where

$\Delta PS_{j,t}$ = producer research benefit in region *j* in year *t*

$\Delta CS_{j,t}$ = consumer research benefit in region *j* in year *t*

$\Delta GS_{j,t}$ = government research benefit in region *j* in year *t*

Aggregation Over Time and Interest Groups

The model generates a series of prices, quantities, and economic surplus measures for the regions of interest for a range of tax or subsidy policies. The remaining problem is to aggregate those measures into summary measures of research benefits. For a given policy scenario, we have the measure of benefits—$\Delta PS_{j,t}$, $\Delta CS_{j,t}$, $\Delta GS_{j,t}$— *for each region in each time period*.

The *real* discount rate must be defined for the computation of the present value of the stream of benefits. A reasonable approach is to fix a single value for all regions, interest groups, and years so that

$$r_{i,t} = r_{j,s} = r$$

We need to define a relevant planning horizon. Thirty years should be adequate for most purposes if we are using discount rates of 5% per year or greater. The *present values* of benefits to interest groups are then defined as

$$VPS_i = \Sigma^{30}_{t=0}\Delta PS_{i,t}/(1+r)^t$$
$$= \Delta PS_{i,0}+\Delta PS_{i,1}/(1+r)+\Delta PS_{i,2}/(1+r)^2+\ldots+\Delta PS_{i,30}/(1+r)^{30} \quad (12a)$$
$$VCS_i = \Sigma^{30}_{t=0}\Delta CS_{i,t}/(1+r)^t$$
$$= \Delta CS_{i,0}+\Delta CS_{i,1}/(1+r)+\Delta CS_{i,2}/(1+r)^2+\ldots+\Delta CS_{i,30}/(1+r)^{30} \quad (12b)$$
$$VGS_i = \Sigma^{30}_{t=0}\Delta GS_{i,t}/(1+r)^t$$
$$= \Delta GS_{i,0}+\Delta GS_{i,1}/(1+r)+\Delta GS_{i,2}/(1+r)^2+\ldots+\Delta GS_{i,30}/(1+r)^{30} \quad (12c)$$

References

Alston, J.M., G.W. Norton, and P.G. Pardey. 1995. Science under Scarcity: Principles and Practices for Agricultural Research Evaluation and Priority Setting. New York: Cornell University Press.

Alston, J.M. et al. 2000. Strategic Technology Investments for LAC Agriculture: A Framework for Evaluating the Local and Spillover Effects of R&D. Washington, DC: International Food Policy Research Institute (IFPRI).

Alston, J.M., and W.K. Wohlgenant. 1990. Appendix 2: Measuring Research Benefits using Linear Elasticity Equilibrium Displacement Models. In Mullen. J.D. and J.M. Alston, eds. *The Returns of the Australian Wool Industry from Investment in R&D.* Rural & Resource Economics Report No. 10, New South Wales Department of Agriculture and Fisheries, Sydney, Australia.

Bartholome, E., and A.S. Belward. 2005. GLC2000: A New Approach to Global Land Cover Mapping from Earth Observation Data. *International Journal of Remote Sensing*. 26 (9). pp. 1959–1977.

Batjes, N. et al. 2009. *Harmonized World Soil Database.* Laxenburg, Austria: International Institute for Applied Systems Analysis.

EM-DAT (Emergency Events Database [for floods, droughts and storms]). www.emdat.be/Database/CountryProfile/countryprofiles.php (accessed on 11 March 2011).

European Space Agency (ESA). 2010. GlobCover 2009 land cover map, v2.3. Available at http://ionia1.esrin.esa.int/

Food and Agriculture Organization, International Institute for Applied Systems Analysis, ISRIC – World Soil Information, Institute of Soil Science – Chinese Academy of Sciences, and Joint Research Centre of the Euporean Commission (FAO/IIASA/ISRIC/ISS-CAS/JRC). 2009. Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

Hijmans, R.J. et al. 2007. The WorldClim Interpolated Global Terrestrial Climate Surfaces. Version 1.4. http://biogeo.berkeley.edu/

Hijmans, R.J. et al. 2005. Very High Resolution Interpolated Climate Surfaces for Global Land Areas. *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org

Jones, P.J., P.K. Thornton, and J. Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for the International Livestock Research Institute (ILRI). Kenya, Nairobi.

Jones, J.W. et al. 2003. The DSSAT Cropping System Model. *European Journal of Agronomy*. 18 (3–4). pp. 235–265.

NASA Land Processes Distributed Active Archive Center (LP DAAC). 2009. *MODIS MCD12Q1 Land Cover 2008 L3 Global 500m SIN Grid.* USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota.

Nelson, G. et al. 2010. *Food Security, Farming and Climate Change to 2050: Scenarios, Results, Policy Options.* IFPRI Research Monograph. Washington, DC: International Food Policy Research Institute.

Rosegrant, M.W. et al. 2008. *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description*. Washington, DC: International Food Policy Research Institute. June.

Wood, S., L. You, and W. Baitx. 2000. *DREAM User Manual 2000.* Washington, DC: International Food Policy Research Institute.

APPENDIX 2

Agriculture and Fisheries Sectors in Fiji

Overview

Fiji is located in the Southwest Pacific Ocean, midway between the equator and the South Pole and between longitudes 175° and 178° west, and latitudes 15° and 22° south (Government of Fiji 2005b). The country has a total land area of 18,333 square kilometers (km^2) and comprises more than 332 islands, of which only one-third are inhabited. The two largest inhabited islands—Viti Levu (10,429 km^2) and Vanua Levu (5,556 km^2)—make up about 87% of the nation's landmass, of which only 16% is suitable for farming. Those lands are primarily found along the coastal plains, river deltas, and valleys of Viti Levu and Vanua Levu islands; the rest is located in the group's smaller outlying islands.

Fiji comprises large mountainous islands, mostly of volcanic origin, and numerous small volcanic islands, low-lying atolls, and elevated reefs. The major islands have a diverse range of terrestrial ecosystems, including extensive areas of indigenous forest. Fiji's coastal ecosystems include mangroves; algae and seagrass beds in shallow reef and lagoon areas; and various types of reefs such as barrier, fringing platform, and atoll or patch reefs.

Climatic Conditions

Fiji has an oceanic, tropical climate with tempering influences of prevalent southeast trade winds producing a mean annual temperature of 28°C. In the dry season (May to October), temperatures average 22°C (72°F); in the rainy season (November to April), temperatures are higher. Rainfall varies significantly, with the windward sides of larger islands being extremely wet, while the leeward sides experience considerably less rainfall (World Bank 2008). Average rainfall increases steadily inland from coastal areas, and usually between December and April, particularly over the larger islands. From May to October, rainfall is often deficient, especially in the dry zone on the western and northern sides of the main islands (Government of Fiji 2005b).

Fiji is prone to El Niño events and tropical cyclones relative to the positioning of the South Pacific Convergence Zone (SPCZ). During an ENSO event, conditions are drier and hotter than normal and can be expected from June to August (Government of Fiji 2005b). During the wet season, Fiji is often traversed by tropical cyclones. On average, some 10–12 cyclones per decade affect some parts of Fiji, and 2–3 of these cyclones can be severe.

Share of Agriculture in Gross Domestic Product

Agriculture remains an important sector of the Fiji economy: 36% of the country's economically active population was involved in agriculture in 2010 (FAO 2011). Agriculture's contribution to GDP, however, has declined considerably in recent years (from 20% in 1995 to 13% in 2009), mainly due to faster growth of the nonagriculture sector (Table A2.1).[1] Notably, rural-based subsistence farming is underestimated in GDP calculations (Hone and Haszler 2006 as cited in SPC 2011b), so these proportions may be higher. But the declining trend for agriculture as a share of total GDP is robust.

In recent years, the economic performance of rural enterprises in Fiji has suffered from declining prices for key commodities and disruption in land tenure arrangements for sugarcane growers (Hone, Haszler and Natasiwai 2008). In particular, the recent reluctance of some traditional landowners to renew sugar leases has been a significant factor in the decline of sugarcane production since about 2000. This has also contributed to the declining share of agriculture in GDP. Moreover, the sugar industry, generally viewed as the backbone of the Fiji economy, has been under severe market pressure in recent years as the European Union (EU) phased out the preferential prices it paid to certain nations, including Fiji (Ahmed et al. 2011; SPC 2011b). Declining output price support for Fiji's sugar has negatively affected the country's sugar industry. In its Joint Country Strategy 2010–2014, the Government

Table A2.1 Real Gross Domestic Product at Factor Cost and Share of Agriculture GDP in Real GDP, Fiji, 1995–2009

Year	Real GDP at Factor Cost (F$ million)	Agriculture GDP (F$ million)	Percentage Share of Agriculture GDP in Real GDP (%)
1995	2,373	476	20
1996	2,487	497	20
1997	2,427	445	18
1998	2,459	410	17
1999	2,673	466	17
2000	2,627	461	18
2001	2,676	435	16
2002	2,761	455	16
2003	2,784	435	16
2004	2,935	457	16
2005	4,327	609	14
2006	4,407	639	14
2007	4,370	608	14
2008	4,379	638	15
2009	4,249	562	13

Source: Ahmed, M. et al. 2011. Food Security and Climate Change: Rethinking the Options. *Pacific Studies Series*. Manila: Asian Development Bank.

1 Agriculture includes forestry, hunting, and fishing, as well as the cultivation of crops and the production of livestock.

of Fiji (2011), together with the Secretariat of the Pacific Community (SPC), emphasized rejuvenating the agriculture sector, particularly nonsugar agriculture and livestock, in anticipation of the decline of the sugar industry.

In addition to the above-mentioned reasons for the state of agriculture in the country, the Fiji Department of Agriculture (2011b) attributes the sector's decline in importance to vulnerability to natural disasters, minimal private investment in agriculture, inadequate infrastructure, marketing deficiencies, and soaring production costs due to high input costs. Lack of private investment in agriculture is due to a weak business climate stemming from structural issues related to land leases and uncertainty in the country's regulatory and legal environments (IMF 2011). Coups and political instability have also contributed to sluggish private investment.

Population and Human Development

Ahmed et al. (2011) estimated that the population of Fiji is about 848,000, with a density of 46 persons per km^2 in 2010. Among the 15 provinces, Ba, with 231,760 people, is the most-populated province; with 2,002 people in 2007 (Table A2.2), Rotuma is the least populated (FBS 2011). The Fiji Bureau of Statistics (FBS 2011) estimated that in 2007, around 50% of the population was living in the rural areas.

According to the FIBS (2011), 31% of the population lives below the internationally accepted poverty line of $1.25 purchasing power parity in 2009. However, Fiji has the most developed economy in the Pacific. This seems to be more due to tourism, although the key role of subsistence agriculture and fishing communities in the country's rural areas cannot be discounted (FAO 2007). The Ministry of Finance and National Planning (MFNP) (2004)

Table A2.2 Population by Province, Fiji, 2007

Province	Population
Ba	231,760
Naitasiri	160,760
Rewa	100,787
Macuata	72,441
Nadroga	58,387
Tailevu	55,693
Cakaudrove	49,344
Ra	29,464
Serua	18,249
Lomaiviti	16,461
Bua	14,176
Lau	10,683
Kadavu	10,167
Namosi	6,898
Rotuma	2,002

Source: Fiji Bureau of Statistics (FBS). 2011. *Fiji Facts and Figures as at 1st July 2010*. Suva.

projected that the population will reach the one million level in 2016. This indicates that pressure on food availability, access to clean water, housing, health, education, employment, and other basic services will only intensify.

Poverty curtailing human development is prevalent, not only in terms of monetary resources, but also in terms of the denial of a healthy and creative life, decent standard of living, access to basic resources, freedom, dignity, self-respect, and respect for others (UNDP 1997). In 1997, UNDP's *Human Development Report* (HDR) introduced a Human Poverty Index (HPI) that is not solely dependent on monetary value. It examines short life spans and lack of access to basic education and public and private resources as basic dimensions of deprivation. Acknowledging that poverty is more multidimensional than these three factors indicate, HDR established 10 indicators of human development in 2010. These indicators include nutrition, child mortality, years of schooling, school enrollment, cooking fuel, toilets, water, electricity, floors, and assets grouped into three dimensions: *health* (nutrition, child mortality); *education* (years of schooling, school enrollment) and *living standards* (cooking fuel, toilets, water, electricity, floors, and assets). Together, these three dimensions form the Human Development Indicators (HDI) (UNDP 2010).

HDI's examination of the status, development, and improvement of health, education, and living standards in a country provides an important tool in developing and implementing policy (UNDP 2010). In the 2010 HDI rankings, Fiji ranked 86th of 169 countries and was included in the "Medium Human Development" category (World Bank 2010). This classification suggests improved progress in health, education, and living standards, as well as other parameters, including quality of life, access to basic resources, freedom, dignity, and self-respect (UNDP 1997).

Health

In 2004, the National Food and Nutrition Center (NFNC) (2009) conducted a national nutrition survey of Fiji. Results indicated that around 79% of young children (less than 2 years old) were born with standard birth weight. Around 11% of infants were born with low birth weight (below 5.5 pounds [lbs]), and 11% of children under 5 years old were considered underweight. The survey also showed that 14% of children under 18 years old were found to be overweight, and 12% were underweight.

NFNC (2009) likewise reported that adults (18 years old and above) weighed 4.5–5.2 kilograms more than they did in 1993. Using the body mass index (BMI) as indicator, around 38% were considered healthy, 32% overweight, 24% obese, and 6% underweight. The survey also showed that obesity, at 28%, is more prevalent in urban areas than in rural communities, where it is at 22%. The Ministry of Health (2002) reported that, of Fijians between 15 and 64 years old, 29% were overweight and 18% were obese. Obesity is also more prevalent in urban areas and among women (SPC 2002). Using waist circumference as a reference, women (at 51%) have a higher risk of developing noncommunicable diseases than do men (14%) (NFNC 2009).

Education

Data on school enrollments in Fiji were collected by FBS (2011). In 2008, primary school enrollments were estimated at 151,652, but dropped by around 15% in 2009 (129,444). The decline in primary school enrollments was primarily attributed to female enrollees: 83,978 students in 2008 versus 62,240 enrolees in 2009. Similarly, male enrollee numbers had slight decreases, from 67,634 in 2008 to 67,204 in 2009 (FBS 2011). The number of schools dropped slightly between 2008 and 2009, from 727 to 721. Unlike primary schools, secondary schools almost maintained the status quo in enrollments: 67,746 students were enrolled in 2008 compared with 67,072 in 2009. 2008 enrollments comprised 32,554 boys and 35,192 girls compared with 32,029 boys and 35,043 girls in 2009 (FBS 2011).

Living Standards

The Government of Fiji has improved its health-care facilities, including primary, preventative, and curative services (MFNP 2004). Half the population, however, resides in rural areas that lack health services due to remoteness and lack of supplies, which makes it difficult to attractive the needed medical personnel. To address these issues, the MFNP (2004) has suggested the following actions in its national health strategy:

(i) improving the health status of rural communities by supporting disease prevention and control, promoting community health services, and institutionalizing compulsory rural services for doctors and health specialists;
(ii) improving the supply of water and strengthening national food and health programs; and
(iii) encouraging health professionals to spend time in Fiji as part of human development initiatives, and reinforcing training in rural health services.

Around 76% of children are immunized against infectious diseases (e.g., measles), which indicates improved child health and mortality outcomes (MFNP 2004). This is relatively high compared with other Pacific nations, and reflects the success of the Ministry of Health's comprehensive national immunization program, as well as its primary health care and the effectiveness of its rural clinics and stations (MFNP 2004).

Aside from this comprehensive immunization program for children and improved maternal health, investments in water and sanitation infrastructure are critical to the healthy lives of Fijians. A household income and expenditure survey conducted in 2002 showed that 96% of urban communities had access to a safe water supply, and that 79% of urban households used flush toilets (MFNP 2004).

Food Production

Fiji comprises 300 islands with a total land area of 18,333 km^2 (FDA 2011a). The *iTaukeians*[2] own around 88% of the land and the state around 4%; the rest is freehold land (8%) with the exception of a small percentage (0.3%)

2 The Fijian Affairs Amendment Decree of 2010 replaced the terms "Fijian," "Indigenous," or "Indigenous Fijian" with the term *iTaukei.* http://www.fijianaffairs.gov.fj/iTaukei.html)

owned by the Rotuman (i.e., the indigenous people of Rotuma Islands). Of the total land area, 93% is devoted to agriculture, and the remaining 3% to nonagriculture.

Agricultural land is further divided into areas allocated to temporary crops, permanent crops, fallow area, pastureland, coconut land, natural forests, and planted forests (FDA 2011a). Actual land use for permanent crops is highest, at 31%. Pastures occupy 19%, and natural forests 17%. The decline in agricultural land is due to residential and industrial development, a shift from rural farming to urban jobs, deregulation policies, low prices for crops, and land tenure issues (FDA 2011a).

In 2009, sugarcane accounted for 93% of agricultural production by volume in Fiji, or 2.2 million metric tons (FDA 2011a). This was followed by cassava, dalo, and coconut (Table A2.3). Root crops, mainly cassava and yams, are the primary staples of the *iTakuei* diet. Rice is also cultivated, but minimally (less than 1%).

Table A2.3 Output of Fiji's Major Crops, 2009
(metric tons per year)

Major crop	Output (mt/yr)	Percentage Share in Total
Sugarcane	2,197,948	93.72
Cassava	58,772	2.51
Dalo (Taro)	56,645	2.42
Coconut (copra) nuts	10,634	0.45
Yaqona (Kava)	6,067	0.26
Rice	4,288	0.18
Bananas	3,392	0.14
Pineapple	2,829	0.12
Watermelons	2,781	0.12
Ginger	1,946	0.08

Source: Fiji Department of Agriculture (FDA). 2011a. *Report on the Fiji National Agricultural Census 2009.* Economic Planning and Statistics Division. Suva.

Food Consumption

Cereal consumption was the highest of the food commodities, ranging from 1,351 kilograms per capita per year (kg/capita/yr) in 1992 to 1,081 kg/capita/yr in 2006, and acting as a major contributor of energy in Fiji (Table A2.4). Nevertheless, the annual consumption rate declined at 1% per year during this period. Local production and importation of rice (to offset low production) made this commodity available to the public (FBS 211).

Rootcrop consumption was estimated at 90 and 103 kg/capita/yr in 1992 and 2006, respectively. An annual average increase in the intake of root crops of 13% was also calculated for this period. It is important to note that the shift from root crop to cereal intake may be due to changes in consumer preferences.

Table A2.4 Estimated Level and Annual Percentage Change in Daily Per Capita Food Demand in Fiji, 1992–2006

Commodity	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
FOOD DEMAND (kg) [a]															
Cereal	1,351	1,368	1,305	1,224	1,234	1,222	1,060	1,187	1,175	1,126	1,094	1,266	1,210	1,428	1,081
Sugar	446	382	417	439	393	430	399	447	467	371	398	401	514	414	409
Root crops	90	107	132	193	252	242	231	199	250	216	288	288	406	450	403
Nuts and oil seeds	136	93	77	77	98	97	114	130	105	130	114	77	78	84	84
Pulses	43	79	81	73	79	71	112	69	67	84	86	91	70	72	56
Vegetables	16	18	18	20	21	28	19	18	28	36	34	34	29	35	37
Fruits	17	24	24	20	25	22	19	13	16	17	15	14	16	13	16
Meat	174	178	177	173	175	175	180	179	186	165	170	179	178	193	205
Milk	77	79	78	79	84	82	77	82	61	54	47	72	87	105	90
Eggs	13	14	14	15	15	15	19	15	15	14	15	13	13	18	18
Fish	109	120	126	136	140	128	77	134	131	157	168	181	242	227	223

Commodity	1992–1993	1993–1994	1994–1995	1995–1996	1996–1997	1997–1998	1998–1999	1999–2000	2000–2001	2001–2002	2002–2003	2003–2004	2004–2005	2005–2006
ANNUAL CHANGE (%) [b]														
Cereal	1.26	(4.61)	(6.21)	0.82	(0.97)	(13.26)	11.98	(1.01)	(4.17)	(2.84)	15.72	(4.42)	18.02	(24.30)
Sugar	(14.35)	9.16	5.28	(10.48)	9.41	(7.21)	12.03	4.47	(20.56)	7.28	0.75	28.18	(19.46)	(1.21)
Root crops	18.89	23.36	46.21	30.57	(3.97)	(4.55)	(13.85)	25.63	(13.60)	33.33	0.00	40.97	10.84	(10.44)
Nuts and oil Seeds	(31.62)	(17.20)	0.00	27.27	(1.02)	17.53	14.04	(19.23)	23.81	(12.31)	(32.46)	1.30	7.69	0.00
Pulses	83.72	2.53	(9.88)	8.22	(10.13)	57.75	(38.39)	(2.90)	25.37	2.38	5.81	(23.08)	2.86	(22.22)
Vegetables	12.50	0.00	11.11	5.00	33.33	(32.14)	(5.26)	55.56	28.57	(5.56)	0.00	(14.71)	20.69	5.71
Fruits	41.18	0.00	(16.67)	25.00	(12.00)	(13.64)	(31.58)	23.08	6.25	(11.76)	(6.67)	14.29	(18.75)	23.08
Meat	2.30	(0.56)	(2.26)	1.16	0.00	2.86	(0.56)	3.91	(11.29)	3.03	5.29	(0.56)	8.43	6.22
Milk	2.60	(1.27)	1.28	6.33	(2.38)	(6.10)	6.49	(25.61)	(11.48)	(12.96)	53.19	20.83	20.69	(14.29)
Eggs	7.69	0.00	7.14	0.00	0.00	26.67	(21.05)	0.00	(6.67)	7.14	(13.33)	0.00	38.46	0.00
Fish	10.09	5.00	7.94	2.94	(8.57)	(39.84)	74.03	(2.24)	19.85	7.01	7.74	33.70	(6.20)	(1.76)

kg = kilograms, ( ) = negative value.
Sources:
[a] Fiji Bureau of Statistics (FBS). 2011. *Fiji Facts and Figures as at 1st July 2010*. Suva.
[b] Authors' estimates from FBS 2011.

The annual per capita consumption of meat and meat products rose from 174 kg in 1992 to 205 kg in 2006, with an estimated average expansion of 1.28% per year in food intake. The intake of fish and seafood products rose from 109 kilocalories (kcals) in 1992 to 249 kcals in 2007, representing approximately 7.83% average yearly consumption growth.

Consumption of other food commodities, such as milk and dairy products, rose by an average 2.62% per year. High importation of dry milk products encouraged this increase (NFNC 2009). Sugar contributed only 0.24% yearly growth in consumption from 1992 to 2006; production declined during the 2000 political crisis, although its importation assured its availability. The country's 14% sugar consumption is above the recommended population nutrient goal of 10% defined by World Health Organization (NFNC 2009). High intake of sugar can lead to serious health problems, such as diabetes and obesity.

Pulses consumed were estimated to have risen by an average of 5.86% per year from 1992 to 2006. The low local production of dried legumes contributed to low consumption despite this crop being the basis of dhal, a bean stew that provides important low-cost, high-protein content to the diets of urban and rural families in Fiji.

Trade

The Food and Agriculture Organization of the United Nations (FAO) (2011) listed the five major agricultural commodities of Fiji in 2008 (Table A2.5). Sugar has the highest export value at an average of $117 million during 2000–2009. Other key agricultural exports include pastry, taro, molasses and wheat flour, which are marketed to Australia, New Zealand, Japan, the Republic of Korea, the United States, and within the Pacific Islands (McGregor, Gonemaituba, and Stice 2009).

The declining trends in agriculture noted above have contributed to an increased reliance on agricultural imports to meet food demand. Wheat, sheep meat, milk, and rice top the list in value of agricultural imports (Table A2.6). With continuing growth in imports, by 2008–2009 agricultural imports were about double the average for the decade shown in Table A2.6. Prasad (2010) argued that Fiji should not be importing these agricultural products to this degree because the country has sufficient resources like land and labor, and favorable climate conditions. Given lack of storage facilities, especially for

Table A2.5 Volume and Value of Fiji's Top Five Agricultural Exports (2000–2009 average values)

Commodity	Volume (metric ton)	Value ($'000)
Sugar, raw centrifugal	258,650	117,434
Pastry	5,941	10,387
Taro (cocoyam)	10,098	10,368
Molasses	112,834	7,081
Wheat flour	13,301	5,100

Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. http://faostat.fao.org/

Table A2.6 Volume and Value of Fiji's Top Five Agricultural Imports (2000–2009 average values)

Commodity	Volume (metric ton)	Value ($'000)
Wheat	117,504	32,883
Sheep meat	8,874	14,883
Milk, whole dried	2,823	8,820
Rice, husked	20,943	8,682
Food, prepared, not otherwise specified	2,763	6,615

Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. http://faostat.fao.org/

(easily perishable) vegetables, and insufficient government interventions or policies, these products are imported instead of being produced dometically (Kumar and Bhati 2010).

Major Crops

Sugarcane

Overview and History

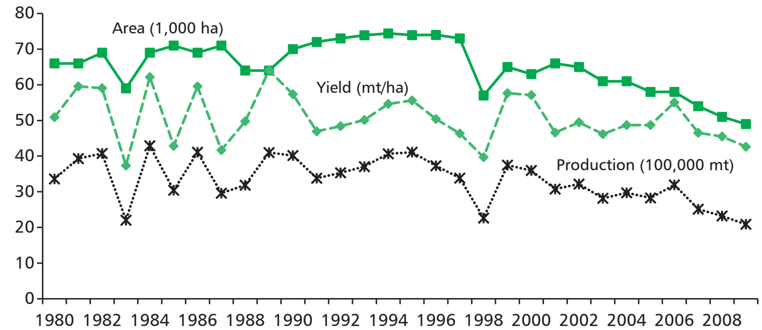
Sugarcane is Fiji's most important agricultural industry, accounting for over one-third of the country's industrial activity. Of the country's arable land, about 24% is under sugarcane. An estimated 22,000 individuals grow sugarcane, farming an average 3–4 hectares (ha) of land. The majority of these sugarcane farmers produce less than 200 metric tons (mt) per year (FSC 2002).

Early European discoverers and settlers found sugarcane growing when they arrived in Fiji. Around 1873, the first large-scale sugarcane was planted in Suva (SRIF 2011). At first, sugarcane was grown as a second choice to cotton, but by 1880 it had displaced both cotton and copra. It then became Fiji's major export commodity. In 1879, the British government brought indentured laborers from India to work on various plantation crops, including sugar. Most of the indentured laborers stayed on and settled small farms. Today, most of Fiji's cane growers are descendants of these indentured laborers from India. While indigenous Fijians own most farmland, local residents of Indian ancestry farm it and produce about 90% of all sugarcane. The sugarcane is processed into raw sugar and molasses by the Fiji Sugar Corporation (FSC). Notably, the Fiji Government, which holds about 68% ownership in FSC, is taking over the company after it accumulated losses of more than F$200 million in 2009–10 (ADB 2011). The company's operations are now funded through the national budget.

Production

Sugarcane production averaged 3.33 million mt from 1980 to 2009 (Figure A2.1, Table A2.7). In the same period, the area harvested to sugarcane averaged 65,340 ha for an average sugarcane yield of 50.69 t/ha. Wide fluctuations in annual sugarcane output are observed in Fiji (Figure A2.1). In terms of growth rates, sugarcane production fell by 1.82% annually

Figure A2.1 Sugarcane Area Harvested, Production, and Yield, Fiji, 1980–2009



ha = hectare, mt = metric ton.

Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. http://faostat.fao.org/

Table A2.7 Average Sugarcane Output, Area Harvested, Yield, and Growth Rate, Fiji, 1980–2009

Item	1980–2009	Growth Rate (%) 1980–1990	1990–2000	2000–2009	1980–2009
Output (mt millions)	3.33	(0.07)	(1.60)	(4.97)	(1.82)
Area Harvested (ha 000s)	65.34	(0.19)	(1.86)	(3.24)	(0.98)
Yield (mt/ha)	50.69	0.12	0.14	(1.82)	(0.85)

ha = hectare, mt = metric ton, ( ) = negative value.

Source: Compiled by authors from Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. http://faostat.fao.org/

from 1980 to 2009. In the same period, the area harvested to sugarcane and sugarcane yield were declining at a rate of 0.98% and 0.85% per year, respectively. It is notable that sugarcane production in 2009 (2.09 million mt) was significantly below (38%) the 1980 level (3.36 million mt). It is also noteworthy that in January 2009, floods in Fiji—reportedly the worst since 1931—greatly affected sugarcane farmers. Loss in sugarcane output was estimated at about 131,409 mt, valued at about $8.0 million using a postdevaluation cane price of $61.17/ton (Lal, Rita, and Khatri 2009).

From 1980 to 1990, sugarcane production was highly erratic. It generally posted a negative growth rate, decreasing at an average of 0.07% per year. While yield grew at a rate of 0.12% per year, area harvested to sugarcane was falling by a slightly higher rate (0.19% per year), offsetting the positive impact of yield on production. It should be noted that in some years during the period 1980–1990, cyclones badly damaged sugarcane. Cyclone Oscar in 1983 devastated the main sugar-growing areas in the Western Division, resulting in a $20 million loss of earnings for cane farmers; similarly, two 1985 cyclones (cyclones Eric and Nigel) resulted in losses of $21.7 million (Benson

1997). Cyclones can damage sugarcane, dislodging crops and causing cane to break, but generally not uprooting plants. In addition to cyclones, sugarcane was also badly affected by drought during the period 1980–1990. Large parts of sugarcane areas had to be replanted following a severe 1983 drought, during which rainfall in the dry season was uneven and conditions were often too dry for sugar production, thus reducing yields (Benson 1997).

In the succeeding years, from 1990 to 2000, production fell at a much faster rate, declining at 1.60% per year as the area harvested to sugarcane was declining by 1.86% per year The El Niño of 1997/98 caused a drought that wiped out two-thirds of Fiji's new sugarcane plantings. From 2000 to 2009, trends in sugarcane production declined faster (4.97% per year) as the area harvested to sugarcane continued to decline (3.24% per year), accompanied by declining sugarcane yields (1.82% per year).

The decline in area harvested and yield can be attributed to land lease problems that began affecting the industry in the late-1990s. In Fiji, land tenure is about leases, their expiry, and the nonrenewal of leases. The first leases in Fiji expired in 1997, and the land issue still remains unsolved (Anderson and Jenshagen 2010). The expiry of leases on sugarcane farms stops farmers from reinvesting in cane assets. Due to the state's inability to solve the land lease problems, uncertainty surrounding the renewal of leases after they expire has led to lost confidence among farmers and a subsequent decrease in investment in new cane planting. Moreover, expiring land leases have resulted in an increase in the number of farmers leaving the industry (FDA 2011b).The majority of the land leases for non-indigenous sugarcane farmers that expired after 1997 were not renewed. The expiring land leases have accompanied the non-use of land for sugarcane production by landowners; the bulk of the land remains unused and in many cases has reverted to bushland (Narayan 2004).

Sugarcane farming in Fiji is centered in the sugarcane-growing provinces of the Western and Northern divisions. In 2009, Ba, Macuata, and Ra were the top three sugarcane-producing provinces, contributing 52%, 26%, and 12%, respectively, of the country's total sugarcane production (Table A2.8). Ba had the largest harvested area (20,735 ha), followed by Macuata (10,596 ha) and Ra (5,368 ha). While the share of total sugarcane production was higher in the Western Division (58%) than the Northern Division (21%), its average yield was slightly lower (53 mt/ha vs. 54 mt/ha). Ra province in the Western Division had the lowest yield (48 mt/ha), whereas Cakaudrove in the Northern Division had the highest (71 mt/ha).

Consumption

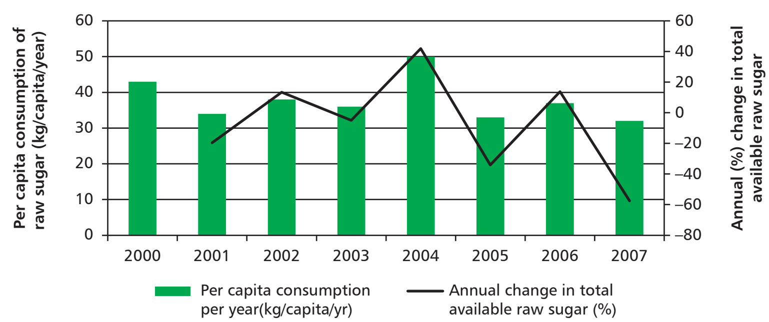
The sugarcane produced by farmers is processed into raw sugar for consumption. From 2000 to 2007, per capita consumption of raw sugar declined at a rate of 1.56% per year (Figure A2.2, Table A2.9), primarily due to a decline in the total available supply of raw sugar (and raw sugar production) over the same period (6.73% per year). In years when the negative change in per capita consumption was high (–34% in 2004–2005 and –57% in 2006–2007), domestic production for export was also very high (80.8%–99.7% in 2004–2005 and 81.4%–92.8% in 2006–2007). Production was primarily for export, not local consumption. From 2000 to 2001, while the share of exports to domestic production (94.6%–84.4%) declined, per capita

Table A2.8 Sugarcane Output, Area Harvested, and Yield by Division and Province, Fiji, 2009

Division/ Province	Output (mt)	Area Harvested (ha)	Yield (mt/ha)	Percentage Share in Total (%)
Western	**1,613,504**	**30,329**	**53**	**58**
Ba	1,139,809	20,735	55	41
Nadroga	216,047	4,226	51	8
Ra	257,648	5,368	48	9
Northern	**584,444**	**10,787**	**54**	**21**
Cakaudrove	13,496	191	71	0.5
Macuata	570,948	10,596	54	21
Total	**2,782,393**	**51,902**	**54**	**100**

ha = hectare, mt = metric ton.
Source: Fiji Department of Agriculture. 2011a. *Report on the Fiji National Agricultural Census 2009*. Economic Planning and Statistics Division. Suva.

Figure A2.2 Per Capita Consumption of Raw Sugar and Annual Change in Total Available Raw Sugar Supply, Fiji, 2000–2007



kg = kilogram.
Source: Devised by authors from Source: National Food and Nutrition Centre. Various years. National Food and Nutrition Centre Report of Fiji. Various annual reports. http://www.nutrition.gov.fj/reports_1.aspx

raw sugar consumption was expected to increase; it declined, however, because the total available raw sugar supply fell as a result of the increase in stocks.

Trade

The Fiji economy was largely dependent on the production and export of sugar from its pre-independence days, but the dominance of the industry decreased with the advent of tourism in the 1960s and the government's commitment to private investment and economic growth. Nevertheless, sugar remains the country's main export commodity, and from 2004 to 2009, sugar exports accounted for 24% of total export earnings on average (Table A2.10). Over

Table A2.9 Domestic Supply, Annual Per Capita Consumption, and Annual Change in Total Raw Sugar Supply Available for Food, Fiji, 2000–2007

Year	Domestic Supply (mt)					Annual Per Capita Consumption (kg)
	Production	Imports	Stocks	Exports	Total Supply Available for Food	
2000	335,000	0	(17,784)	317,000	35,784	43
2001	293,000	0	16,867	247,373	28,760	34
2002	330,000	0	8,393	289,000	32,607	38
2003	294,000	0	0	263,000	31,000	36
2004	312,000	0	16,000	252,000	44,000	50
2005	292,000	0	(28,000)	291,000	29,000	33
2006	307,000	0	24,000	250,000	33,000	37
2007	237,000	0	3,000	220,000	14,000	32
Average	**300,000**	**0**	**2,810**	**266,172**	**31,019**	**38**
Annual Change (%)						
2000–01	(12.54)			(21.96)	(19.63)	(20.93)
2001–02	12.63			16.83	13.38	11.76
2002–03	(10.91)			(9.00)	(4.93)	(5.26)
2003–04	6.12			(4.18)	41.94	38.89
2004–05	(6.41)			15.48	(34.09)	(34.00)
2005–06	5.14			(14.09)	13.79	12.12
2006–07	(22.80)			(12.00)	(57.58)	(13.51)
Average	**(4.11)**			**(4.13)**	**(6.73)**	**(1.56)**

Note: Per capita consumption indicates the national average per capita supply of foodstuffs available, in kilograms per year. According to the *Food Balance Sheets*, per capita supply is equal to per capita consumption.
Source: National Food and Nutrition Centre. Various years. National Food and Nutrition Centre Report of Fiji. Various annual reports. http://www.nutrition.gov.fj/reports_1.aspx

the same period, sugar contributed an average of F$211 million annually to the country's economy.

From 2000 to 2009, Fiji exported about 81% to 99% of its raw sugar production (Figure A2.3), but the volume of raw sugar exports has been declining in response to declining production. The country has also been plagued with declining milling efficiency.

Coconut

Overview and History

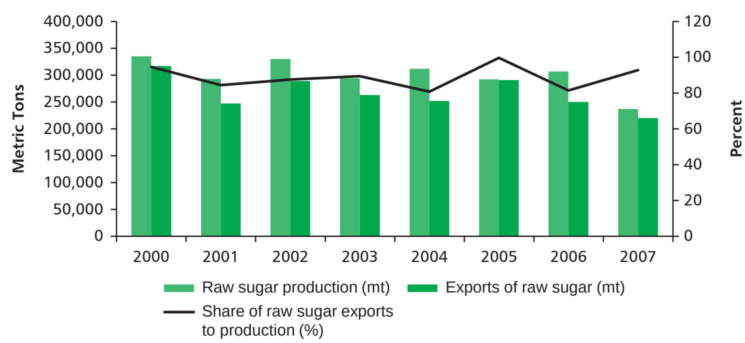
Coconut is an important commodity to the livelihood of thousands of people in Fiji, particularly those who live in the rural and outer islands. An estimated 40,000 households rely to a greater or lesser extent on coconut as a source of cash income (Government of Fiji 2005a). Of the total arable land in Fiji, 23% is under coconut. Coconut is mostly grown in the Eastern and

Table A2.10 Value of Sugar Exports and Share in Total Export Earnings, Fiji, 2004–2009 (F$ million)

Year	Value of Sugar Exports (F$ million)	Total Export Earnings (F$ million)	Percentage Share in Total Export Earnings
2004	209.20	950.70	22.00
2005	223.70	847.60	26.39
2006	215.10	834.30	25.78
2007	185.00	828.80	22.32
2008	248.10	982.80	25.24
2009	187.10	894.80	20.91
Average	**211.37**	**889.83**	**23.75**

Note: Total export earnings exclude re-exports.
Source: Fiji Bureau of Statistics. 2011. *Fiji Facts and Figures as at 1st July 2010*. Suva.

Figure A2.3 Production, Exports, and Share of Raw Sugar Exports in Raw Sugar Production, Fiji, 2002–2007



mt = metric ton.
Source: Constructed by authors from National Food and Nutrition Centre. Various years. National Food and Nutrition Centre Report of Fiji. Various annual reports. www.nutrition.gov.fj/reports_1.aspx

Northern divisions, which dominate the total area planted. In Fiji, coconut planting time is during the wet season, between October and April. Among the recommended varieties for local cultivars are Fiji Tall, Rotuman Tall, and Niu Leka (FDA 2011b); the recommended traditional cultivars include Niu ni magimagi, Niu drau, Niu Kitu, and Niu Yabia; the recommended introduced cultivars are Malayan Red Dwarf, Malayan Green Dwarf, and Malayan Yellow Dwarf; and the recommended hybrids are Malayan Red Dwarf and Rotuman Tall, and Malayan Yellow Dwarf and Rotuman Tall. Dwarf cultivars and hybrid coconuts only take 3 to 4 years to bear nuts compared with tall varieties, which take five to seven years.

Fiji's coconut industry dates back to pre-World War I, because coconuts provided a source of food and shelter. The commercial industry even pre-dates European settlement, with oil pressed from coconut meat being sold to traders in the early 19th century (ACC/CAC 1985). By the middle of the 19th century, Fijians in the Eastern Islands were producing surplus oil (and later copra) to pay taxes and church contributions, and to purchase goods from trade stores that accepted payment in copra. In 1875, the year after cession, copra exports exceeded 2,000 mt and expanded rapidly to reach 4,372 mt by 1877. This made copra Fiji's principal export commodity at that time. It became almost the exclusive crop of Cakaudrove province and of Eastern Fiji estate owners. The coconut industry's rapid ascendancy—particularly its copra production—came about due to the failure of experiments in other plantation crops; a sustained high copra price; and the availability of cheap labor, first from Solomon Islands and New Herbrides, and then from India. Within a decade, however, sugar outperformed copra as an export earner.

For the first 3 decades of the 1900s, the estate sector of the coconut industry enjoyed rapid expansion in terms of profitability and employed workers (ACC/CAC 1985). Later on, emphasis shifted toward Fijian village copra production; the number of Fijian estate workers fell during the 2 decades leading up to Word War II. In this period of severe price depression, the estates halted planting and replanting, and reduced their workforce to levels below those necessary to maintain production levels. Meanwhile, Fijian village producers increased their production to maintain their living standards. Brookfield reports that Lauan, non-estate, copra production increased from 1,500 mt in 1907 to reach 4,000 mt in 1940, which represented 25% of national production that year. This shift away from the estates has continued as a gradual process until the present day. Currently, about 20% of all copra produced comes from large plantation estates; the remaining 80% is produced by smallholders (Singh 2008).

Production

Coconut production averaged 184,963[3] mt from 1990 to 2009 (Table A2.11). Meanwhile, area harvested to coconut averaged 61,826 ha for an average yield of 2.99 mt/ha. On average, coconut production fell by 2.55% annually during the period 1990–2009 (Figure A2.4). In the same period, coconut yield declined at a rate of 2.32% per year, and the area harvested to coconut fell by 0.22% per year. Notably, coconut production in 2009 (150,000 mt) was about 40% lower than its 1990 level (251,250 mt).

Coconut production from 1990 to 2000 generally showed a rapid decline in output (2.92% per year) as coconut yield and area harvested fell at rates of 1.01% and 1.92%, respectively. As noted, Fiji was subjected to two El Niño events and an unusually large number of tropical cyclones during this period (PICCAP Fiji 2005). UN DHA (1993) reported that it would take up to a year for crops to fully recover from Cyclone Kina, which hit in 1993. Cyclones can cause premature coconuts to fall, and delay the setting of new nuts. Older trees can take 3 to 5 years to recover, and younger trees that do not bear nuts for up to 7 years can be knocked down (Benson 1997). The downward trend in coconut production between 1990 and 1999 can also be attributed to a

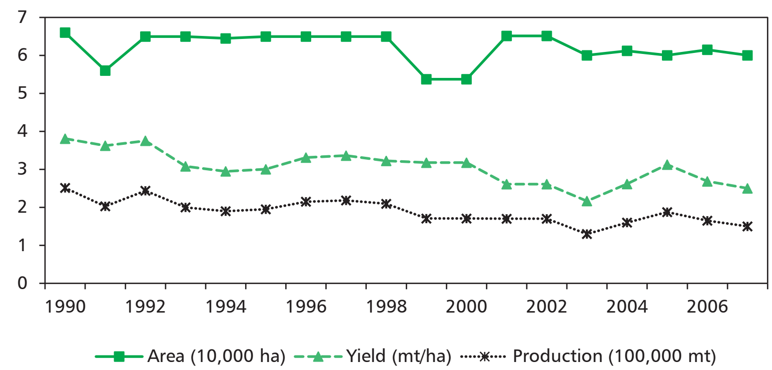
3 The values of available coconut production data from 2000 to 2007 by the National Food and Nutrition Centre (NFNC) of Fiji were about 23%–52% lower than the 2000 to 2007 coconut production data reported by the FAO. The NFNC report noted that since coconut remains an important daily source of food and cash crop for many households in both rural and urban parts of Fiji, some under-estimation may have occurred due lack of subsistence data.

Table A2.11 Average Coconut Production, Area Harvested, Yield, and Growth Rate, Fiji, 1990–2009

Item	1990–2009	Growth rate (%) 1990–2000	2000–2009	1990–2009
Production (mt)	184,963	(2.92)	(1.79)	(2.55)
Area (ha)	61,826	(1.92)	(0.31)	(0.22)
Yield (mt/ha)	2.99	(1.01)	(1.60)	(2.32)

ha = hectare, mt = metric ton, ( ) = negative value.
Source: Compiled by authors from Food and Agriculture Organization of the United Nations. 2011. FAOSTAT. http://faostat.fao.org/

Figure A2.4 Coconut Area Harvested, Production, and Yield, Fiji, 1990–2009



ha = hectare, mt = metric ton.
Source: Food and Agriculture Organization of the United Nations. 2011. FAOSTAT. http://faostat.fao.org/

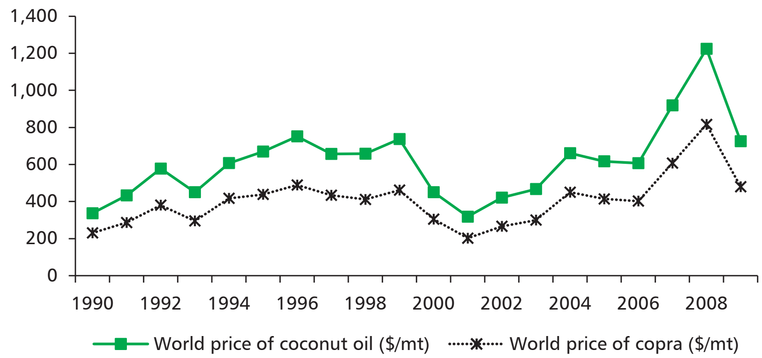
large decline in the area harvested to coconuts from 1998 to 1999, which was related to the first expiry of land leases in 1997.

From 2000 to 2009, coconut production continued to decline but at a slower pace (1.79% per year). On average, coconut yield declined more rapidly (1.60% per year), whereas the drop in area harvested slowed (0.31% per year).

In Fiji, the decline in coconut production has been attributed to natural disasters (cyclones and drought), the expiry of land leases, and industrial and commercial developments (FDA 2011a). In Vanua Levu, coconut plantations are depleting as real estate booms make it more attractive for plantation owners to sell their land rather than to maximize coconut production. Coconut trees are thus increasingly cut down to make way for property development (FDA 2011a).

Coconut farmers in Fiji commonly dry the nuts to produce copra and sell them to millers. Due to rising freight costs, which have a particularly significant impact on isolated plantations, and low profitability due to unfavorable copra market prices, many farmers have lost interest in coconut farming. The relatively low (long-term) world price of copra and coconut oil and increased

Figure A2.5 World Market Price of Copra and Coconut Oil, 1995–2009



Source: World Bank. 2011. World Development Indicators. Washington, DC. http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

cultivation of substitute crops found to be relatively more profitable, have also contributed to the decline in coconut production (Singh 2008). The price of copra and coconut oil has been volatile over the years (Figure A2.5).

The Fiji Department of Agriculture (FDA) (2011a) also notes that a growing number of plantation owners in Vanua Levu, an area that supplies most of Fiji's copra, have decided to either diversify into other crops or subdivide their properties and sell them due to low returns to coconut farming. Other factors that lead to decreasing coconut production in Fiji are increased numbers of senile (nonfruit-bearing) trees and the decreased planting of new trees; the spread of coconut diseases and pest infestations (e.g., coconut crabs and rhinoceros beetles); the impact of the land tenure system (through which a family's land resources are divided into smallholdings); and, recently, labor shortages (Singh 2008). It should be noted that Fiji has started replacing senile palms with high-yielding hybrid varieties in the country's coconut-growing regions.

Consumption

Based on NFNC data, coconut is mainly used for manufacturing, including all manufactured food products (Table A2.12). About 64% of the total available coconut supply is processed, and about 26% is for gross food, which represents the quantity available to the population prior to a primary food commodity (i.e., the coconut nut) being processed into edible food products.

In the absence of coconut production data by province, data on copra production by province is used to provide a geographic picture of the coconut industry (Table A2.13). The Eastern and Northern divisions are the major copra-producing areas in Fiji. In 2009, the Eastern Division contributed 47% to total copra production, and the Northern Division contributed 46%. Lau (located in the Eastern Division), Cakaudrove, and Bua (both in the Northern Division) were the top three copra-producing provinces, accounting for 40%, 35%, and 9% of total copra production, respectively. While the percentage share in total copra production was highest in Lau, Cakaudrove had the largest area planted to coconut, at 1,625 ha.

Table A2.12 Domestic Use of Coconut, Fiji, 2000–2007

Year	Domestic Use (mt)			
	Total Available Coconut Supply	Manufacture	Waste	Gross food
2000	104,275	66,736	10,428	27,112
2001	130,959	83,814	13,096	34,049
2002	113,547	72,670	11,355	29,522
2003	75,254	48,163	7,525	19,566
2004	79,835	51,094	7,984	20,757
2005	89,220	57,101	8,922	23,197
2006	88,036	56,343	8,804	22,889
2007	79,713	51,016	7,971	20,725
Average	**95,105**	**60,867**	**9,511**	**24,727**

Source: Compiled by authors from National Food and Nutrition Centre. Various years. National Food and Nutrition Centre Report of Fiji. Various annual reports. www.nutrition.gov.fj/reports_1.aspx

Table A2.13 Copra Production and Area Planted to Coconut by Province and Division, Fiji, 2009

Division/ Province	Copra Production		Area Planted to Coconut	
	mt	% of Total Copra Production	ha	% of Total Area Planted
Central	**374**	**4**	**194**	**1**
Naitasiri	66	1	18	0.1
Rewa	191	2	56	0.4
Serua	11	0.1	5	0.04
Tailevu	106	1	114	1
Western	**405**	**4**	**330**	**2**
Ba	128	1	162	1
Nagroga	26	0.2	22	0.1
Ra	251	2	145	1
Northern	**4,849**	**46**	**12,707**	**85**
Bua	940	9	3,196	21
Cakaudrove	3,727	35	9,117	61
Macuata	182	2	394	3
Eastern	**5,006**	**47**	**1,778**	**12**
Lau	4,270	40	1,625	11
Lomaiviti	368	3	60	0.4
Rotuma	368	3	94	1
Total	**10,634**	**100**	**15,009**	**100**

ha = hectare, mt = metric ton.
Source: National Food and Nutrition Centre. Various years. National Food and Nutrition Centre Report of Fiji. Various annual reports. www.nutrition.gov.fj/reports_1.aspx

From 2000 to 2007, per capita consumption of coconut averaged 30 kg/yr. In the same period, per capita consumption of coconut exhibited a downward trend, declining at a rate of 1.98% per year, primarily due to a decline in the total domestic production of coconut (Table A2.14). In the years when a negative change in per capita consumption was high, domestic production was also declining. The country did not import enough to maintain stable consumption levels. It should be noted, however, that the NFNC recognizes that there may be some underestimation in their consumption calculations due to lack of subsistence data. They note that coconut remains an important cash crop and daily food source for many households in both rural and urban areas of Fiji, but they acknowledge that subsistence data on production were excluded.

Table A2.14 Domestic Production and Annual Per Capita Consumption of Coconut, Fiji, 2000–2007

Year	Domestic Supply (mt) (= P + A – C)				Annual Per Capita Consumption (kg)	Change in Annual Per Capita Consumption (%)
	Production (A)	Imports (B)	Exports (C)	Total Available Coconut Supply		
2000	104,251	24	0	104,275	33	
2001	130,936	27	4	130,959	42	27.27
2002	113,523	27	3	113,547	36	(14.29)
2003	75,207	51	4	75,254	23	(36.11)
2004	79,835	0	0	79,835	25	8.70
2005	89,329	0	109	89,220	27	8.00
2006	88,198	0	162	88,036	27	0.00
2007	79,741	0	28	79,713	25	(7.41)
Average	**95,128**	**16**	**39**	**95,105**	**30**	**(1.98)**

kg = kilogram, mt = metric ton, ( ) = negative value.
Note: Per capita consumption indicates the national average per capita supply of foodstuffs available, in kilograms per year.
Source: National Food and Nutrition Centre. Various years. National Food and Nutrition Centre Report of Fiji. Various annual reports. www.nutrition.gov.fj/reports_1.aspx

Trade

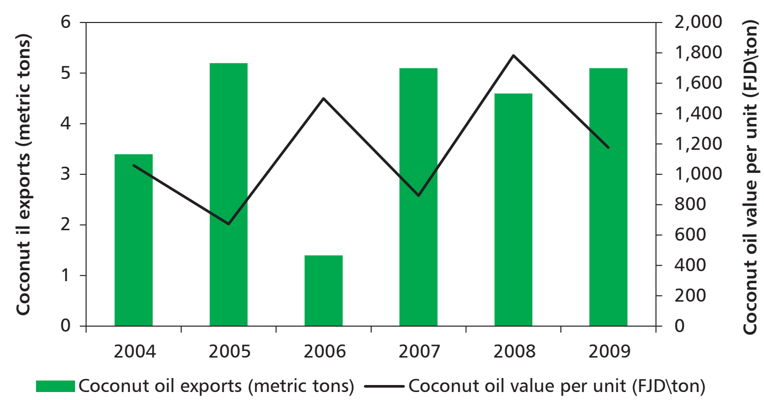
Although earnings from copra and coconut oil are higher compared with other coconut products, their share in total foreign earnings is miniscule, averaging 0.52% from 2004 to 2009 (Table A2.15). Combined earnings from both commodities during that period averaged F$4.63 million. It seems that Fiji has not been able to take advantage of rising coconut oil prices, in years which they occur, by increasing exports (Figure A2.6). Singh (2008) noted that, in 2008, both millers and coconut producers were not able to achieved needed adjustments in their production when the price of coconut oil was high. At the time of rising prices, the volume of copra supplied to the mills was comparatively less than at times of falling prices. As such, profits made

Table A2.15 Value of Copra and Coconut Oil Exports and Percentage Share in Total Export Earnings, Fiji, 2004–2009

Year	Value of Copra Exports (F$ million)	Value of Coconut Oil Exports (F$ million)	Total Export Earnings (F$ million)	Percentage Share in Total Export Earnings
2004	0	3.60	950.70	0.38
2005	0	3.50	847.60	0.41
2006	0.04	2.10	834.30	0.26
2007	0	4.40	828.80	0.53
2008	0	8.20	982.80	0.83
2009	0.2	6.00	894.80	0.69
Average	0.04	4.63	889.83	0.52

Source: Fiji Bureau of Statistics. 2011. *Fiji Facts and Figures as at 1st July 2010*. Suva.

Figure A2.6 Volume of Coconut Oil Exports and Value Per Metric Ton of Coconut Oil Exported from Fiji, 2004–2009



Source: Fiji Bureau of Statistics. 2011. *Fiji Facts and Figures as at 1st July 2010*. Suva.

during times of rising prices were far less than the amount of losses sustained during times of falling prices.

About 30% of the coconut oil produced in Fiji is used domestically as food and in cosmetics (FDA 2011a). According to the Copra Millers Fiji Limited (CMFL),[4] one of the two larger local manufacturers of crude coconut oil, about 94% of their sales are exported to Europe and 6% are sold locally. While CMFL mainly produces crude coconut oil, they have plans to diversify into high-value products like virgin coconut oil; biodiesel; and refined, bleached, and deodorized oil.

4 CMFL is 94% owned by the government and 6% owned by individual coconut growers.

Taro

Overview and History

In Fiji, taro—known as *dalo*—is one of the country's most important staple food crops. It is high in carbohydrates, is a good source of calcium, and has been a key crop for families, providing essential cash flow for households. In recent years, taro has emerged as an important export crop, and is now the country's second major agricultural export earner due to the high prices offered by New Zealand and the United States. Taro farming generates income for farmers and has contributed significantly to the country's GDP in the past 14 years.

In Fiji, taro's main planting season is between July and January; off-season planting is between March and June. Taro is grown mostly in the wetter areas, including eastern Viti Levu, where annual rainfall ranges from 3,000 to 4,500 mm (FDA 2010b). In the higher rainfall areas, taro is grown throughout the year. Among the recommended taro varieties are Samoa hybrid, Samoa, Tausala-ni-Samoa, Vula Ono, Maleka Dina, Dalo ni Toga, Koro kece, Wararasa, and Toakula (FDA 2010b). Modern (hybrid) varieties, such as Maleka Dina and Warasa, dominate farms—particularly exporting farms (NatureFiji–MareqetiViti 2011). Hybrid varieties can be harvested about 6–8 months after planting, whereas traditional taro varieties take longer to mature (about 9–12 months).

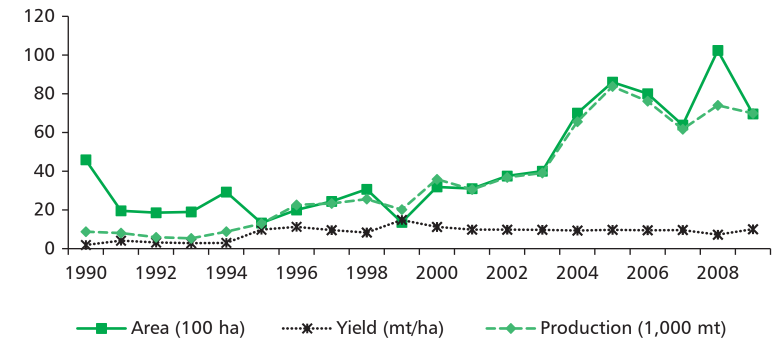
About 125 varieties of taro are known in Fiji, of which at least 70 were grown and consumed by Fijians before the arrival of other settlers and before commercialization of the root crop (Nature Fiji–Mareqeti Viti 2011). For centuries, taro has been a staple of the Fijian diet; moreover, it has been ranked more highly than other crops because of its traditional significance, where it is used for *magiti'* (feast) in Fijian ceremonies. Taro's commercialization in Fiji began in the 1950s with exports to New Zealand. It boomed as a commercial crop in 1993, when taro leaf blight struck neighboring Samoa (an exporter of taro), decimating its taro industry. Fiji filled the void in the international market, and was soon exporting more taro in response to increased demand from overseas markets.

Production

From 1990 to 2009, taro production averaged 35,744 mt. In the same period, area harvested to taro averaged 4,232 ha, and taro yields averaged 8.26 t/ha. Taro production increased significantly during the period 1990–2009, from 8,780 mt to 69,863 mt (Figure A2.7), or by 13.83% annually (Table A2.16) (FAO 2011). Production increased in response to government assistance and high demand for taro (FDA 2011a). Both taro yield and area harvested exhibited a positive trend, with taro yield growing at a rate of 6.51% per year, and area harvested increasing at a rate of 6.26% per year.

From 1990 to 2000, taro production increased rapidly. This period showed growth in taro output of about 17.33% per year as taro yield grew at a rate of 17.92% per year from a very low trend in 1990. The decimation of Samoa's taro export industry, allowed Fiji to become a year-round, international supplier of taro. Since then, with increasing demand from both local and overseas markets, the Agronomy Section of the Fiji Agriculture Department and other agricultural research bodies prioritized research to increase taro

Figure A2.7 Area Harvested, Production, and Yield of Taro, Fiji, 1990–2009



ha = hectare, mt = metric ton.
Source: Food and Agriculture Organization of the United Nations. 2011. FAOSTAT. http://faostat.fao.org/

Table A2.16 Average Taro Output, Area Harvested, Yield, and Rate of Growth, Fiji, 1990–2009

		Growth Rate (%)		
Item	1990–2009	1990–2000	2000–2009	1990–2009
Output (mt)	35,743.80	17.33	10.35	13.83
Area (ha)	4,231.75	–1.22	12.97	6.26
Yield (mt/ha)	8.26	17.92	–1.94	6.51

ha = hectare, mt = metric ton, ( ) = negative ton.
Source: Compiled by authors from Food and Agriculture Organization of the United Nations. 2011. FAOSTAT. http://faostat.fao.org/

yields, resulting in many new taro varieties and hybrids (Nature Fiji–Mareqeti Viti 2011).

During 2000–2009, taro production continued to grow, but at a slower rate than in the previous decade. On average, production increased at a rate of 10.35% per year during this timeframe. With continued increased demand, area harvested also increased by 12.97% per year. Moreover, concerted efforts by the Ministry of Agriculture resulted in more farmers growing taro under the Flatland Development Program, which provided them with planting materials, agrochemicals, and tractors for land preparation (Government of Fiji 2005a). In that period, however, taro yield exhibited a downward trend, declining at a rate of 1.94% per year. Thus, the main source of production growth from 2000 to 2009 was expansion in area harvested.

Major taro-producing areas in Fiji are in the Central and Northern divisions. In 2009, Naitasiri, Tailevu and Cakaudrove were the top three taro-producing provinces, contributing 44%, 17%, and 13% to the country's total production respectively (Table A2.17). Natisiri harvested the largest taro area (2,403 ha), while Tailevu harvested 930 ha, and Cakaudrove harvested 1,235 ha. Notably, while these three provinces harvested the highest shares of taro production, Rotuma had the highest yield (14.83 mt/ha), which, at less than 1%, accounted for the smallest share in total taro production.

Table A2.17 Taro Production, Area Harvested, and Yield by Division and Province, Fiji, 2009

Division/ Province	Production (mt)	Area Harvested (ha)	Yield (mt/ha)	Percentage Share in Total Production
Central	**40,340**	**3,919**	**10.29**	**71**
Naitasiri	24,770	2,403	10.31	44
Namosi	2,538	224	11.33	4
Rewa	1,111	113	9.84	2
Serua	2,557	250	10.25	5
Tailevu	9,363	930	10.06	17
Western	**2,978**	**952**	**3.13**	**5**
Ba	499	150	3.32	1
Nadroga	645	202	3.20	1
Ra	1,835	600	3.06	3
Northern	**10,359**	**1,702**	**6.09**	**18**
Bua	2,715	333	8.16	5
Cakaudrove	7,161	1,235	5.80	13
Macuata	483	134	3.60	1
Eastern	**2,968**	**289**	**10.25**	**5**
Kadavu	1,454	159	9.17	3
Lau	321	29	10.91	1
Lomaiviti	1,002	89	11.32	2
Rotuma	191	13	14.83	0.3
Total	**56,645**	**6,863**	**8.25**	**100**

Source: Fiji Department of Agriculture. 2011a. *Report on the Fiji National Agricultural Census 2009*. Economic Planning and Statistics Division. Suva.

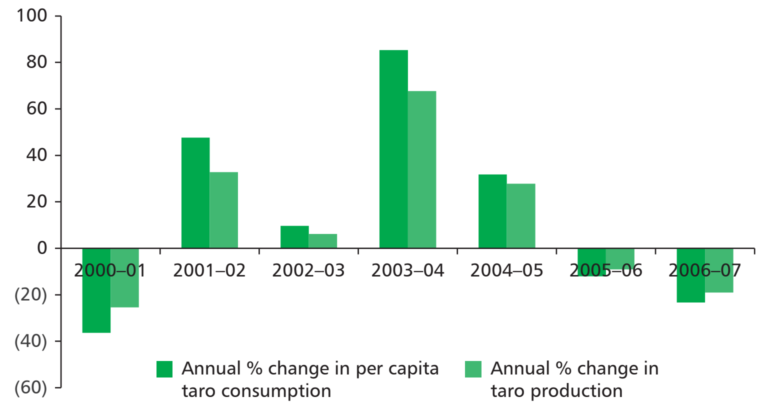
Consumption

Taro is an important staple food crop in Fiji. According to Vilsoni (1993), the demand for taro—especially during the festive Christmas period—appears to be inelastic, because consumers purchase taro regardless of price. Annual per capita consumption of taro increased at a rate of 14.46% per year during 2000–2007, rising from 33 kg to 56 kg, or averaging 49 kg. In years when a negative change in per capita taro consumption is observed, domestic taro production is low. The same can be said for a positive change (Figure A2.8, Table A2.18).

Trade

Fiji is currently the top exporter of taro in the Pacific region, and the second-largest exporter of taro in the world after the People's Republic of China, in terms of volume (McGregor et al. 2011). From 2004 to 2009, taro exports contributed an average of F$21 million annually to the Fiji economy (Table A2.19). In the past few years, Fiji's annual taro export volume hovered around 10,000 mt, with about 65% going to New Zealand, and the balance to Australia, the United States, and other countries. Almost 70% of Fiji's

Figure A2.8 Annual Percentage Change in Production and Per Capita Consumption of Taro, Fiji, 2000–2007



( ) = negative value.
Source: Constructed by authors from National Food and Nutrition Centre. Various years. National Food and Nutrition Centre Report of Fiji. Various annual reports. www.nutrition.gov.fj/reports_1.aspx

Table A2.18 Domestic Supply and Annual Per Capita Consumption of Taro, Fiji, 2000–2007

Year	Domestic Supply (metric tons) (= A + B – C)				Annual Per Capita Consumption (kg)	Change in Annual Per Capita Consumption (%)
	Production (A)	Imports (B)	Exports (C)	Total Available Supply		
2000	37,137	0	8,873	28,264	33	
2001	27,705	0	9,249	18,456	21	(36.36)
2002	36,796	0	9,733	27,063	31	47.62
2003	39,083	0	9,660	29,423	34	9.68
2004	65,545	0	9,938	55,607	63	85.29
2005	83,751	0	9,959	73,792	83	31.75
2006	76,156	0	11,434	64,722	73	(12.05)
2007	61,662	0	11,949	49,713	56	(23.29)
Average	**53,479**	**0**	**10,099**	**43,380**	**49**	**14.66**

kg = kilogram, ( ) = negative value.
Note: Per capita consumption indicates the national average per capita supply of foodstuffs available, in kilograms per year. According to the *Figi Food Balance Sheet*, per capita supply is equal to per capita consumption.
Source: National Food and Nutrition Centre. Various years. National Food and Nutrition Centre Report of Fiji. Various annual reports. www.nutrition.gov.fj/reports_1.aspx

exported taro is produced on the island of Taveuni, where pink taro of the Tausala ni Samoa variety is grown in the absence of taro beetles. While Taveuni grew rapidly as a center for commercial taro production following the demise of Samoa's taro export industry, its exports have stagnated in recent years due to declining productivity, increasing production costs, and market access problems with its exports to Australia and New Zealand (McGregor et al.

Table A2.19 Value of Taro Exports (F$ million) **and Percentage Share in Total Export Earnings, Fiji, 2004–2009**

Year	Value of Taro Exports (F$ million)	Total Export Earnings (F$ million)	Percentage Share in Total Export Earnings
2004	18.70	950.70	1.97
2005	19.00	847.60	2.24
2006	20.90	834.30	2.51
2007	23.60	828.80	2.85
2008	22.20	982.80	2.26
2009	20.10	894.80	2.25
Average	**20.75**	**889.83**	**2.33**

Note: Total export earnings exclude re-exports.
Source: Fiji Islands Bureau of Statistics (FBS) 2011. Fiji Islands Facts and Figures as of 1st July 2010. Fiji Islands Bureau of Statistics, Suva, Fiji.

2011). The balance of Fiji's taro exports (including both pink and white taro varieties) comes from high rainfall areas on Viti Levu.

Fiji's market access problems relating to Australia and New Zealand are due to quality issues (Table A2.20). Between March and August 2010, Australia rejected several containers of fresh taro from Fiji due to corm rots, a soil-borne fungus that infects taro at soil level, causing corms and roots to rot and leaves to wilt. Currently, the Australian Centre for International Agricultural Research (ACIAR) is assisting Fiji's Ministry of Primary Industries, which is managed by SPC's Land Resources Division, in obtaining cleaner pathways to ensure the quality of the taro exported (SPC 2011a). According to Losalini Leweniqila, principal research officer for Plant protection at Fiji's Department of Agriculture, farmers do not commonly know the requirements for exporting taro or may not be adhering to them, resulting in the rejection of taro by importing countries (Volua 2011).With the pathway in place, farmers will be able to follow stringent requirements to source clean planting materials and follow proper husbandry and hygienic growing practices.

Table A2.20 Taro Exports by Destination Country, Fiji, 2005–2009

Destination Country	Taro Exports (metric ton)				
	2005	2006	2007	2008	2009
New Zealand	6,302	6,974	7,469	6,842	6,169
Australia	1,878	2,703	2,390	2,264	1,969
United States	1,720	1,722	1,677	1,531	1,080
Hawaii			162	51	210
Other	59	35	196	106	54
Total	**9,959**	**11,434**	**11,894**	**10,794**	**9,482**

Source: Secretariat of the Pacific Community. Pacific Island Trade database. http://www.pacifictradestatistics.com/

Rice Paddy

Overview

Rice has been an import-substitution industry providing income to an estimated 1,500 households in the rural areas of Fiji. It is cultivated through three types of farming—irrigated, rainfed wetland, and rainfed dryland—depending on the availability of water, and to some extent, the topography (Prasad and Narayan 2005). Irrigated rice accounts for 20% of all local rice production. Rainfed wetland production is considered the country's the dominant system of rice farming, accounting for 54% of total rice production. Rainfed dryland production accounts for the remaining 26% of domestic rice production and 36% of the total rice area. Under the rainfed dryland system, rice is grown from November to May, in association with other dryland crops such as sugarcane and pulses. Current yields average about 2.2 mt/ha and 2.8 mt/ha in rainfed and irrigated rice ecosystems respectively (Rao et al. 2007).

Production

Rice production averaged 18,774 mt from 1980 to 2009 (Table A2.21), and area harvested to rice averaged 8,452 ha for an average rice yield of 2.25t/ha. Rice production generally exhibited a downward trend from 1980 to 2009 (Figure A2.9). Notably, rice production in 2009 (11,637 mt) was 35% lower than its 1980 level (17,846 mt). In terms of growth rates, rice production fell by 1.36% yearly during 1980–2009. Rice yield grew at a rate of 0.88% per year, whereas the area harvested to rice declined at a rate of 2.19% annually. The main source of production growth is thus yield increases.

From 1980 to 1990, rice production generally increased at a rate of 6.39% per year. During this period, growth in rice production was mainly due to expansion of the area planted to rice, given that area harvested was rising at a rate of 4.71% annually, while rice yield only grew at a rate of 1.58% per year.

During this period, Fiji Government continued its long-term aim of achieving self-sufficiency and reducing spending on food imports. Thus, the government also continued to implement policies conceived in the 1970s to enhance rice production, including providing support to farmers through direct subsidies, and price support by restricting imports through high duties. Other incentive packages in the form of fertilizer credit facilities, extension services, and irrigated water were provided to farmers (Prasad and Narayan 2005). Moreover, the Fiji Government emphasized maintaining

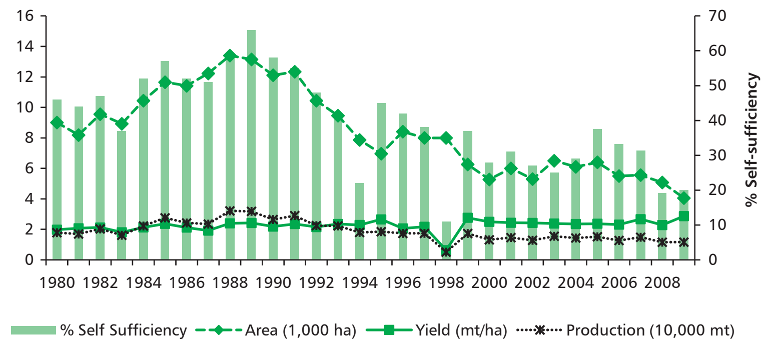
Table A2.21 Average Rice Production, Area Harvested, Yield, and Growth Rate, Fiji, 1980–2009

Item	1980–2009	Growth Rate (%) 1980–1990	1990–2000	2000–2009	1980–2009
Production (mt)	18,773.63	6.39	(9.35)	(0.92)	(1.36)
Area (ha)	8,452.40	4.71	(6.99)	(1.71)	(2.19)
Yield (mt/ha)	2.25	1.58	(1.57)	0.88	0.88

ha = hectare, mt = metric ton, ( ) = negative value.

Source: Compiled by authors from Food and Agriculture Organization of the United Nations. 2011. FAOSTAT. http://faostat.fao.org/

Figure A2.9 Rice Area Harvested, Production, Yield, and Percent Self-sufficiency, Fiji, 1980–2009



ha = hectare, mt = metric ton.
Source: Food and Agriculture Organization of the United Nations. 2011. FAOSTAT. http://faostat.fao.org/

and consolidating irrigated systems in its 1981–1985 development plan. The government undertook to rationalize capital-intensive irrigated rice schemes with a view to phasing out heavy capital and employing more appropriate technology. Gravity-fed irrigation systems were introduced in place of more expensive pump systems. In the 1986–1990 development plan, the government continued to pursue the objective of self-sufficiency in rice production by trying to overcome constraints identified during the previous planning period, such as properly extending appropriate cultural practices for high-yielding varieties, and improving the low level of extension-research linkages in delivering research results to farmers. Given these efforts, rice self-sufficiency was generally on the rise, from 37% in 1980 to 66% during the 1990s. Notably, the 1983 levels of rice self-sufficiency (37%) and rice production (16,160 mt) were low (Figure A2.9), possibly due to Cyclone Oscar and severe drought that year.

In the subsequent decade, 1990–2000, average rice production fell by 9.35% per year. Yield and area harvested both exhibited a downward trend. Average rice yields fell by 1.57% per year, and area harvested to rice declined by 6.99% per year. Rice production was significantly affected in 1998 by a severe drought, triggered by El Niño, that lasted from September 1997 to August 1998 and caused streams and aquifers to dry up. From 1990 to 2000, the country's self-sufficiency ratio declined. During this period, Fiji's economic policy agenda shifted remarkably, moving away from import-substitution to export-oriented growth. Rice self-sufficiency began to drop because of the government's deregulation policies during the early 1990s (allowing the importation of rice), the drought of the late-1990s, and expiry of land leases (Prasad and Narayan 2005; FDA 2011a).

Consumption

Rice is a staple in the diets of all ethnic groups in Fiji. On average, annual per capita rice consumption from 2000 to 2007 was 55 kg (Table A2.22). In most years in which there was a negative change in annual per capita

Table A2.22 Domestic Rice Supply and Annual Per Capita Consumption, Fiji, 2000–2007

Year	Domestic supply (metric tons) (= A + B – C)				Annual Per Capita Consumption[a] (kg)
	Production (A)	Imports (B)	Exports (C)	Total Available Rice Supply	
2000	13,170	35,700	72	48,798	60
2001	14,612	26,945	441	41,116	50
2002	12,852	28,450	244	41,058	49
2003	15,504	34,155	84	49,575	59
2004	14,358	36,108	1,189	49,277	58
2005	15,189	36,108	147	51,150	60
2006	12,732	25,740	215	38,257	45
2007	14,870	32,758	168	47,460	56
Average	**14,161**	**31,996**	**320**	**45,836**	**55**
			Annual Change (%)		
2000–01	10.95	(24.52)	512.50	(15.74)	(16.67)
2001–02	(12.04)	5.59	(44.67)	(0.14)	(2.00)
2002–03	20.63	20.05	(65.57)	20.74	20.41
2003–04	(7.39)	5.72	1,315.48	(0.60)	(1.69)
2004–05	5.79	0.00	(87.64)	3.80	3.45
2005–06	(16.18)	(28.71)	46.26	(25.21)	(25.00)
2006–07	16.79	27.26	(21.86)	24.06	24.44
Average	**2.65**	**0.77**	**236.36**	**0.99**	**0.42**

kg = kilogram, ( ) = negative value.

[a] Per capita consumption indicates the national average per capita supply of foodstuffs available, in kg per year. According to the *Fiji Food Balance Sheet*, per capita supply is equal to per capita consumption.

Source: National Food and Nutrition Centre. Various years. National Food and Nutrition Centre Report of Fiji. Various annual reports. http://www.nutrition.gov.fj/reports_1.aspx

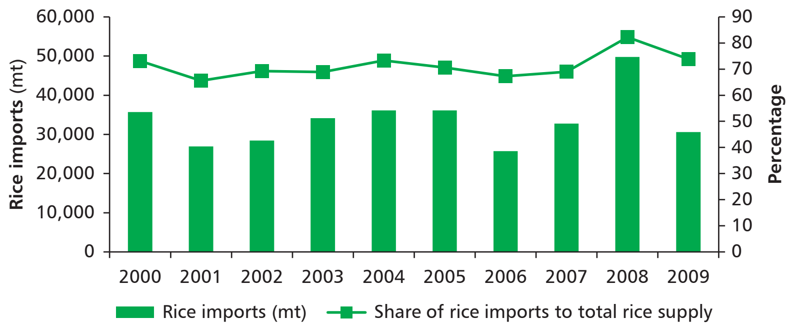
rice consumption, the government increased the country's rice imports. Fiji currently imports about 31,966 mt of rice to meet domestic demand. During 2000–2001, there was a large decrease in per capita consumption (16.67%), which may be attributed to a decline in rice imports (24.52%). On the other hand, the declines in per capita rice consumption of 2% during 2001–2002 and 1.69% during 2003–2004 may be attributable to decreased rice production (12.04% and 7.39%, respectively).

Meanwhile, the largest decline in annual per capita consumption (25% during 2005–2006), was due to the simultaneous drop in production (16.18%) and imports (28.71%). In 2006, a coup disrupted economic activities.

Trade

Fiji imported an average of about 33,636 mt per year of rice during 2000–2009. The volume of rice imports fluctuated during the period, with imports decreasing in years when domestic rice production rose (Figure A2.10). In the early 1990s, as already mentioned, government policy moved from import-substitution policy toward export-oriented growth. Deregulation policies allowed higher rice imports. From 2000 to 2009, the

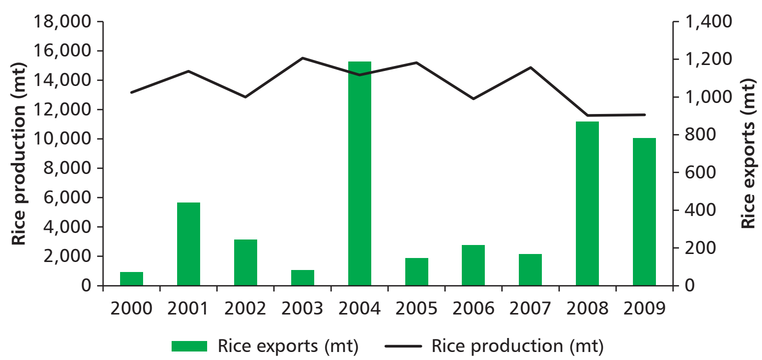
Figure A2.10 Rice Imports and Percentage Share in Total Rice Supply, Fiji, 2000–2009



mt = metric ton.

Source: National Food and Nutrition Centre. Various years. National Food and Nutrition Centre Report of Fiji. Various annual reports. www.nutrition.gov.fj/reports_1.aspx

Figure A2.11 Rice Exports and Production, Fiji, 2000–2009



Source: National Food and Nutrition Centre. Various years. National Food and Nutrition Centre Report of Fiji. Various annual reports. www.nutrition.gov.fj/reports_1.aspx

share of imported rice in the total available rice supply ranged from 66% to 82%. The government initiated a rice revitalization program around 2005 in efforts to increase rice production and decrease dependence on imports. The impact of this program remains to be seen, because domestic rice production and the share of rice self-sufficiency continue to be low (Figure A2.11).

Regarding exports, Fiji exported an average of 421 mt of rice per year between 2000 and 2009. It is not surprising that the trend in rice exports followed the same pattern as that of rice production (Figure A2.11).

Fisheries

Overview

Fiji are endowed with 1.29 million square kilometers (km^2) of water area and 5,010 kilometers (km) of continental coastline (FAO 2009). Given such abundant water resources, fisheries is an important sector. Around half of

Fiji's population lives in rural communities and is dependent on subsistence farming and fishing for their food needs and livelihoods. Fishing activities, including capture fisheries and aquaculture, first took place in Fiji in the 1950s (Amoe 2010).

Pacific islands fisheries comprise six major categories: (i) coastal commercial fisheries, (ii) coastal subsistence fishing, (iii) offshore locally based fishing, (iv) offshore foreign-based fishing, (v) freshwater fishing, and (vi) aquaculture. Fiji has the smallest water area and thus the lowest fish harvest of the three study countries, but the highest harvest and value of aquaculture production of the three countries at $1.75 million in 2007 (Table A2.23). Aquaculture is an alternative source of livelihood and nutrition security, and lessens pressure on the country's coastal resources.

Table A2.23 Production and Value of Output of Fisheries Sector, by Fishing Category, Fiji, 2007

Category	Production (mt or pieces)	Value ($)
Coastal ('000)		
Commercial	9.5	33,750
Subsistence	17.4	33,812.5
Offshore ('000)		
Locally based	13.74	29,293.75
Foreign-based	0.49	527.5
Freshwater ('000)	4.15	4,287.5
Aquaculture		
Tons	247	1,749,375
Pieces ('000)	48.1	

Sources: Gillett, R. 2009. *Fisheries in the Economies of the Pacific Island Countries and Territories*. Manila: Asian Development Bank; Food and Agriculture Organization 2010. FishStatJ statistical database. Rome, Italy. www.fao.org/fishery/statistics/software/fishstat/en

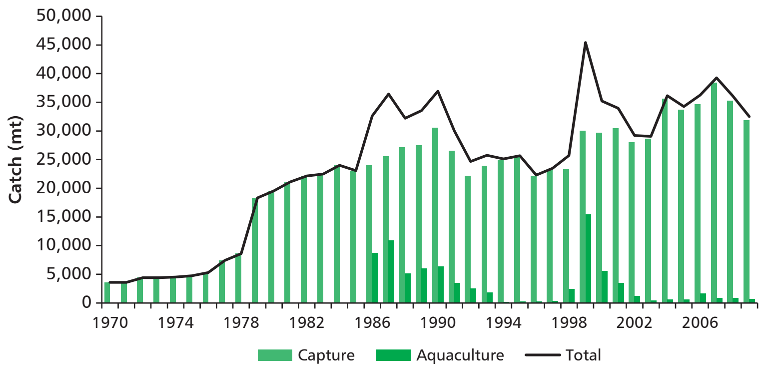
Production

FAO (2010) estimated the total fish production (capture and aquaculture) from marine and inland waters in 1970 to 2009 (Figure A2.12). Total fish production reached 35,525 mt in 2009, with contributions from capture fisheries of 31,855 mt, and from aquaculture of 888 mt (Table A2.24). The highest fish catch was 45,431 mt in 1999, after which irregular trends in capture-fisheries harvests were observed. Aquaculture production was developed in 1986. Similar to capture fishing, the largest aquaculture harvest recorded was 15,444 mt in 1999; this level has not been achieved since.

Inland or Freshwater Resources

Freshwater clams, eels, crustaceans, and introduced species such as tilapia and carp are the fisheries resources harvested from inland ecosystems (Gillett 2009). FAO (2010) estimated inland production to be around 2,250 mt in 2009, with 90% contributed by capture fisheries and 10% by aquaculture.

Figure A2.12 Total Fish Production from Capture Fisheries and Aquaculture, Fiji, 1970–2009



mt = metric ton.
Source: ???.

Table A2.24 Total Production from Capture Fisheries and Aquaculture, Fiji, 1986–2009

Year	Capture FIsheries	Aquaculture	Total
1986	23,954	8,660	32,614
1987	25,566	10,896	36,462
1988	27,137	5,089	32,226
1989	27,513	6,045	33,558
1990	30,562	6,353	36,915
1991	26,556	3,493	30,049
1992	22,188	2,499	24,687
1993	23,919	1,832	25,751
1994	24,924	184	25,108
1995	25,464	200	25,664
1996	22,026	255	22,281
1997	23,114	365	23,479
1998	23,291	2,408	25,699
1999	29,987	15,444	45,431
2000	29,660	5,575	35,235
2001	30,438	3,511	33,949
2002	27,991	1,206	29,197
2003	28,643	394	29,037
2004	35,574	562	36,135
2005	33,708	562	34,270
2006	34,643	1,618	36,261
2007	38,429	830	39,259
2008	35,201	888	36,089
2009	31,855	670	32,525

Source: Food and Agriculture Organization. 2010. FishStatJ statistical database. Rome. www.fao.org/fishery/statistics/software/fishstat/en.

Currently, there are no reliable data for inland fisheries (catch, value, marketing, and others) (Gillett 2009).

Marine Resources

The coastal areas of the two main islands of Fiji, Viti Levu and Vanua Levu, are experiencing a move toward commercial marine development, whereas fishing on the other islands is mainly subsistence-based. Offshore and coastal fishing are the two main categories of marine fisheries in Fiji.

Offshore Fisheries

Offshore fishing refers to tuna longlining (a commercial fishing technique) from local and foreign-based vessels, while coastal fishing refers to subsistence fishing for home consumption, sale in local markets, and for export. It is difficult to distinguish between subsistence and commercial fishing in the larger, less-isolated islands where both types of fishing activities are monetized (MFNP 2002).

Tuna is one of the most valuable marine species in Fiji's waters. *Industrial* tuna fishing involves large-scale fishing that consists of pole-and-line fishing done in offshore fisheries and in licensed exclusive economic zones (EEZ), longline fishing carried out in EEZs, purse-seine fishing occasionally used in EEZs, and longline fishing done offshore and in EEZs. The catch from the first three of these fishing methods is mainly destined for canneries, whereas the catch from longline fishing is destined for direct consumption as sashimi (FAO 2009).

Pole-and-line fishing by local fishers, particularly commercial tuna fishing, was the main focus of the industry in the mid-1970s. In the 1980s, longline fishing became more popular when the fishing activities of fleets based in the Republic of Korea and Taipei,China were established in Fiji waters. Among the tuna species caught in Fiji's EEZ, high seas, and neighboring waters (with licenses), the highest catch is that of albacore, at 11,689 mt in 2006 (Table A2.25) (Amoe 2010).

Pole and Line Skipjack

The use of this fishing gear declined in the 1980s because of a differential pricing system that penalized local operators and the high catch of purse-seine vessels. A new vessel that targets skipjack tuna for value-added processing is under trial (MFNP 2002).

Long Line for Canning

As already mentioned, longline fishing is used offshore by foreign-based vessels to fish albacore. The Fiji Government does not provide assistance (MFNP 2002).

Domestic Sashimi Fisheries

Domestic sashimi fisheries were developed by one or two local companies in Suva with support from the Government of Fiji. This fisheries subsector grew from one boat in 1989 to over 55 boats in 2000 and contributes to the direct employment of 2,000 people and indirect employment of 8,000 (MFNP 2002). Domestic sashimi fisheries provided around $85 million to

Table A2.25 Total Catch of Various Species of Tuna and Billfish by the Domestic Longline Fleet, Fiji, 2005–2009

	Total Catch[a] (mt)				
	2005	2006	2007	2008	2009[b]
Albacore	8,816	11,689	7,076	7,609	7,166
Bigeye	419	764	551	667	689
Yellowfin	1,970	2,210	1,704	2,748	2,564
Swordfish	175	221	104	195	97
Blue marlin	197	215	108	214	101
Black marlin	68	16	19	7	44
Striped marlin	123	122	56	65	34
Other billfish	NA	364	227	124	173
Others	3,580	4,907	2,453	2,445	2,981
Total	**15,348**	**20,508**	**12,298**	**14,238**	**13,849**

mt = metric ton.
[a] Catch estimates do not include fish caught in Fiji's territorial seas and archipelagic waters.
[b] 2009 catch is provisional.
Source: Amoe, J. 2010. *Annual Report to the Western and Central Pacific Fisheries Commission. Part 1: Information on Fisheries, Research and Statistics 2009*. Fisheries Department, Ministry of Primary Industries. Suva.

the economy of Fiji in 2000 (MFNP 2002). Despite the benefits derived from this subsector, full expansion cannot be attained because of lack of air cargo space (MFNP 2002).

Small-Scale Tuna Fisheries

This type of fishery consists of small-scale tuna handline fishing with high potential, the main challenge of which is availability of storage areas due to daily unloading (MFNP 2002). Table A2.26 presents data on the total tuna catch from locally based offshore vessels in Fiji.

Artisanal Fishing

This type of fishing contributes considerably to domestic fish supply and employment, includes small-scale commercial catches for domestic sales.

Table A2.26 Tuna Catch and Bycatch by Offshore Locally-Based Vessels in Fiji, 2003–2007 (metric ton)

	Albacore	Bigeye	Yellowfin	Total Tuna	Bycatch
2003	6,881	889	2,482	10,252	2,062
2004	11,290	1,254	4,164	16,708	5,579
2005	8,901	423	1,989	11,313	4,182
2006	11,802	771	2,231	14,804	5,903
2007	9,395	839	2,852	13,086	2,995

Source: Ministry of Finance and National Planning. 2004. *Strategic Development Plan 2007–2011. Millennium Development Goals, Fiji National Report*. Suva.

Substantial sales of nonfin fish, such as shellfish, mollusks, crustaceans, and seaweed, as well as trochus shells, beche-de-mer, and mother of pearl shells, were recorded by the Ministry of Finance and National Planning (2002).

Aquaculture

Aquaculture was initiated in Fiji in the mid-1980s. Its importance was realized when aquaculture produce catering to the rising demand of the local market—particularly due to the tourism industry—sold at attractive prices.

The Government of Fiji provides support services in aquaculture development through distribution of newly hatched fry to existing and new fish farms. It also supports the expansion of clam programs in Makogai Island's main station and other ocean nurseries. The culturing of pearls is also expanding and comands high prices, especially in Japanese markets, because of its exceptional quality (MFNP 2002).

Consumption and Nutrition Security

Fish is an important source of protein. FAO (2009) estimated per capita fish consumption of Fiji at around 36.8 kg in 2005. Several factors influence the level of fish demand: population growth, soaring fish prices (due to overexploitation of inshore fishing grounds, Fiji's currency devaluation, and escalating fuel costs), and the relative costs of fish substitutes (FAO 2009). Per capita fish consumption increased from 109 kcals in 1992 to 223 kcals in 2006 (NFNC 2009). In 2006, fish ranked fourth in importance in Fiji's food consumption (after cereals, sugars, and root crops). It is therefore necessary to ensure availability of supply for the local population. Aquaculture is one approach (Billings and Pickering 2010) to ensuring such supply.

In 2004, a national survey showed that 23.4% of households in Fiji consume seafood on a daily basis (FAO 2009). This trend was similarly observed in the consumption of imported fish such as canned mackerel, tuna, and sardines. In addition, fish is relatively more resilient to natural disasters (e.g., cyclones and floods) compared with terrestrial crops. The effects of these disasters on fisheries are less pronounced, and the recovery period is shorter (FAO 2009).

Fisheries and the Country's Economy

One of Fiji's main export commodities is large fresh tuna. The quality and quantity of tuna export developed rapidly due to the high market value of Japanese sashimi, and increased demand from the United States and other markets (MFNP 2002). The export value of fisheries products, including subsistence fisheries, increased from $50 million in 1997, to $85 million in 1998, to $135 million in 1999, including canned fish at $29 million and beche-de-mer at $4 million (MFNP 2002). Table A2.27 shows the value of exports of fish products from Fiji from 2004 to 2007.

In 2003, the fisheries sector contributed 1.9% to Fiji's GDP. Fishery exports contributed 9.1% to total exports, and access fees paid by foreign fishing vessels accounted for about 0.03% of total government revenue. Further, the fisheries sector accounted for about 3.8% of full-time employment in the country (ADB 2005). FAO (2009) estimated that direct employment offered by the fisheries sector directly benefited 6,900 employees, and indirectly benefited 1,900.

Table A2.27 Value of Fisheries Exports and Percentage Share of Fisheries Exports in Total Exports, Fiji, 2004–2007

Year	Value of Fisheries Exports ($ million)	Value of Total Exports ($ million)	Percentage Share of Fisheries Exports in Total Exports
2004	49.1	696.2	7.1
2005	50.9	705.5	7.2
2006	56.9	694.2	8.2
2007	63.3	518.0	12.2

Source: Food and Agriculture Organization. 2009. *Climate Change and Food Security in the Pacific*. Rome. ftp://ftp.fao.org/docrep/fao/012/i1262e/i1262e00.pdf

ADB (2005) estimated the number of people employed in various activities of the fisheries sector (Table 2.28), these in aggregate accounting for 3.8% of the total labor force of Fiji in 2004 (FAO 2009).

Offshore fishing improves the employment opportunities of *iTakeui*. Table A2.29 presents the number of Fiji employees in the country's tuna industry, based on a study by the the Forum Fisheries Agency (FAO 2009).

Impacts of Climate Change on Fisheries

The Pacific Climate Change Science Program (PCCSP) built on the assessment done by the IPCC, which waws based on a detailed set of climate change projections. PCCSP evaluated 24 global climate models (GCMs), 18 of which represent the climate of the western tropical Pacific Islands (ABM and CSIRO 2011). From these 18 models, three emissions scenarios—B1 (low), A1B

Table A2.28 Estimated Number of Employees in Fiji's Fisheries Sector, 2004, by Subsector

Category	Employees (full-time equivalent)
Offshore fishery	510
Inshore artisanal	2,137
Subsistence	3,000
Marine aquarium	650
Aquaculture	550
Game and charter fishing	60
Tuna cannery	800
Other fish processors	639
Input suppliers	185
Fish markets	340
Department of Fisheries	243
Slipways/Ports	30
Total	**9,144**

Source: Asian Development Bank 2005. Republic of the Fiji Islands: Fisheries Sector Review. *Technical Assistance Consultant's Report*. Manila.

Table A2.29 Number of Employees Working in Offshore Fisheries, Fiji, 2002–2008

Year	Employees Working: On Vessels	Employees Working: In Shore-Based Facilities	Total
2002	893	1,496	2,389
2006	330	2,200	2,530
2008	150	1,250	1,400

Source: Food and Agriculture Organization. 2009. *Climate Change and Food Security in the Pacific*. Rome. ftp://ftp.fao.org/docrep/fao/012/i1262e/i1262e00.pdf

(medium), and A2 (high)—were used to evaluate the climate of Fiji, as well as the climate of the other two study countries (ABM and CSIRO 2011).

Even in the absence of climate change, there are apparent threats to coastal areas and fisheries resources. Population growth, urbanization, and industrial and economic development exert pressure on coastal areas, including the mangrove ecosystem. The conversion of mangroves to industrial, tourism, or residential areas results in the loss of breeding grounds for fish and other aquatic mammals, and the loss in protection against the sea during cyclones and tsunamis (Woodward et al. 2000). This makes the coastal areas of Fiji vulnerable to the effects of the sea-level rise and coastal erosion brought about by changes in climate conditions. In addition, improper (industrial, commercial, household) waste disposal and pollution discharges; inappropriate agricultural practices; soil erosion and siltation; extensive beach sand mining; unsuitable development, such as jetties; use of destructive fishing practices; and other factors lead to the deterioration of coastal and aquatic resources. In addition, the rise in sea level due to global warming as result of climate change threatens the productivity of Fiji fisheries.

On Viti Levu, 86% of the coastline is less than five meters above sea level (World Bank 2000). This area is exposed to intensive urban development, watershed deforestation, and overexploitation of coastal resources, including mangroves. The destruction of the mangrove ecosystem has resulted in the shoreline retreat of 15–20 meters in some Viti Levu villages over the past decades (Mimura and Nunn 1998).

Based on a World Bank report (2000), the coastline of Viti Levu will be strongly affected by climate change. More intense cyclones cause further coastal erosion and inundation, a rise in water temperature (0.9°C–1.3°C in 2050), and encroachment of seawater on the coasts (23–43 centimeters in 2050), which will disturb the coastal areas of Viti Levu (World Bank 2000). These effects are estimated to cause annual economic losses of $8 million–$20 million by the year 2050 (World Bank 2000).

Sea-Surface Temperature

Global warming triggers a rise in sea-surface temperature. A 1°C increase in surface temperature causes coral bleaching, which is fatal to coral reefs (World Bank 2000). In Fiji, coral bleaching was observed during the 1997–1998 El Niño event and in April 2000 (World Bank 2000). Coral reefs might not be able to adapt to a succession of high water temperatures, this ultimately resulting in coral bleaching. The World Bank (2000) calculated the value of the loss to fisheries, habitat, and tourism to be $14 million annually by the year 2050.

Fiji's Meteorological Service, Australian Bureau of Meteorology, and Commonwealth Scientific and Industrial Research Organisation (FMS/AMB/CSIRO 2011) note the relatively constant annual water temperature of 20–27°C of Fiji from 1950s to the late-1980s.This notwithstanding, an estimated 0.07°C increase in water temperature per decade from 1970 to the present has been observed in the country. However, natural variability that influences sea-surface temperature occurs on a regional scale, thus making it difficult to distinguish a long-term trend (ABM and CSIRO 2011).

Ocean Acidification

Human activities trigger the emission of CO_2. When CO_2 reacts or dissolved in sea water, it becomes slightly more acidic. This results in ocean acidification (ABM and CSIRO 2011). Acidic water affects the growth of corals and other organisms, particularly those that build their skeletons using carbonate minerals. ABM and CSIRO (2011) reported the slow rise in the concentration of CO_2 in Fiji's waters since the 18th century.

Seawater aragonite ($CaCO_3$) saturation was measured based on large-scale distribution of coral reefs across the Pacific Islands, and seawater chemistry. Guinotte et al. (2003) noted that seawater aragonite saturation above 4 is optimal for coral growth; 3.5–4 is adequate, and 3–3.5 is considered marginal. Coral reef ecosystems were not found below level-3 seawater aragonite saturation, indicating that such conditions are extremely marginal and will be difficult to support coral growth (Guinotte et al. 2003). In the late 18th century, seawater aragonite saturation measurements showed a reduction of about 4.5 to an observed value of about 3.9 ± 0.1 in 2000 within Fiji maritime boundaries (ABM and CSIRO 2011).

Ocean acidification projections were performed under the Coupled Model Intercomparison Project (CMIP3). ABM and CSIRO (2011) described the intensification of acidification of the ocean during the 21st century. The high confidence in the estimated buildup of acidification may be attributed to the rising oceanic uptake of CO_2 due to proliferation of atmospheric CO_2 levels. In essence, ocean acidification affects the health of coral reef ecosystems, on top of coral bleaching (due to rising water temperatures), storm surges, and environmental pressure on fishing resources (ABM and CSIRO 2011).

Projected estimations from CMIP3 revealed annual maximum aragonite saturation values below 3.5 by about 2035, with a subsequent declining trend in Fiji waters (ABM and CSIRO 2011). This estimate has moderate confidence because climate models are without explicit representation of the carbon cycle, and with relatively low resolution and significant regional biases.

Sea-Level Rise

A rise in sea level may be attributed to swelling of ocean water due to warming and melting of glaciers and ice sheets. ABM and CSIRO (2011) reported a rise in the sea level of the Fiji of about 6 millimeters (mm) per year since 1993, based on satellite imagery. This finding is higher than the estimate of global average sea-level rise of 2.8–3.6 mm per year. The rise in sea level in Fiji may be in some part due to natural fluctuations of seawater that occur because of El Niño Southern Oscillation.

Projections regarding the extent of sea-level rise in Fiji were studied by ABM and CSIRO (2011). The results of this study indicated an estimated 3 cm–16 cm increase in sea-level height in 2030 under the high-emissions scenario (Table A2.30). The combination of sea-level rise, together with natural year-to-year changes might intensify the impact of storm surge and coastal flooding (ABM and CSIRO 2011). In addition, although the rate of glacier melting in Antarctica and Greenland needs further investigation, this phenomenon could also cause rising sea levels in the Pacific.

Table A2.30 Projected Sea-Level Rise Under Three Emission Scenarios, Fiji, 2030, 2055, and 2090

Scenario	Sea-Level Rise (cm)		
	2030	2055	2090
Low-emissions scenario	5–16	10–27	16–47
Medium-emissions scenario	5–15	9–31	20–59
High-emissions scenario	3–16	8–31	21–62

cm = centimeter.

Note: Values represent 90% of the range of values projected by the models, and represent changes relative to the average value for the period 1980–1999.

Source: Australian Bureau of Meteorology (ABM) and Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2011. *Climate Change in the Pacific: Scientific Assessment and New Research. Volume 2: Country Reports*.

References

Agricultural Commodities Committee/Coconut Advisory Council (ACC/CAC). 1985. *Commodity Profile: Coconut. A Programme for the Future Development of the Coconut Areas*. Suva.

Ahmed, M. et al. 2011. Food Security and Climate Change: Rethinking the Options. *Pacific Studies Series*. Manila: Asian Development Bank.

Amoe, J. 2010. *Annual Report to the Western and Central Pacific Fisheries Commission. Part 1: Information on Fisheries, Research and Statistics 2009*. Fisheries Department, Ministry of Primary Industries. Suva.

Anderson, S. and H. Jenshagen. 2010. *An Analysis of the Sugar Industry and Its Global Competitiveness–The Case of Fiji*. Bachelor Thesis. Linnaeus University School of Business and Economics, Sweden.

Asian Development Bank (ADB). 2005. *Republic of the Fiji Islands: Fisheries Sector Review*. Technical Assistance Consultant's Report. Manila.

Australian Bureau of Meteorology (ABM) and Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2011. *Climate Change in the Pacific: Scientific Assessment and New Research. Volume 2: Country Reports*. Aspendale, Victoria, Australia.

Benson, C. 1997. The Economic Impact of Natural Disasters in Fiji. *Overseas Development Institute Working Paper 97*. London.

Billings, G. and T. Pickering. 2010. Fiji Launches Milkfish Aquaculture Project for Food Security. *SPC Fisheries Newsletter.* 132. May/August.

Copra Millers Fiji Limited (CMFL). Undated. Copra Millers Fiji Limited brochure. Balaga Bay, Savusavu, Fiji.

Fiji Bureau of Statistics (FBS). 2011. *Fiji Facts and Figures as at 1 July 2010*. Suva.

Fiji Department of Agriculture (FDA). 2007. Taro/Dalo Beetle Management in Fiji. *Technical Bulletin*. 3. April.

_______. 2010a. Agriculture Programme Overview Briefing to Commissioner Central and Commissioner Eastern. 18 February.

_______. 2010b. Coconut. Crop Farmers Guide. http://www.agriculture.org.fj/_resources/main/files/33.jpg (Accessed on 7 July 2011)

_______. 2011a. *Report on the Fiji National Agricultural Census 2009*. Economic Planning and Statistics Division. Suva.

_______. 2011b. *Revitalization of Coconut Industry*. 16 August. Ministry News & Updates. www.agriculture.org.fj/index.cfm?si=main.resources&cmd=forumview&uid=news&cid=1622

Fiji Sugar Corporation (FSC). 2002. The Fiji Industry. Fijian Studies. 1 (2). Fiji Institute of Applied Studies.

_______. 2009. *Fiji Sugar Corporation Annual Report 2009*.

Food and Agriculture Organization of the United Nations (FAO). 2007. Selected Indicators of Food and Agricultural Development in the Asia–Pacific Region 1996–2006. Rap Publication 2007/15. Regional Office for Asia and the Pacific. Bangkok.

_______. 2009. *Climate Change and Food Security in the Pacific*. Rome. ftp://ftp.fao.org/docrep/fao/012/i1262e/i1262e00.pdf

_______. 2010. FishStatJ statistical database. Rome. www.fao.org/fishery/statistics/software/fishstat/en

_______. 2011. FAOSTAT. Rome. http://faostat.fao.org/

Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB.

Government of Fiji (GOF). 2005a. *Climate Change The Fiji Islands Response. Fiji's First National Communication Under the Framework Convention on Climate Change 2005*. Suva.

_______. 2005b. *Fiji Today 2004/2005*. Ministry of Information, Communications and Media Relations. Suva.

Hone, P. and H. Haszler. 2006. Estimating the Size of the Fiji Islands Agricultural Sector. S*chool Working Paper—Economic Series 2006*. Suva: University of the South Pacific.

Hone, P., H. Haszler, and T. Natasiwai. 2008. Agricultural Supply Response in Fiji. Contributed Paper Presented to 52nd Annual Conference: Australian Agricultural and Resource Economics Society, Canberra. 6–8 February.

Kumar, S. and J. Bhati. 2010. Challenges and Prospects for Sustainable Development of Agriculture and Agribusiness in Fiji Islands. University of the South Pacific, School of Economics Working Paper No. 2010/09. Suva: School of Economics, University of South Pacific.

Lal, P.N., R. Rita, and N. Khatri. 2009. *Economic Costs of the 2009 Floods in the Fiji Sugar Belt and Policy Implications*. Gland: IUCN.

McGregor, A., W. Gonemaituba, and K. Stice. 2009. Natures Way Cooperative (Fiji) Ltd : A Case Study of Agriculture for Growth in the Pacific. Rome: Food and Agriculture Organization. Available: http://www.faopacific.ws/Portals/167/publications/AG%20for%20Growth%20Reports/Natures_Way_Cooperative_(Fiji)Ltd%20final.pdf

Mimura, N., and P.D. Nunn. 1998. Trends of Beach Erosion and Shoreline Protection in Rural Fiji. *Journal of Coastal Research* . 4(1). pp. 37–46.

Ministry of Finance and National Planning (MFNP). 2002. 20-Year Development Plan (2001–2020) for the Enhancement of Participation of Indigenous Fijians and Rotumans in the Socio-Economic Development of Fiji. Parliament of Fiji. Parliamentary Paper No. 73 of 2002.

_______. 2004. *Strategic Development Plan 2007–2011. Millennium Development Goals, Fiji National Report.* National Planning Office, Ministry of Finance and National Planning. Fiji.

Narayan, P.K. 2004. An Empirical Analysis of Sugarcane Production in Fiji, 1970–2000. *Economic Analysis & Policy*. 34(1).

National Food and Nutrition Centre (NFNC). Various Dates. *National Food and Nutrition Centre Report of Fiji Islands*. Various annual reports. Suva.

______. 2009. *Fiji National Nutrition Survey. Main Report*. Suva.

Nature Fiji–Mareqeti Viti. 2011. www.naturefiji.org/endspecies.php?info=Taro

Pacific Islands Climate Change Assistance Programme (PICCAP) Fiji. 2005. *Climate Change The Fiji Islands Response. Fiji's First National Communication Under the Framework Convention on Climate Change 2005*. Suva.

Prasad, B. 2010. Global Crisis, Domestic Crises and Crisis of Confidence: Which Way Forward for Fiji? *Pacific Economic Bulletin*. 25(2). pp. 1–24.

Prasad, B., and P. K. Narayan. 2005. *Contribution of the Rice Industry to Fiji's Economy: Implication of a Plan to Increase Rice Production*. No. 2005/7. Department of Economics, University of the South Pacific. Suva.

Rao, S.K. et al. 2007. Cultivation Techniques to Enhance Rice Production in Fiji. *Rice Production Technology Bulletin*. Research Division, Ministry of Agriculture, Fisheries and Forests. Republic of Fiji.

Secretariat of the Pacific Community (SPC). 2011a. *Fiji and the Secretariat of the Pacific Community Joint Country Strategy 2010–2014*. Jointly compiled by the Secretariat of the Pacific Community and the Fijian Government. Noumea, New Caledonia.

______. 2011b. SPC Assists Biosecurity Authority of Fiji on Taro Export. www.spc.int/en/component/content/article/216-about-spc-news/676-spc-assists-biosecurity-authority-of-fiji-on-taro-export.html

Singh, J. 2008. Fixing the Copra Industry. *The Fiji Times*. 4 December 8. www.fijitimes.com/story.aspx?id=107923

Sugar Research Institute of Fiji (SRIF). 2011. www.srif.tk/1_13_History.html

United Nations Department of Humanitarian Affairs (DHA). 1993. Fiji-Cyclone Kina January 1993 UN DHA Situation Reports 1–6. Suva.

United Nations Development Programme (UNDP). 1997. *Human Development Report 1997: Human Development to Eradicate Poverty*. New York: Oxford University Press. http://hdr.undp.org/en/reports/global/hdr1997/

______. 2010. *Human Development Report 2010: The Real Wealth of Nations: Pathways to Human Development*. New York: Oxford University Press. http://hdr.undp.org/en/reports/global/hdr2010/

Vilsoni, F.. 1993. Sustainable Taro Culture: Fiji Situation. In Ferentinos, L., ed. *Proceedings of the Sustainable Taro Culture for the Pacific Conference.* University of Hawaii, Honolulu, Hawaii. 24–25 September 1992. pp. 84–87.

Woodward, A. et al. 2000. Protecting Human Health in a Changing World: The Role of Social and Economic Development. *Bulletin of the World Health Organization*. 78(9). pp. 1148–1155.

World Bank. 2000. *Cities, Seas and Storms. Managing Change in Pacific Island Economies*. *Volume IV. Adapting to Climate Change*. Washington, DC. http://siteresources.worldbank.org/INTPACIFICISLANDS/Resources/4-TOC.pdf

_______. 2008. Reducing the Risk of Disasters and Climate Variability in the Pacific Islands. Washington, DC.

_______. 2010. *World Development Report 2010: Development and Climate Change*. Washington, DC.

_______. 2011. World Development Indicators. Washington, DC. http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

APPENDIX 3

Agriculture and Fisheries Sectors in Papua New Guinea

Overview

Papua New Guinea (PNG) is located in the Southwest Pacific between latitudes 1° and 12° south. It is the largest of the Pacific Island states, having a total land area of 459,854 square kilometers (km^2). PNG occupies the eastern half of the island of New Guinea and includes four large islands (Manus, New Ireland, New Britain, and Bougainville), and over 600 lesser islets and atolls to the north and east. The country shares a border with the Indonesian province of West Papua to the west, and has Australia to the south, the Solomon Islands to the east, and the Federated States of Micronesia to the north.

PNG has a challenging terrain. More than half of its total land area (52%) comprises mountains and hills, nearly 19% is plains or plateaus, 18% is floodplains, and a smaller proportion is volcanic landforms or raised coral reefs and littoral areas (Allen and Bourke 2009). As such, PNG has various types of environments ranging from mountain glaciers to humid tropical rainforests, swampy wetlands, and pristine coral reefs. About 25% of PNG's total land area is used for agriculture. The remaining landmass is not suited for agricultural production because it is too steep or too high in altitude (too cold), has too much rainfall, or is flooded yearly (Allen and Bourke 2009). About two-thirds of the land used for agriculture is on mountains and hills (63%); 12% is on volcanic landforms; 11% is on plains and plateaus; and 9% is on floodplains. Only 7% of PNG's land area is classified as high or very high quality for agricultural production; an estimated 20% is of moderate quality. Most food production is from land of moderate to low quality.

Climatic Conditions

PNG's climate is characterized by high rainfall, humidity, and high temperatures that are generally uniform throughout the year. The lowland and coastal areas are hot, with temperatures in the range of 24°–35°C (75°–95°F) and high humidity. The highland regions are cooler, with temperatures of about 12–28°C (54°–82°F) and with less humidity. Altitude and latitude, or distance from the equator, influence temperatures in PNG. Above 500 meters (m), temperatures falls at a regular rate of 0.5°C for every 100 m increase in altitude, or 5°C for every 1,000 m. In addition, the further away from the equator a place is located in PNG, the greater the range in its temperatures during the year.

PNG is one of the wettest countries on earth, in that much of the country regularly receives 2,000–4,000 milllimeters (mm) of rain per year, and a few areas receive more than 7,000 mm per year. In other areas, annual rainfall is below 1,500 mm. Very high rainfall occurs on three areas of the main highland valleys, specifically to the west and along the north and south sides of the main range (Allen and Bourke 2009). High rainfall also takes place on the south coast of New Britain and on south Bougainville Island. Very high annual rainfall of over 7,000 mm every year is received from Ok Tedi in the far northwest of Western Province, southeast into the northern Gulf Province. Locations where annual rainfall is more than 4,000 mm tend to be too wet and have too much cloud cover for good agricultural production. Meanwhile, annual rainfall is below 2,000 mm in the northern part of East Sepik Province, the Markham Valley in Morobe Province, part of the adjacent Ramu Valley in Madang Province, the northern part of Eastern Highlands Province, the southern third of Western Province, the coastline of Central Province, and the Cape Vogel–Rabaraba area of Milne Bay Province.

In many parts of the country, most rain falls between January and April, with the least falling between May and August. Conversely, in some parts (Gulf Province, the Huon Gulf around Lae and Finschhafen, the southern part of mainland Milne Bay Province, the southern coast of New Britain, and the south of Bougainville Island) more rain falls between May and August.

Seasonal rainfall differences can be measured as the relative difference in rainfall between the dry and wet seasons. No discernible seasonal rainfall pattern is observable in some parts of the country—the northern part of Western Province, much of Southern Highlands Province, the southern parts of Sandaun and East Sepik provinces, Manus Province, and some of the islands in Milne Bay Province—because rain falls all year round. In other areas—the southern half of Western Province, inland and coastal southeast Central Province, the north coast of mainland Milne Bay Province, most of Eastern Highlands Province, and the Markham Valley and north coast of the Huon Peninsula in Morobe Province—rainfall is strongly seasonal. There are no parts of PNG that are dry all year round.

PNG's annual rainfall is highly reliable in that it varies little from year to year across most of the country. It does, however, infrequently experience periods of abnormally low rainfall associated with the warm phase of El Niño Southern Oscillation (ENSO). In 1997 for instance, a strong ENSO event catalyzed the development of frost (particularly in highlands), causing prolonged drought that seriously disrupted food production countrywide. About 150,000 people were estimated to be eating wild foods by October of that year. By December, the estimate has risen to 260,000 based on a second nationwide field assessment. Moreover, a further 980,000 people were assessed to be eating poor quality garden food, in reduced quantities (Allen and Bourke 2009).

Share of Agriculture in Total Gross Domestic Product

Agriculture provided income, employment, and livelihood to 70% of PNG's economically active population in 2010 (FAO 2011). On average, agriculture contributed 36% to GDP from 1995 to 2010, but its contribution declined somewhat over this timeframe from 35% to 33% (Table A3.1). Factors constraining agricultural development in PNG are the poor state of infrastructure (transport and roads) and high costs of transport (PNG MAL

Table A3.1 Real GDP at Factor Cost, Agricultural GDP, and Percentage Share of Agricultural GDP in Real GDP, Papua New Guinea, 1995–2010

Year	Real GDP at Factor Cost (Kina million)	Agricultural GDP (Kina million)	Percentage Share of Agriculture in Real GDP (%)
1995	7,467	2,615	35
1996	7,960	2,811	35
1997	7,455	2,575	35
1998	7,804	2,629	34
1999	7,948	2,992	38
2000	7,753	3,054	39
2001	7,750	2,909	38
2002	7,905	2,892	37
2003	8,252	3,116	38
2004	8,299	3,109	37
2005	8,625	3,284	38
2006	8,823	3,318	38
2007	9,454	3,458	37
2008	10,079	3,608	36
2009	10,632	3,632	34
2010	11,381	3,759	33

GDP = gross domestic product.
Source: Asian Development Bank. 2011a. Food Security and Climate Change in the Pacific: Rethinking the Options. *Pacific Studies Series*. Manila.

2007a). PNG has one of the highest sea transport costs in the Asia–Pacific region, thus reducing the economic viability of production for exports and limiting the growth of domestic import replacement activities. For instance, it is cheaper to ship a ton of cocoa from the town of Rabaul to Singapore than from Baining to Rabaul, both of which are located in East New Britain Province.

Furthermore, domestic markets are often far from production areas and have no access at all in outer islands (PNG MAL 2007a). PNG's rugged terrain and scattered islands make the costs of transportation high. For example, Unggai Benai coffee farmers pay as much as K20,000 a year to hire youths to carry coffee bags for two days to access a road. With higher transportation costs, farmers earn less for their produce, creating a disincentive to reinvest in yield-enhancing inputs and technologies.

PNG's complicated land tenure system has also contributed to the slow pace of agricultural development. The majority of land is under customary ownership, and the administrative system is inefficient and ineffective. As most customary lands are unregistered (and often with disputed ownership), farmers can't use the land as collateral to obtain loans to invest more in their farm.

In addition, the threat posed by the government's inability to provide security and guarantee the rule of law has hindered agricultural development. With the threat of a breakdown of law and order (and uncertain property rights), farmers are discouraged from growing crops (PNG MAL 2007a). In particular, clashes between rival clans battling for control of resources in the highlands have made marketing and business conditions difficult, and theft of coffee, mostly from plantations, is rampant (FAO, NARI, and World Bank 2002). The country's vulnerability to natural disasters also undermines agricultural development. For instance, the tsunami in 1998, drought and frost caused by El Niño in 1997, and volcanic eruptions that devastated Rabaul in 1994 led to decreased agricultural production.

Research-extension-farmer linkages have been weak in PNG, further limiting farmers' ability to increase their production. Research findings on agricultural innovations, proper farm practices, and production technologies that can increase productivity are not effectively transferred to farmers (PNG MAL 2007a). Downsizing, corporatization, and decentralization of government services in the agriculture sector to the provincial level have been closely correlated with the disintegration of government extension services to farmers, particularly to smallholders and subsistence farmers in remote areas. Given that political support and budget for agriculture at the national and provincial levels are limited, resources available for extension at the local level are minimal.

Lack of market information has also hindered agricultural development. Farmers don't have information on the flow of markets, prices, supply, and consumer preferences with which to make appropriate decisions on which agriculture activities or enterprises they should invest in to generate income. As a result, at times they cultivate and sell crops with little demand, or at the wrong time, or in insufficient quantities.

Population and Human Development

PNG is the largest island in the Pacific with a population of 5,190,786 in 2000 (NSO 2002). Of this, more than 80% lives in the rural areas, 6% in rural nonvillages and 13% in urban areas (Allen and Bourke 2009).

The country is divided into 21 provinces spread across four regions and one district: the Southern region, Highlands, Momase, Islands, and the National Capital District (NCD) (Table A3.2). Among the rural villages, Eastern Highland province has the highest population (1.39 million people), while Manus has the lowest (34,899 people). Southern Highland Province has the highest urban population (546,265 people) and Bougainville has the lowest (4,107 people). Rural nonvillage settlers are found mostly in West New Britain (54,969 people), and the least number occupy Manus (1,276). The rural nonvillage population generally lives in mining settlements, logging camps, mission housing, schools, and research stations (Allen and Bourke 2009).

During 1990–2000, the annual population growth rate was estimated at 3.24%, with the highest in the Highlands Region (3.65%) and lowest in the Southern Region (0.21%) (NSO 2002). Given this growth rate, the total PNG population is expected to double every 30 years (Allen and Bourke 2009). With increasing population, and demand for basic needs such as food, clothing, shelter, education, and services, actual growth is likely to be greater.

PNG is not exempt from the poor conditions in the Pacific region. As early as the 1960s, it was classified as "less developed" and "disadvantaged" (the popular terms of that time) (Allen 2009). Measurements of development

Table A3.2 Rural, Rural Nonvillage, and Urban Population by Region and Province, Papua New Guinea, 2000

Region/Province	Population			
	Rural	Rural Nonvillage	Urban	Total
Papua region				
Western	107,837	12,445	33,022	153,304
Gulf	92,265	6,320	11,013	106,898
Central	157,058	21,165	5,760	183,983
Milne Bay	188,334	9,327	12,751	210,412
Oro	106,288	15,406	11,371	133,065
Highlands				
Southern Highlands	526,398	8,813	110,154	546,265
Enga	283,498	4,014	7,519	295,031
Western Highlands	371,014	39,094	29,917	440,025
Simbu	242,748	7,201	9,754	259,703
Eastern Highlands	1,393,418	13,243	26,311	432,972
Momase				
Morobe	356,100	46,869	57,743	460,712
Madang	308,135	18,626	38,345	365,106
East Sepik	303,706	7,492	31,983	343,181
Sandaun	166,919	4,508	14,314	185,741
Lae City	0	0	78,692	78,692
Islands				
Manus	34,899	1,276	7,212	43,387
New Ireland	103,259	4,346	10,745	118,350
East New Britain	174,230	35,613	10,290	220,133
West New Britain	109,299	54,969	20,240	184,508
Bougainville	167,156	3,897	4,107	175,160
National Capital District	0	0	254,158	254,158
Papua New Guinea	**4,192,561**	**311,924**	**686,301**	**5,190,786**

Source: National Statistical Office of Papua New Guinea. 2002. Papua New Guinea 2000 Census: Final Figures. National Statistical Office of Papua New Guinea, Port Moresby..

included food consumption, cash income, and access to health and education services, which are similar to present-day measures of poverty. World Bank (2011) reported that around 40% of the PNG population lives on less than $1 per day. More than 80% of the rural population experiences widespread poverty. Many rural villagers do not have access to basic services or living conditions, and much of the rural population depends on subsistence agriculture (World Bank 2011b) as their only means of livelihood, despite the difficult terrain and vulnerability to pests and climatic changes (Allen 2009). Poverty in urban areas is often defined by reduced access to basic education and the high cost health services, such that cash income is insufficient to meet daily household consumption and other needs (Allen 2009).

In 2010, PNG's human development index (HDI) ranking was 137 of 169 countries; it was thus classified as being under low human development (UNDP 2010). HDI estimates the country's health, education and living standards, the three basic measures of human development (UNDP 2010). PNG's HDI was around 0.431 in 2010, representing a considerable improvement over the 1980 index of 0.295 (UNDP 2010).

Health

Saweri (2004) reported that the major health and nutrition issues in PNG, particularly in young children and women, included malnutrition, iodine deficiency, and noncommunicable diseases. Low birth weight (less than 2.5 kilograms [kg]) was reported for at least 10% of infants born in health facilities in 2003; comparable shares were 9.7% in 2002, 8.9% in 2001, and 9.9% in 2000 (Saweri 2004).

A national nutrition survey conducted in 1982–1983 reported the occurrence of Marasmus in infants, a severe case of protein malnutrition characterized by energy deficiency. In addition, around 38% of children under 5 years old were below the 80% median of weight-for-age (Saweri 2004). The survey reported that almost half (45%) of the children under 5 years old suffered from underweight and lived in eight districts gravely affected by drought caused by El Niño (Saweri 2004).

Other diseases include anemia in pregnancy, which was found in 45% of mothers in 1992–1993, and in 83% and 91% children under five years old in Madang and Sepik, respectively—both are low-lying coastal areas—and in 35% children under 5 years in Western Highlands (Saweri 2004). Goiter is common, and in 1992–1993 was found in 13.7% of children 8 to 10 years old living in remote mountainous districts (Saweri 2004).

Rural villages have relatively low levels of obesity, but around 48% of the population in a periurban village near the National capital district (NCD) was found to be obese, as was around 26% in a settlement near Port Moresby (Saweri 2004).

Obesity (measured as a body mass index [BMI] greater than 30) was found to be prevalent in 3.3% of men and 2.2% of women living in the rural highlands, whereas these rates were 16% for both men and women among the rural coastal population, and 27% and 38% for men and women, respectively, among urban coastal populations (based on a 1991 diet and cardiovascular risk factors survey) (Saweri 2004).

Another nationally representative household survey was conducted in 1996, in which nutritional inputs and outcomes of the rural and urban populations were examined (Gibson and Rozelle 1998). Average calorie availability across rural and urban areas was 2,660 calories per person per day (Gibson 2001b). Results, however, showed increases of 4%–7% in nutrient availability for every 10% increase in a household's economic resources (Gibson 2001b). Stunted growth of children occurs more in rural than in urban areas (40% compared with 20%) (Gibson 2001b). This low height-for-age may be due to accumulated malnutrition resulting from extended periods of inadequate food intake and past episodes of infection and sickness (Gibson 2001b). Mueller (2001) reported that children from the highlands were generally shorter and stockier than those in lowlands. Variations in nutrition depend on socioeconomic status and local subsistence agriculture (Gibson 2001a). For example, childrens' growth patterns are better in systems based on cassava and sweet potatoes and the consumption of local and imported high-quality foods, such as cereals, legumes, tinned fish or meat and fresh fish (compared with staple-based diets of only bananas, sago, and taro (Mueller 2001).

The World Health Organization (WHO) (2010) reported communicable diseases to be the leading health problems in PNG (malaria, tuberculosis, diarrhea, acute respiratory diseases, and HIV).

Education

Children begin primary school at the age of 7, and enrollment is for 6 years. Primary enrolments declined slightly from 559,817 in 2000 to 532,250 in 2006 (World Bank 2011). Female students remained the same at 44% from 2000 to 2006. In contrast, the number of secondary enrollments rose from 143,501 in 1999 to 190,321 in 2003 (World Bank 2011). The adult literacy rate (those above 15 years old) rose from 57% in 2000 to 60% in 2009 (World Bank 2011).

Living Standards

Due to lack of information, only one indicator regarding access to improved water was used to determine living conditions in PNG. In urban areas, 89% of the population had access to a source of improved water in 1995, but this declined to 87% in 2008 (World Bank 2011). Additionally, 32% of the rural population had access to a source of improved water in 1995, compared with 33% in 2008 (World Bank 2011).

In terms of health services, the PNG Government developed the new National Health Plan for 2011–2020, which was a redesigned sectorwide approach with stronger involvement of the central government (WHO 2010). With this change, it is expected that health services will be upgraded, particularly in the villages, given that more than half the population lives in rural areas.

Food Production

As in other Pacific countries, in PNG root crops dominate food production (Table A3.3). Sweet potato contributed 2.87 million tons, or 64% of total food production in 2000 (Bourke et al. 2009). Bougainville, Morobe, Oro, West New Britain, New Ireland, Central, Madang, East New Britain, Milne Bay, and Gulf provinces are dominant producers of sweet potato.

Bananas ranked second in production, at 436,496 tons in 2000 (Bourke et al. 2009), and are commonly grown in Morobe, East New Britain, Central, and Madang provinces. Cassava is an important crop in the lowlands, contributing 271,894 tons in 2000 (Bourke et al. 2009). Highest production was observed in Milne Bay, where it is in alternate planting with sweet potato, followed by taro and yams, then cassava.

Colocasia taro (229,088 tons in 2000) is farmed in most areas of PNG and is a supplementary crop (Bourke et al. 2009). Colocasia taro is the most important staple crop after sweet potato. Madang, East Sepik, and Morobe provinces are key producers of Colocasia taro. Lesser yam (*Dioscorea esculenta*),

Table A3.3 Year-2000 Production of Major Crops in Papua New Guinea

Crop	Production (tons)	Percentage Share in Total Production (%)
Sweet potatoes	2,871,851	63.57
Bananas	436,496	9.66
Cassava	271,894	6.02
Colocasia taro	229,088	5.07
Chinese taro	226,536	5.01
Lesser yams (*Dioscorea esculenta*)	180,370	3.99
Coconuts	100,929	2.23
Greater yams (*D. alata*)	91,358	2.02
Sago	82,962	1.84
Irish potatoes	18,759	0.42
Taro (*Alocasia*)	2,389	0.05
Queensland arrowroot	1,431	0.03
Taro (*Amorphophallus*)	1,217	0.03
Swamp taro	823	0.02
Yams (*D. nummularia*)	478	0.01
Aerial yams (*D. bulbifera*)	467	0.01
Rice	407	0.01
Yams (*D. pentaphylla*)	37	0.00

Source: Bourke, R.M., and V. Vlassak. 2004. *Estimates of Food Crop Production in Papua New Guinea*. Land Management Group, Research School of Pacific and Asian Studies. Canberra: The Australian National University; in Bourke. R.M. et al. 2009. Food Production, Consumption and Imports. In Bourke R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea*. Canberra: The Australian National University Press.

yielding about 226,536 tons in 2000 (Bourke et al. 2009), is grown in Morobe, Madang, East New Britain, and West New Britain provinces.

Food Consumption

Consistent with production, sweet potato is the main food consumed in PNG. Annual per capita consumption rose from 260 kg in 1996 to 416 kg in 2006 (Table A3.4) (Bourke et al. 2009). Annual per capita consumption growth was also recorded for bananas, yams, cassava, and Irish potatoes from 1996 to 2006. Annual per capita taro consumption declined from 62 kg to 45 kg (Bourke et al. 2009).

Rice and wheat are important imported crops in PNG in terms of consumption. Bourke (2001) and Gibson (2001a) showed the difference in consumption by rural and urban population for rice and wheat. As of 1996, annual per capita rice consumption averaged 24 kg in rural areas, 66 kg in urban areas, and 31 kg for PNG as a whole. Annual per capita wheat flour consumption in 1996 was 7 kg in rural areas, 31 kg in urban areas, and 11 kg for PNG as a whole. Finally, total annual per capita consumption of rice and wheat flour was estimated to be 31 kg in rural areas, 97 kg in urban areas, and 42 kg for PNG as a whole in 1996. This pattern reflects the availability of, and accessibility to imported food that ensures PNG's food

Table A3.4 Annual Per Capita Consumption of Major Crops, Papua New Guinea, 1996 and 2006 (kg)

Commodity	Annual Per Capita Consumption (kg) 1996	2006
Sweet potatoes	260	416
Bananas	83	84
Taro	62	45
Yams	28	53
Cassava	25	52
Irish potatoes	3	4

Source: Bourke. R.M. et al. 2009. Food Production, Consumption and Imports. In Bourke R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea*. Canberra: The Australian National University Press.

security. Although there are short- and long-term food supply problems, the availability and accessibility of food, and meeting the necessary minimum calorie requirements is not an issue in PNG (Bourke 2001). Short-term food issues occur due to extreme climatic events such as frost and excessive rainfall, cycles in planting rates, and human disease epidemics (Bourke 2001). Long-term problems include very low cash incomes and land degradation associated with population growth. Both short- and long-term threats relate to the need for cash income, and for developing subsistence agriculture (Bourke 2001). Rice imports rose significantly during 1997–1998—from 170,000 to 236,000 tons—due to drought and frosts in 1997 (Bourke 2001).

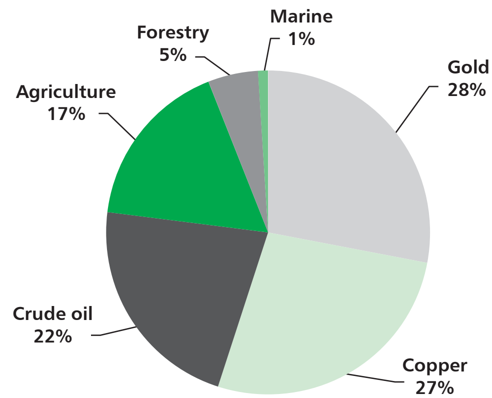
PNG has abundant marine resources including fish, shellfish, and other marine animals. For coastal villages and those living along major rivers, fish is a key food. Estimates from the National Fisheries Authority indicate consumption at 25,000–50,000 tons per year, or 5 kg–10 kg per person per year (Bourke et al. 2009). In addition, fish and seafood caught locally can be consumed at levels as high as 120,000 tons per year, or 24 kg per person per year (Bourke et al. 2009).

Trade

Oil and metals are the driving force of the PNG economy (ADB 2011b). Allen, Bourke, and McGregor (2009) identified mineral resources of gold and copper, and oil as contributing an average of 77% of PNG's total export commodities during 2004–2006. Over that timeframe, agriculture, forestry, and marine resources provided around 17%, 5%, and 1%, respectively (Figure A3.1) (Allen, Bourke, and McGregor 2009).

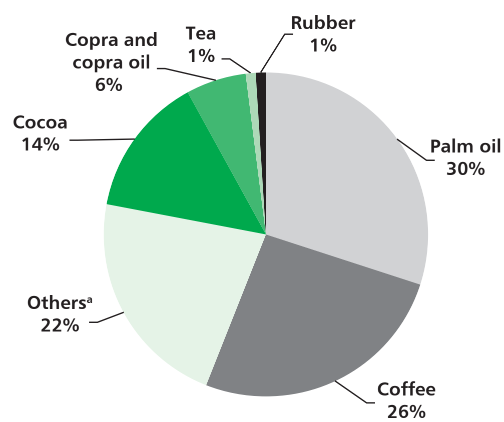
The important agricultural export commodities are palm oil (30% of total exports per year on average in 2004–2006), coffee (26%), cocoa (14%), copra and oil (6%), tea (1%), and rubber (1%) (Figure A3.2) (Allen, Bourke, and McGregor 2009). Other commodities, such as tinned tuna, tinned beef, processed tea and coffee, and spices and minor commodities such as artifacts, crocodile skins, and butterflies, contributed 22% per year on average in 2004–2006. High-value marine products such as bêche-de-mer (sea cucumber),

Figure A3.1 Percentage Shares of Economic Sectors in the Total Value of Exports, Papua New Guinea
(2004–2006 average values)



Source: Bank of PNG in Allen, M., R.M. Bourke, and A. McGregor. 2009. Part 5. Cash Income from Agriculture. In Bourke, R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea*. Canberra: The Australian National University Press.

Figure A3.2 Percentage Shares of Various Agricultural Commodities in the Total Value of Exports, Papua New Guinea
(2004–2006 average values)



[a] Includes tinned tuna, tinned beef, processed tea and coffee, spices, and minor commodities, such as artifacts, crocodile skins, and butterflies.
Source: Bank of PNG in Allen, M., R.M. Bourke, and A. McGregor. 2009. Part 5. Cash Income from Agriculture. In Bourke, R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea*. Canberra: The Australian National University Press.

trochus shell, prawns, and tuna were additional commodities exported from PNG (Bourke et al. 2009).

More recent estimates from the Food and Agriculture Organization (2011) show that palm oil, coffee, and cocoa beans were the top three agricultural exports based on average values for 2000–2009 (Table A3.5).

Table A3.5 Volume and Value of Top Five Agricultural Exports, Papua New Guinea
(2000–2009 average values)

Commodity	Volume (metric tons)	Value ($'000s)
Palm oil	357,719	177,867
Coffee, green	61,872	114,731
Cocoa beans	47,317	83,081
Coconut (copra) oil	43,852	26,628
Palm kernel oil	29,085	18,316

Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Among the cereal crops, rice and wheat are considered of utmost importance to the PNG diet. From 1990, an average of 152,000 tons of rice and 117,000 tons of wheat were imported per year (Bourke et al. 2009). Rice imports further increased to 184,000 tons in 2006; the wheat milled produced flour for bread, biscuits, and instant noodles. The top five imported agricultural commodities are presented in Table A3.6. Detailed import volume and value of other major commodities are presented in Table A3.7. Most of these imported foods come from Australia or New Zealand (Bourke et al. 2009). From early 2000, the importation of potatoes declined in response to production in the highlands; however, the infestation of potato late blight disease resulted in reduced local production and rising imports from 2003 (Bourke et al. 2009).

Since tuna is a highly migratory species, fishing fleets move among fishing areas in the Pacific. Consumer preferences and purchasing power dictate the type of imported fish for consumption (Bourke et al. 2009). PNG favors cold water mackerel because it is cheaper than other imported fish. PNG imports low-value fish species such as tinned mackerel and barracuda fillets often used in fast food restaurants. Imported tinned fish is critical in the diets of urban poor people (Bourke et al. 2009). Around 10–25 kg of fish per person per year was consumed in PNG on average during 2007 (Bourke et al. 2009, Bell et al.

Table A3.6 Volume and Value of Top Five Agricultural Imports, Papua New Guinea (2000–2009 average values)

Commodity	Volume (mt)	Value ($'000s)
Rice, milled	139,922	55,529
Sheep meat	25,748	33,867
Wheat	138,513	28,406
Food, prepared, not otherwise specified	5,828	17,281
Buckwheat	30,191	8,613

Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Table A3.7 Volume and Value of Major Commodity Imports, Papua New Guinea, 2002–2004

Commodity	Volume (tons)			Value (Kina 000s)		
	2002	2003	2004	2002	2003	2004
Sheep meat	20,578	16,845	22,046	76,501	80,094	83,798
Beef	6,615	3,806	3,028	34,535	26,347	25,679
Offal	1,658	1,706	2,382	6,656	8,493	8,506
Pig meat	85	192	200	481	1,244	2,031
Other meat	77	92	118	302	608	1,037
Fish	7,986	9,324	8,903	26,919	24,673	26,652
Onions	1,263	977	955	2,171	2,355	2,294
Potatoes	161	735	502	471	2,118	2,469
Apples	624	674	428	3,489	3,330	2,806
Citrus	225	306	222	1,235	1,396	1,248
Other fruits and vegetables	784	772	805	5,297	5,250	4,845
Milk and other dairy products	5,920	5,938	4,196	32,273	26,161	31,373
Butter and dairy products	678	673	448	6,169	6,644	6,283

Source: Bourke. R.M. et al. 2009. Food Production, Consumption and Imports. In Bourke R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea*. Canberra: The Australian National University Press.

2009, Gillett 2009). Gibson (2000 as cited by Bell et al. 2009) estimated the average national fish consumption to be 28.1 kg/capita/year in urban areas and 10.2 kg/capita/year in rural areas in 2002–2003. Fresh fish represented around 76% and 77% of consumption in urban and rural areas respectively in 2002–2003 (Gibson 2000 as cited by Bell et al. 2009). These levels are relatively small compared with other Pacific countries (Bourke et al. 2009). The low level of protein in PNG diets causes stunting in children. Although people may prefer to add more fish protein to their diets, limited cash income often precludes their doing so (Bourke et al. 2009).

Major Crops

Oil Palm Fruit

Overview and History

Oil palm fruit is an important cash crop for export and domestic use. Oil palm (mainly processed in the form of palm oil) is a leading crop exhibiting steady growth despite its recent introduction into PNG. It has the highest volume of production among the country's other cash crops—i.e., coffee, copra, and cocoa. Palm oil even overtook coffee as PNG's most valuable agricultural export in 2000. Even without government assistance, the country's oil palm industry has continued to expand, as it conducts research and produces high-quality products. The PNG Oil Palm Research Association (OPRA), a nonprofit association incorporated in 1980, is the primarily performer of PNG's oil palm research and focuses only on the most prominent constraints to production.

The country's oil palm production is primarily based on nucleus estates with mills. Smallholders produce about one-third of the country's output. OPRA (2007) estimates that about 166,000 people (3% of the rural population) lived in households that grew oil palm (Allen et al. 2009). Although only a small share of the rural population grows oil palm, many obtain direct or indirect income from the industry through oil mills. In addition to providing income, the estates generate nonfinancial benefits including vital health and education services, road infrastructure, and housing.

Oil palm is entirely grown in lowland locations (up to an altitude of 200 m) and in areas where mean annual rainfall is in the range of 2,000 mm to 4,200 mm (Allen et al. 2009). Oil palm was first introduced to PNG in 1894–1995 by Germans on the Rai Coast (Sack and Clark 1979, quoted in Grieve 1986). Germans also established experimental plantings in the Northern (Oro) Province in the early 1920s (Landell Mills 1991). Nevertheless, commercial development of oil palm only began in 1967 following World Bank recommendations that oil palm be introduced through a nucleus estate–smallholder system in New Britain or Bougainville, with a view to diversifying PNG's agricultural economy and increasing its export earnings (IBRD 1965, Grieve 1986). Under this model, a commercially operated estate produces the oil palm and provides the market, processing, and technical services for smallholders who grow oil palm on adjacent land. The first scheme, New Britain Palm Oil Ltd. was established in 1967 at Hoskins in West New Britain Province (Koczberski, Curry, and Gibson 2001; Allen et al. 2009); it remains the country's largest oil palm development. Other large projects, which all operate on the same model, are located at Bialla in West New Britain, Popondetta in Oro Province, Gurney and Sagarai in Milne Bay Province, along the coast southeast of Kavieng in New Ireland Province, and in the Ramu and Markham valleys in Madang and Morobe provinces (Allen et al. 2009). Other developments operate under a variety of schemes with different components.[1]

Production

Oil palm fruit production averaged 1,169,278 mt from 1985 to 2007 (Table A3.8). Unsurprisingly, oil palm plantation production was higher (766,424 mt) than smallholder production. In the 1980s, oil palm production

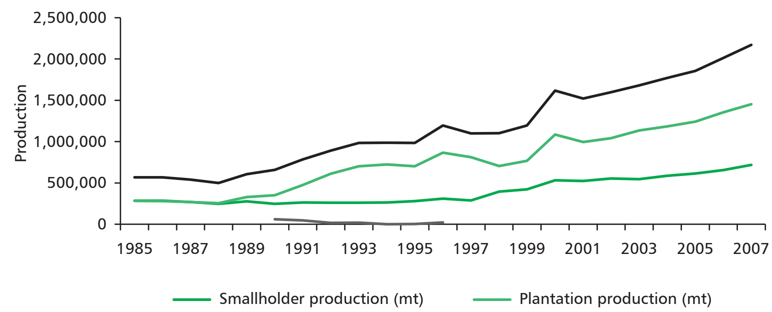
Table A3.8 Average Output and Annual Growth Rate of Output of Oil Palm Fruit by Scale of Production, Papua New Guinea, 1985–2007
(fresh fruit bunches)

	1985–2007	
Scale of Production	Average Output (bunches)	Annual Growth Rate (%)
Smallholder	395,252	4.40
Plantation	766,424	8.22
Total	1,169,278	6.62

Source: Data compiled by Allen, M., R.M. Bourke, and A. McGregor. 2009. Part 5. Cash Income from Agriculture. In Bourke, R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea*. Canberra: The Australian National University Press. Data for 1985–95 are from Oil Palm Industry Corporation; data for 1996–99 are from Palm Oil Producers Association (compiled by DAL); data for 2000–07 are from Ian Orrell, Oil Palm Research Association.

1 For example, in land settlement schemes, settlers are granted 99-year leases over blocks of at least 6 ha of land purchased from customary owners (Allen et al. 2009).

Figure A3.3 Trends in Oil Palm Fruit Production by Scale of Producer, 1985–2007 (fresh fruit bunches)



Source: Data compiled by Allen, M., R.M. Bourke, and A. McGregor. 2009. Part 5. Cash Income from Agriculture. In Bourke, R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea*. Canberra: The Australian National University Press. Data for 1985–95 are from Oil Palm Industry Corporation; data for 1996–99 are from Palm Oil Producers Association (compiled by DAL); and data for 2000–07 are from Ian Orrell of the Oil Palm Research Association.

was almost evenly split between smallholders and large-scale plantations (Figure A3.3), but plantation production began to rise rapidly in the early 1990s with the establishment of nucleus estate schemes in Milne Bay and New Ireland provinces that have relatively insignificant smallholder components (Allen et al. 2009). From 1985 to 2007, oil palm production grew by 6.62% annually; plantation production grew at 8.22% per year, while smallholder production grew by 4.40% per year. In 2007, plantations contributed two-thirds of total oil palm fruit production.

Productivity performance tends to be weaker for smallholders compared with plantations. Allen et al. (2009) note that while yield calculations from total production and total area planted may be underestimated (since data on area planted include both mature and immature palms), it seems that smallholder yields (12.4 mt per hectare [ha]) are considerably lower than those for plantations (20.7 mt/ha). Smallholder oil palm producers face a number of productivity challenges, including wasting of around 70% of loose fruit, having poor crop management, being unable to save consistently and hence invest in farm inputs, and experiencing shortages of farm labor (World Bank and IFC 2010). Extension services provided to smallholders are also limited.

While a public-sector smallholder extension service, the Oil Palm Industry Corporation (OPIC), exists, it is underfunded and low-functioning. Since OPIC is completely reliant on levies paid by smallholders and a voluntary matching payment by private milling companies, its resources are limited. Coupled with weak governance and management, its capacity to provide effective extension services to smallholders is inadequate. In the Hoskins and Popondetta nucleus estate schemes, smallholders particularly encounter land disputes that inhibit replanting, and promote rental arrears and a view that replanting is unnecessary (Koczberski, Curry, and Gibson 2001).[2]

2 The World Bank recognized the importance of assisting smallholders and has funded a 5-year project—the PNG Smallholder Agriculture Development Project—which aims to increase smallholder oil palm productivity, improve local governance through greater community oversight, and increase overall economic activity in the project areas of Oro and West New Britain

Table A3.9 Oil Palm Output by Province, Papua New Guinea, 2006
(metric ton)

Province	Output	
	Metric Ton	% of Total
Milne Bay	229,956	12
Oro	311,248	16
New Ireland	122,651	6
West New Britain	1,315,582	66
Total	**1,979,437**	**100**

Source: Papua New Guinea Department of Commerce and Industry. 2008. *Statistical Digest.* pp. 1–125.

As of 2006, oil palm was grown in four PNG provinces: Milne Bay, Oro, New Ireland, and West New Britain (Table A3.9). In 2006, West New Britain was the leading producer of oil palm, contributing 66% to total production.

Trade

Oil palm is processed in PNG to derive (crude) palm oil, palm kernel oil, refined palm oil, and palm kernel expellant. Of these, crude palm oil is the most important in terms of export volume and value. From 1990 to 2009, oil palm exports averaged 287,461 mt, with a value of K325.725 million. In the same period, the volume of oil palm exports grew by 4.93% per year, while its value rose by 17.74% per year (Table A3.9). This can be attributed to expansion in both smallholder and plantation production. Given the growth in exports, palm oil has become PNG's most important agricultural export. As mentioned, the contribution of oil palm exports to the economy only started in the 1970s, but in 2000 it replaced coffee as the most valuable agricultural export (Table A3.10). The average contribution of oil palm exports to the total value of agricultural exports rose from 5% in 1971–1980, to 30% in 2004–2006 (compared with 43% to 26% for coffee). The volume of oil palm exports is expected to continue to increase in the coming years, based on expanded activities by the milling companies and a new oil palm development by Ramu Sugar Ltd. (PNG MAL 2007a).

Sweet Potato

Overview and History

Sweet potato accounts for 64% of staple food crop production by weight and 63% of food energy production (Bourke and Vlassak 2004). The contribution of other staple food crops is less than 10% of the total national production by weight or food energy. Sweet potato is particularly important in the highlands, where the crop contributes to the food security and cash incomes of more than 90% of the highland population. Sweet potato is a source of cash income

provinces. Strategies include (i) enhancing smallholder productivity by infill-planting of new smallholder village oil palm along existing access roads, upgrading provincial access roads, and establishing sustainable financing for road maintenance, and strengthening of oil palm extension services; (ii) promoting local governance and community participation to support improved provision of local services and infrastructure through participatory processes; and (iii) supporting OPIC (the implementing agency) and the smallholder sector, through training, research, and studies.

Table A3.10 Percentage Shares of Palm Oil, Coffee, and Cocoa in the Total Value of Agricultural Exports, Papua New Guinea, 1951–2006

Years	Percentage Share in Total Value of Agricultural Exports (%)			
	Palm oil	Coffee	Cocoa	Copra
1951–1960	–	2	7	79
1961–1970	–	24	23	46
1971–1980	5	43	25	22
1981–1990	13	47	19	16
1991–2000	31	42	10	14
2001–2006	39	31	20	7
2004–2006	30	26	14	6

– = no data available.
Source: Allen, M., R.M. Bourke, and A. McGregor. 2009. Part 5. Cash Income from Agriculture. In Bourke, R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea*. Canberra: The Australian National University Press.

because surpluses can be sold in domestic markets. It is also significant in rural communities where its foliage is fed to pigs (the most important domestic animal), is sometimes used as a green manure in composted mounds, and is occasionally used by people as a green vegetable (Bourke 2009).

Sweet potato first came to mainland PNG about 300–350 years ago from eastern Indonesia, moving from the Sepik Basin into the Central Highlands. In the Islands Region of PNG, it was introduced after 1800 and more broadly after 1870. The crop became the most important staple food in the central highlands, and by the time European explorers entered the highland valleys in the 1920s, sweet potato dominated PNG agriculture (Bourke 2001). In PNG, sweet potato is grown in low- and high-altitude ecogeographical environments, and over a wide range of soil types and farming systems (Bourke 1985), and by about 99% of the country's rural people (with the exception of some in areas of East Sepik and Western provinces, where land is subject to regular inundation). Given its importance as a food crop, various varieties have been developed to improve productivity. In recent years, PNG's National Agricultural Research Institute (NARI) released 79 sweet potato varieties suitable for normal lowland conditions. All the cultivars have acceptable yields with good market and consumer appeal (NARI 2010). With the release of these cultivars, farmers in the lowland regions will have a wider selection of superior varieties to choose from to improve their food security and incomes. Of the 79 lowland varieties, four are drought tolerant, three mature in 3 to 4 months, and one matures in 4 to 5 months. NARI released five early maturing (5 months), drought-tolerant varieties for the highlands and another 12 early maturing varieties for high altitude areas. Traditional highland varieties take 9 to 12 months to mature, so the new varieties enhance food security, even after frost, which frequently occurs in these areas.

Production

During 1990–2009, sweet potato production in PNG averaged 478,874 mt (Table A3.11), whereas area harvested averaged 102,843 ha and yields averaged

Table A3.11 Growth Rate of Average Output, Area Harvested, and Yield of Sweet Potato, Papua New Guinea, 1980–2009

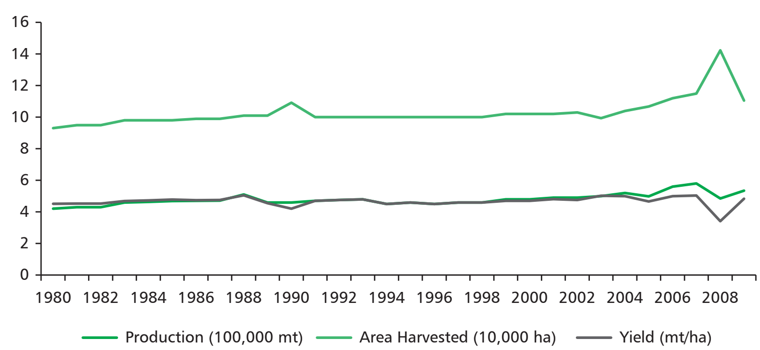
Item	1980–2009	Growth Rate (%) 1980–1990	1990–2000	2000–2009	1980–2009
Output (mt)	478,874	1.39	0.13	1.31	0.83
Area Harvested (ha)	102,843	1.20	(0.21)	2.62	0.98
Yield (mt/ha)	4.67	0.23	0.32	(1.01)	(0.08)

ha = hectare, mt = metric ton, ( ) = negative value.
Source: Compiled by authors from FAOSTAT data.

4.26 t/ha. Sweet potato production generally increased between 1980 and 2009 (Figure A3.4). production in 2009 (534,085 mt) was about 27% higher than in 1980 (420,000 mt). Production grew by 0.83% annually from 1980 to 2009. The total area harvested to sweet potato increased at an average annual rate of 0.98%, but yield declined by 0.08% per year.

From 1980 to 1990, sweet potato production grew at a rate of 1.39% per year, and both area harvested and yield followed an upward trend. The area harvested to sweet potato grew at a rate of 1.20% per year, while yield was growing at a rate of 0.23% per year. In 1990–2000, sweet potato production grew at a slower rate of only 0.13% per year; area harvested declined by 0.21% per year, while yield was growing at 0.32% per year. From 2000 to 2009, production grew relatively faster at a rate of 1.31% per year. But although area harvested grew (2.62% per year), yield growth declined (by 1.01% per year). Overall growth in sweet potato production has generally been due to growth in area harvested. Sweet potato yields have either declined or been virtually static at times because many of the country's agricultural systems are unstable due to land-use intensification (O'Sullivan et al. 1997). Hartemink et al. (2000) found that declining sweet potato yields in PNG's humid lowlands may be attributed to high nematode infestation, accompanied by an increase in vine damage by sweet potato weevils and declining soil fertility.

Figure A3.4 Trends in Area Harvested, Production, and Yield of Sweet Potato, Papua New Guinea, 1980–2009



ha = hectare, mt = metric ton.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Sweet potato is grown in all provinces of PNG, but the major producers are in the five highlands provinces: Southern Highlands, Eastern Highlands, Western Highlands, Enga, and Simbu (Table A3.12). In 2000, Southern Highlands contributed 22% to total estimated sweet potato production, Eastern Highlands and Western Highlands accounted for 16% and 15% respectively, Enga province contributed 12%, and Simbu contributed 10%. Sweet potato is gradually replacing taro in the coastal provinces of Manus and Bougainville due to problems with pests (PNG MAL 2007a).

Consumption

Strong demand for sweet potato exists in both rural and urban areas. The vegetable is consumed by about two-thirds of the rural population and one-third of the urban population (PNG MAL 2007a). The importance of sweet potato to rural households was confirmed by Gibson (2001a), who found that it accounted for the largest average share of household budgets among all food items (11.97%). It was also found that a 10% increase in household income causes a 7% increase in the quantity of sweet potato consumed by rural households. Moreover, among food items, sweet potato has the highest

Table A3.12 Estimated Sweet Potato Output by Province, Papua New Guinea, 2000

Province	Output (metric ton)	Percentage Share in Total Output (%)
Western	6,863	0.24
Gulf	20,308	0.71
Central	49,267	1.72
Milne Bay	43,831	1.53
Oro	53,309	1.86
Southern Highlands	619,561	21.57
Enga	340,745	11.86
Western Highlands	425,964	14.83
Simbu	294,708	10.26
Eastern Highlands	469,939	16.36
Mo robe	194,695	6.78
Madang	77,746	2.71
East Sepik	26,175	0.91
Sandauri	25,036	0.87
Manus	4,477	0.16
New Ireland	38,891	1.35
East New Britain	42,642	1.48
West New Britain	45,103	1.57
Bougainville	92,591	3.22
Total	**2,871,850**	**100.00**

Source: Bourke, R.M., and V. Vlassak. 2004. *Estimates of Food Crop Production in Papua New Guinea.* Land Management Group, Research School of Pacific and Asian Studies. Canberra: The Australian National University.

marginal share of total expenditure for rural households (8.78%).[3] Thus, it was concluded that future research payoff is likely to be greatest from sweet potato. Indeed, sweet potato continues to be a vital staple crop in PNG as evidenced by the increase in annual per capita consumption from 1996 of 260 kg/person/yr in 1996 to 416 kg/person/yr in 2006 (Bourke et al. 2009).

Coconut

Overview and History

The coconut industry is vital to many Papua New Guineans. It provides employment for 309,417 households (2000 National Population Census), representing about 57% of all households in the coconut-growing regions, and 31% of all households nationally (PNG MAL 2007a). About 2 million people are directly or indirectly involved in the coconut industry in PNG.

Coconut cultivation in PNG began long before European settlement. However, its cultivation for commercial purposes only began in the 1880s in the Gazelle Peninsula area of East New Britain Province as coconut meat dried to copra, which was initially in demand for soap manufacture and later for margarine production (Allen et al. 2009). Given high copra prices during World War I, plantation development expanded throughout the country. Commercial coconut planting in the coastal areas of Southern Region began in 1907 after Australia took over administration of Papua from the British Colonial Office. During the first decades of the 20th century, the production and export of copra quickly grew to become the country's most important export commodity during that period. About 90% of all exports in 1921–1922 were copra, but its production and export considerably declined during World War II due to very low prices and disruption of trade and commerce.

In the early 1950s, production and exports returned to pre-war levels, with copra exports accounting for 70% of total exports. Nevertheless, the relative importance of copra and copra oil exports declined greatly, primarily due to development of the coffee, cocoa, and mineral industries in the 1950s, 1960s, and 1970s.

Until the late-1950s, most of the country's coconut (and copra) was produced by plantations, with smallholders only producing an estimated 20% of copra in 1954–1955. As the Australian administration adopted policies to develop smallholder and village copra production in the 1950s, the share of smallholder copra production began to increase. Nowadays, the smallholder sector dominates copra production (70%–85% of total production). The plantation sector's share declined because it was adversely affected by extreme fluctuations in world market prices and rising costs of inputs, particularly fuel and labor (Allen et al. 2009). It was also affected by land tenure uncertainties, particularly as a result of the Plantation Redistribution Scheme of the 1970s, which bought back plantation land from owners and returned it to the previous customary owners. Production of large-scale plantations also declined due to aging palms with reduced productivity (about 50% of plantation-sector palms are 70–80 years old) (Allen et al. 2009).

As the coconut industry continues to contribute to the national economy, primarily through the provision of employment and export

3 The marginal share of total expenditure, or marginal budget share, is the additional amount a household spends on an item when it has an extra K100 of available income (Gibson 2001).

earnings, developing and supporting the coconut industry is a priority for the government. In the National Agricultural Development Plan (NADP) of 2007–2016, the government aims to provide national leadership to revive the coconut industry. Among the strategies intended to achieve this goal are leading the development of coconut-based farming systems in the districts, facilitating the development of coconut replanting programs in the provinces, coordinating and facilitating the redevelopment of abandoned coconut plantations in the provinces, linking coconut development projects to a clean development mechanism policy, and coordinating peer reviews and inter- and intra-institutional cooperation and collaboration. The government also seeks to mobilize and empower stakeholders, investors, smallholders, and plantations to enhance production of high-value coconut products for niche markets, thereby promoting the establishment of farmer cooperatives in districts, establishing market networks in the districts, facilitating capacity building across the industry, and facilitating and providing quality extension services. Promoting downstream processing for value addition in the coconut industry is also an objective. Strategies mentioned are conducting feasibility studies in relevant aspects of downstream processing and developing appropriate coconut downstream processing technologies, and promoting small-scale downstream processing enterprises in the districts. The government is allocating a total of K78 million to coconut development for the 2007–2016 period.

Production

Coconut production averaged 821,100 mt during 1980–2009 (Table A3.13). For the same period, area harvested to coconut averaged 233,467 ha for an average yield of 3.53 tons/ha. During 1980–2009, coconut production was highly erratic (Figure A3.5), growing by only 0.17% annually. Yields grew at a miniscule rate of 0.42% per year, while the area harvested to coconut fell by 0.25% annually. Coconut production in 2009 (930,000 mt) was only 5% higher than its 1980 level (883,000 mt). Most of the coconut trees in the country are well past their peak for contributing to low production, and while some replanting was done in the early 1980s, the variety of hybrid coconut that was planted was susceptible to the Scapanes beetle, and nearly all of the newly planted palms died upon reaching maturity (FAO, NARI, and World Bank 2002).

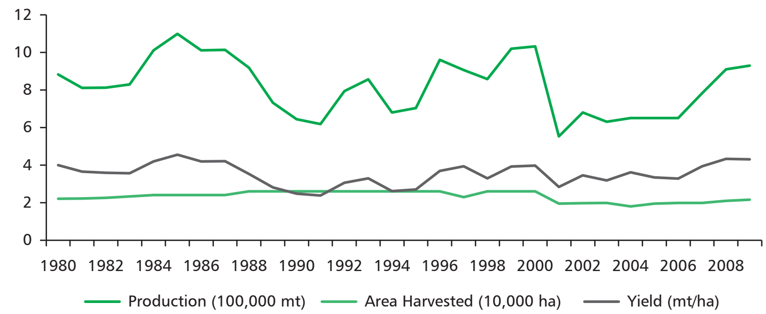
Coconut production generally declined between 1980 and 1990 (at 1.10% per year). The area harvested to coconut grew by 1.94% per year during

Table A3.13 Level and Growth Rate of Average Output, Area Harvested, and Yield of Coconut, Papua New Guinea, 1980–2009

		Growth Rate (%)			
Item	1980–2009	1980–1990	1990–2000	2000–2009	1980–2009
Output (mt)	821,100	(1.10)	4.44	2.12	0.17
Area Harvested (ha)	233,467	1.94	0.00	(0.60)	(0.25)
Yield (mt/ha)	3.53	(2.98)	4.44	2.95	0.42

ha = hectare, mt = metric ton.
Source: Compiled by authors from FAOSTAT data.

Figure A3.5 Trends in Area Harvested, Production, and Yield of Coconut, Papua New Guinea, 1980–2009



ha = hectare, mt = metric ton.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

the period, but coconut yields fell at a rate of 2.98% per year. From 1990 to 2000, coconut production posted an upward trend, growing by 4.44% per year. Coconut yields also grew at a rate of 4.44% per year, while the area harvested was stagnating. From 2000 to 2009, coconut production continued to increase, but at a slower rate of about 2.12% per year. During this period, area harvested to coconut declined at a rate of 0.60% per year, while coconut yields grew at a rate of 2.95 annually. Coconut production generally declined between 1985 and 1995 (Figure A3.5). This can be attributed to very low prices of copra and coconut oil (Allen et al. 2009). With low prices of these commodities in the international market, farmers (and plantations) have less incentive to increase production to process copra.

In the mid-1990s, world prices for copra and coconut oil began to rise, so coconut production also rose. However, with the recovery in prices, the Copra Marketing Board (CMB), which regulates the marketing and export of copra in PNG, made costly and often unwise investments, and maintained excessive overhead (FAO, NARI, and World Bank 2002). Thus the industry had little protection (in terms of government price assistance) as the world price of copra collapsed in the late-1990s. This had a significant effect on coconut production, such that in 2001, it reached a 2-decade low of 553,000 mt. The collapse of the world price, together with CMB's high-cost structure, high debts, and related administrative problems, resulted in producer prices being further depressed. In 2007 and 2008, world prices of copra and copra oil increased.

Due to the lack of coconut production data by province, data on copra production by province was assessed to provide a geographical picture of the country's coconut industry. The provinces of East New Britain, Madang, and Bougainville (formerly North Solomons) are the major copra producing areas in PNG. In 2006, East New Britain contributed 42% to total copra production, Madang accounted for 24%, and Bougainville (North Solomon) accounted for 13% (Table A3.14). East New Britain province is the major smalholder copra producing area, while Madang is a main producer of plantation copra (Allen et al. 2009).

Table A3.14 Copra Output by Province, Papua New Guinea, 2006

Province	Output (mt)	% of Total Output
Central	1	0.001
Milne Bay	1,488	1.48
Morobe	533	0.53
Madang	23,751	23.70
East Sepik	673	0.67
Manus	140	0.14
New Ireland	10,431	10.41
East New Britain	42,224	42.13
West New Britain	7,845	7.83
North Solomons	13,136	13.11
Total	**100,222**	**100.00**

mt = metric ton.
Source: Papua New Guinea Department of Commerce and Industry. 2008. *Statistical Digest*. pp. 1–125.

Consumption

Coconut is an important food source in PNG and is consumed by 30% of the population. Specifically, about 34% of the urban population and 28% of the rural population consumed coconut for food in 1996 (PNG Household Survey 1996 as cited by Gibson 2001a). While a significant volume of coconut is also fed to pigs or used to produce copra in some coastal locations, the only available data were on coconut production for human consumption (Table A3.15). As of 2000, the highest production of coconut for human consumption was in East Sepik (18%), followed by Madang (14%), Milne Bay (10%), Bougainville (9%), and East New Britain (9%) provinces. While a significant share of the country consumes coconut, estimated annual per capita consumption has declined from 44 kg/person/year in 1996 to 20 kg/person/year in 2006 (Bourke et al 2009).

Trade

Coconut is PNG's fourth most important agricultural export commodity, and copra and copra oil are the main coconut products exported. Over the years, export earnings from copra and copra oil have fluctuated because production (and consequently volume exported) is sensitive to variations in export prices and competition from other vegetable oils in international markets (PNG MAL 2007a; Allen et al. 2009). From 1990 to 2009, copra exports averaged 44,190 mt, with a value of K24 million, while copra oil exports averaged 43,395 mt, with a value of K61 million (Table A3.16). While the average volume of exports was higher for copra than for copra oil during 1990–2009, it is notable that the volume of copra exports declined (at 5.09% per year), while copra oil exports rose (2.56% per year).

The share of copra being domestically processed into copra oil has steadily risen since the 1960s (Allen et al. 2009), causing the volume of exported copra to decrease. There were notable declines in the volume of copra exported between 2000 and 2003, which can be attributed to declining

Table A3.15 Estimated Coconut Output for Human Consumption, Papua New Guinea, 2000

Province	Output (mt)	Percent share of Total Output (%)
Western	4,312	4
Gulf	2,857	3
Central	5,142	5
Milne Bay	9,795	10
Oro	1,549	2
Southern Highlands	449	0.4
Morobe	5,704	6
Madang	14,091	14
East Sepik	17,806	18
Sandauri	8,133	8
Manus	1,956	2
New Ireland	5,612	6
East New Britain	8,847	9
West New Britain	5,101	5
Bougainville	9,575	9
Total	**100,930**	**100**

Source: Bourke, R.M., and V. Vlassak. 2004. *Estimates of Food Crop Production in Papua New Guinea.* Land Management Group, Research School of Pacific and Asian Studies. Canberra: The Australian National University.

production as a result of significant declines in export prices. Additional contributing factors include deteriorating infrastructure and rising transport costs, fewer purchasing depots,[4] and a switch from exporting copra to processing it into oil in-country (Allen et al. 2009). In 2009, the value of copra oil exports (K87.9 million) was more than seven times that of copra exports (K12.4 million).

Rice Paddy

Overview and History

Rice is becoming an important staple food in PNG. Its popularity is increasingly due to its long storage life, ease of transporting and cooking, and potential for animal feed (PNG MAL 2007a). Only about 2% of rice demand is met through domestic production, and most of the country's rice production is non-irrigated.

4 Previously, the Kokonas Indastri Koporesen (KIK, formerly the Copra Marketing Board) purchased copra from growers at fixed prices at depots and subdepots, but between 2001 and 2005, the number and geographic extent of active purchasing depots significantly contracted, from 22 depots in 11 provinces in 2001, to 15 depots in 10 provinces in 2002, and 10 depots in 9 provinces in 2005. This reflects the shift in copra purchasing activity from KIK to the copra oil mills. Currently, most copra in the Islands Region is purchased by Coconut Products in Rabaul, which disadvantages smallholder producers who do not have access to the mills and who were previously serviced by KIK.

Table A3.16 Volume and Value of Copra and Copra Oil Exports, Papua New Guinea, 1990–2009

Year	Copra Exports		Copra Oil Exports	
	Volume (mt)	Value (Kina '000)	Volume (mt)	Value (Kina '000)
1990	55,300	8,700	34,800	11,600
1991	44,000	5,200	33,200	12,800
1992	47,500	11,800	34,800	24,200
1993	59,000	14,200	45,500	19,600
1994	50,300	14,700	34,700	20,100
1995	64,200	27,400	33,100	29,700
1996	99,200	49,000	49,600	51,400
1997	90,300	47,200	48,600	51,100
1998	58,100	38,800	53,200	69,700
1999	63,500	66,500	50,300	95,800
2000	67,200	59,900	48,000	65,800
2001	46,400	15,500	27,100	27,300
2002	15,800	10,700	28,200	33,300
2003	8,400	6,500	47,700	67,400
2004	19,200	17,200	45,100	81,000
2005	22,300	17,300	54,400	93,700
2006	12,700	8,300	41,500	60,400
2007	12,600	10,300	51,300	121,900
2008	32,600	45,100	62,000	202,700
2009	15,200	12,400	44,800	87,900
Average	44,190	24,335	43,395	61,370
Annual growth (%)	(5.09)	5.87	2.56	13.41

mt = metric ton, ( ) = negative value.
Source: Bank of Papua New Guinea Quarterly Economic Bulletin Statistical Tables http://www.bankpng.gov.pg/

Rice was first introduced before 1900 by Catholic missionaries in the Central and Sandaun provinces, and probably in other areas (Bourke et al. 2009). Similarly, in inland Finschhafen in the Sarawaget Mountains of Morobe Province, Lutheran missionaries initiated rice cultivation in the early 1900s. At present, this is the only place in PNG where rice has become a "traditional" crop. After 1918, rice growing in Papua, particularly the Southern Region, was a required village activity under the Native Plantation Ordinance (1918). Indian instructors were brought over by the Papuan colonial administration to help establish a fully equipped rice mill so that the territory could be self-supporting in rice. Thereafter, various attempts[5] were made to promote rice cultivation in different parts of the country.

5 See Bourke et al 2009 for a detailed history of rice cultivation in various parts of PNG.

Production

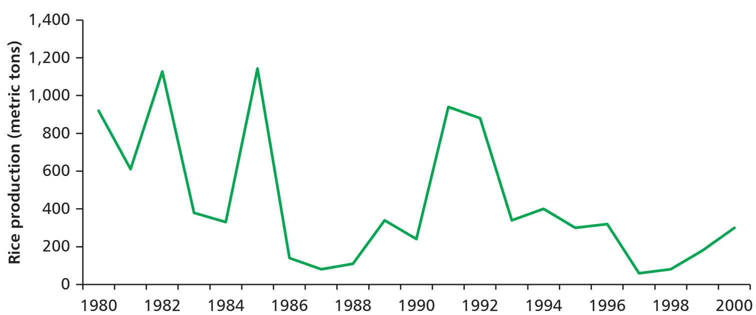
Rice production averaged 439 mt per year during 1980–2000 (Table A3.17), but production generally fluctuated (Figure A3.6). On average, rice production declined by 11.1% annually during that period. Rice production estimates in 2000 (300 mt) are about 67% lower than the 1980 levels (27,155 mt). Bourke et al. (2009)[6] notes that production increased in some locations from 2000, because imported rice became more expensive due to the devaluation of the Kina. They add that the peak of recent expansion in rice cultivation occurred in about 2001–2003, and that production appears to have declined since then. Rice production in Madang Province was about 80 metric tons (mt) in 2003, 60 mt in 2004, and 40 mt in 2005. Little rice was cultivated in the highlands by 2005. The Trukai Rice depot at Erap in the Markham Valley was only able to buy 4 mt of locally grown rice in 2004, and 7 mt in 2005. According to Bourke et al. (2009), while the government at times claims significant local production, these estimates are considered to be politically

Table A3.17 Estimated Average Output and Growth Rate of Rice Production, Papua New Guinea, 1980–2000

Item	1980–2000
Production (metric ton)	439
Average annual growth rate (%)	(11.1)

Source: Authors' calculations; basic data compiled by Bourke. R.M. et al. 2009. Food Production, Consumption and Imports. In Bourke R.M. and T. Harwood, eds. Food and Agriculture in Papua New Guinea. Canberra: The Australian National University Press.

Figure A3.6 Trends in Estimated Rice Output, Papua New Guinea, 1980–2000 (metric tons)



Source: Compiled by Bourke. R.M. et al. 2009. Food Production, Consumption and Imports. In Bourke R.M. and T. Harwood, eds. Food and Agriculture in Papua New Guinea. Canberra: The Australian National University Press; data for 1980–90 are from Department of Agriculture and Livestock (1992: 51); data for 1991–2000 are from Blakeney, M., and R. Clough. 2001. An Assessment of Grain Production and Imports in PNG, 1975–2000. In Bourke, R.M., M.G. Allen, and J.G. Salisbury, eds. *Food Security for Papua New Guinea*. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. ACIAR Proceedings No. 99. Canberra: Australian Centre for International Agricultural Research. pp. 23–29.

6 While Bourke et al. (2009) mentions the perceived trend from 2001 to 2005, no annual national rice production data for these years were presented.

motivated and not realistic. In PNG's NADP, 2007–2016, domestic rice production in 1998 was estimated to be 500 mt, and more than 20,000 mt in 2005.

Consumption

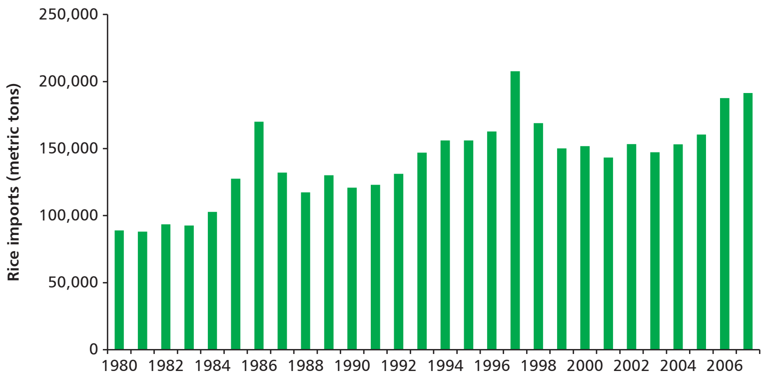
An estimated 35% of the Papua New Guineans eat rice, and it is consumed by both urban and rural people alike. Based on the 1996 PNG Household Survey, about 87% of the urban population consumes rice, and 26% of rural people eat rice (as cited by Gibson 2001a). On average, rice accounted for the largest share of household budgets (among food items) for urban households (5.26%), but it represented a lesser share in rural households (3.93%) (Gibson 2001a). As previously discussed, rural households spend the largest share of their food budgets on sweet potato (11.97%). Bourke et al. (2009) found that imported rice only provides an estimated 9% of the country's food energy; locally produced staples (mainly sweet potato) provide an estimated 68% (Bourke et al. 2009). Annual per capita consumption of imported rice in PNG is about 30 kg/person/year, while annual per capita consumption of root crops, bananas, and sago is over 500 kg (Bourke and Harwood 2009). It is notable that annual per capita consumption of imported rice virtually remained the same during 1996–2006 (31 kg/person/year in 1996 compared with 30 kg/person/year in 2006). This plateau may be attributable to a significant increase in the price of rice since 1997, caused by the fall in the value of the kina (Bourke et al 2009).

Trade

Rice imports in PNG generally increased from 1980 to 2007 (Figure A3.7), represent a growth rate of 2.8% per year. This increased volume is mainly due to population growth (Bourke et al. 2009). From 1980 to 2007, rice imports averaged 141,253 mt (Table A3.18). Notably, a significantly high volume of rice was imported in 1997 (207,690 mt) in response to reduced local production due to the droughts and frosts that occurred that year. After 1998, rice imports fell and hovered around 151,000 mt per year between 1999 and 2005. A notable increase occurred in 2006 (184,000 mt) because of increased sales in the highlands and in Port Moresby, probably due to the expanded incomes of coffee producers, and an improved national economy (Bourke et al. 2009).

The average growth rate of rice imports has fallen behind the population growth rate in recent years (Bourke et al. 2009). The slowing of rice imports can be attributed to the devaluation of the kina in 1997, which resulted in an increase in the price of imported rice. According to PNG MAL (2007a), interest in growing rice has increased since the kina was depreciated. As the price of imported rice has increased, the government has continued to pursue a rice import-substitution policy. However, as noted by Gibson (1992), as long as PNG's domestic rice industry cannot deliver prices comparable with the world market, the majority of PNG households would still be worse off because local rice would cost more than imported rice.

Figure A3.7 Trends in Rice Imports, Papua New Guinea, 1980–2007
(metric ton)



Source: Compiled by Bourke. R.M. et al. 2009. Food Production, Consumption and Imports. In Bourke R.M. and T. Harwood, eds. Food and Agriculture in Papua New Guinea. Canberra: The Australian National University Press.; data for 1980–99 are from Gibson. 2001a. Food Demand in the Rural and Urban Sectors of PNG. In Bourke, R.M., M.G. Allen, and J.G. Salisbury, eds. *Food Security for Papua New Guinea*. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, PNG University of Technology, Lae, 26–30 June 2000. ACIAR Proceedings No. 99, App. C); data for 2000–2007 are from Trukai Industries Ltd., Port Moresby.

Table A3.18 Average Volume and Growth Rate of Rice Imports, Papua New Guinea, 1980–2007 (metric tons)

Item	1980–2007
Rice imports (metric ton)	141,253
Average annual growth rate (%)	2.8

Source: Authors' calculations; basic data compiled by Bourke. R.M. et al. 2009. Food Production, Consumption and Imports. In Bourke R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea*. Canberra: The Australian National University Press.

Fisheries

Among the Pacific Island countries, PNG has the largest fisheries zone at 2.4 million km^2 (Allen, Bourke, and McGregor 2009). Coastal areas and offshore islands offer abundant and diverse marine resources. In addition to the marine environment, extensive inland river systems can be found in East Sepik and Western provinces.

Some of the fishing activities in the mainland and islands are gleaning on reef flats; spear-fishing; and shallow-water handlining using dug-out canoes, outrigger canoes, outboard-powered fiberglass dinghies, and netting and trapping in large rivers (Allen, Bourke, and McGregor 2009). Netting barramundi, catfish, and shark are some of the fishing activities in the swampy coastal areas. A commercial lobster fishery can be found in the southern part of the Western province. Bêche-de-mer and trochus shell are important invertebrates for commercial purposes. Giant clams are harvested mainly for subsistence. Milne Bay Province supports pearl farming, with juvenile oysters coming from Samarai Islands. Prawn trawling is done in the Gulf of Papua.

Categories of Fisheries

PNG operates six categories of the fisheries: (i) coastal commercial fisheries, (ii) coastal subsistence fisheries, (iii) offshore locally based fisheries, (iv) offshore foreign-based fisheries, (v) freshwater fisheries, and (vi) aquaculture. Table A3.19 presents a brief description of each category, mainly adapted from Gillett (2009).

FAO (2011) estimates total fish production in PNG to be 230,103 t in 2009, mainly supplied by capture fisheries. Aquaculture was introduced in 1999 through the farming of genetically improved farmed tilapia, which was released to fish farmers in 2002. Hence, low production of farmed tilapia at this point may be due to technical issues such as limited supply of inputs (fish feed and high-quality fingerling). Capture production doubled from 55,874 t in 1999 to 110,108 t in 2000. Note also that since 2000, capture fisheries have been growing.

Table A3.19 Volume and Value of Fish Harvest by Fisheries Subsector, Papua New Guinea, 2007

Fishery	Volume (ton)	Value (Kina)
Coastal commercial	5,700	80,000,000
Coastal subsistence	30,000	105,000,000
Offshore locally based	256,397	1,024,089,635
Offshore foreign-based	327,471	1,143,631,355
Freshwater	17,500	49,000,000
Aquaculture	200	2,000,000
Total	**637,268**	**2,403,720,990**

Source: Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB.

Coastal Commercial Fisheries

Important export fisheries commodities include bêche-de-mer; shell products, such as trochus and mother of pearl; shrimp; fish; and crab (Allen, Bourke, and McGregor 2009). The National Fisheries Authority (NFA), as reported by Gillett (2009), gave the following description of the status of PNG's coastal commercial fisheries: beche de mer production declined but with a rising value of K37 million for 679 t in 2006; production in lobster fisheries changed minimally, but prices have risen; prawn/shrimp production was at 400–1,300 t, and in 2004 the export value of about 600 t was $4 million; and trochus and pearl shell production is about equal, and prices are on the rise. Harvests of coastal reef fish and deepwater snapper had declined due to inefficient petrol-driven boats (i.e., fuel costs) and marketing system.

Coastal Subsistence Catch

The subsistence fisheries sector is not well documented in PNG despite being the most valuable component of the country's fishing industry by both volume and value (Allen, Bourke, and McGregor 2009). Almost 500,000 people participate in coastal (and inland) subsistence fisheries, resulting in a 25,000 t–50,000 t harvest of marine products yearly (Allen, Bourke, and McGregor 2009).

Gillett (2009) presented three estimates of annual coastal subsistence harvest in PNG: 20,588 t at $41,176,000 in the late-1980s to the early 1990s (Dalzell et al. 1996); 26,000 t (Preston 1996); and 26,000 at K52 million in the late-1990s (Gillett and Lightfoot 2002). A recent estimate that considered increasing human population and expansion of freshwater subsistence production reported a total of 47,500 t coastal subsistence fish harvests.

Offshore Locally Based Production

Offshore fisheries are an important contributor to fish exports. Major locally based commercial fisheries in offshore fishing areas in PNG predominantly focus on tuna and, to some extent, sharks (Allen, Bourke, and McGregor 2009). Tuna contributed about 14% to the total value of marine exports in 1996, rising to 75% in 2006 (Allen, Bourke, and McGregor 2009). Around 80% of the yellowfin and bigeye tuna caught was of export quality, and around 20% was for nonexport or the domestic market. The rising tuna catch and its value in fish exports (Table A3.20) resulted in establishment of the national fisheries policy framework (as articulated in the Fisheries Management Act 1998); the reform of the PNG's NFA; interventions of donor-funded projects; revisions in taxation regimes; development of the domestic tuna industry, including canning factories in Madan, Lae, and Wewak; and depreciation of kina (Allen, Bourke, and McGregor 2009).

Offshore Foreign-Based Fisheries

Offshore foreign-based tuna fisheries use purse-seiners (Kumoru 2008). Harvests have been increasing from 99.981 t in 2001 to 311,877 t in 2007 (FFA 2008, Bourke et al. 2009) with respective values of $83.52 million and $454.09 million (Table A3.21).

Table A3.20 Annual Volume and Value of Tuna Harvest of Locally-Based Offshore Fisheries, Papua New Guinea, 2001–2007

	2001	2002	2003	2004	2005	2006	2007
Purse seine					260		
Catch (t)	95,202	128,600	164,168	207,809	230,681	218,664	251,638
Value ($)	75,291,905	100,222,963	122,810,818	1,801,287,514	212,089,155	213,083,697	332,266,645
Longline							
Catch (t)	2,830	2,857	3,895	5,939	4,354	4,135	4,759
Value ($)	10,436,125	10,198,339	12,668,605	18,256,525	11,514,005	13,257,921	13,363,607

t = ton, $ = US dollar.

Notes: Longline catch has been increased by 30% and purse seine catch by 5%. Longline catch value has been reduced by 25% to obtain dockside tuna values rather than destination market values, and increased by 10% to account for the sale of bycatch; it is assumed that almost no purse seine catch is transshipped, so the Forum Fisheries Agency (FFA) figures are not adjusted for transport costs.

Sources: Forum Fisheries Agency (FFA). 2008. The Value of Western and Central Pacific Fisheries Commission (WCPFC) Tuna Fisheries. Honiara, Solomon Islands. Unpublished report, and consultant's estimate in Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB.

Table A3.21 Estimated Annual Volume and Value of Tuna Harvest of Offshore Foreign-Based Fleets, Papua New Guinea, 2001–2007

	2001	2002	2003	2004	2005	2006	2007
Catch (t)	99,981	93,958	263,273	208,175	175,528	265,199	311,877
Value ($)	83,524,215	77,168,612	208,164,010	189,712,193	166,877,298	266,008,242	454,088,920

t = ton, $ = US dollar.
Sources: Forum Fisheries Agency. 2008. The Value of Western and Central Pacific Fisheries Commission (WCPFC) Tuna Fisheries. Honiara, Solomon Islands. Unpublished report; Bourke. R.M. et al. 2009. Food Production, Consumption and Imports. In Bourke R.M. and T. Harwood, eds. Food and Agriculture in Papua New Guinea. Canberra: The Australian National University Press.

Freshwater

Commercial-scale freshwater fisheries are limited in PNG. A small barramundi (*Lates calcarifer*) fishery was found in south-flowing rivers, but the population of this fish has declined recently, and seasonal freshwater prawns were harvested at a maximum of 10 t/year (Coates 1996).

More than 80% of PNG's people live in inland areas without direct access to the sea (Gillett 2009). People living in highland areas face the challenge of poor freshwater fish stocks, but they still engage in fishing activities focusing on eel and other exotic species (Coates 1996).

Fish production from PNG's freshwater resources was estimated at 17,500 t, valued at K49 million in mid-2000 (Gillett 2009).

Aquaculture

Rural aquaculture was initiated in PNG in 1954 by the Highlands Aquaculture Development Centre under the Department of Agriculture, Stock, and Forestry (Smith et al. 2007). The main objectives of introducing aquaculture were, and remain, to increase protein content in the diets of the highlanders, and to increase their cash incomes and develop a new commercial industry for smallholder farmers (Smith et al. 2007).

Ero et al. (2011) reported the most common type of aquaculture to be pond culture, found in Morobe, Eastern Highlands, Chimbu, and Western Highlands Provinces. Tilapia and common carp are cultured in small, pond-based farms (Ero et al. 2011). Ponds are operated with relatively little technology, mainly for subsistence as source of cheap protein and, to some extent, as a source of income (Ero et al. 2011).

Aside from tilapia, other species cultured include rainbow trout, pearl oysters, and seaweed (Ero et al. 2011). Gillett (2009) presents the fish species cultured in PNG in mid-2000: tilapia, with estimated annual production of 30t–40 t valued at K297,500; carp, at 20–30 t valued at K212,500; trout, at 5 t–10 t valued at K187,500; and prawns, at 5 t valued at K175,000. Tilapia and carp were cultured for subsistence purposes, whereas trout and prawns were cultured for restaurants and supermarkets. Crocodiles are cultured for export.

Consumption and Nutrition Security

Bell et al. (2009) reported annual per capita fish consumption of 28.1 kg/year (76% fresh fish) in urban areas and 10.2 kg/year (77% fresh fish) in rural areas during 2002–2003. Gibson (2000) estimates annual average per capita consumption of 10 kg of fresh, frozen, or dried fish valued at K60 million in 1996. Higher annual per capita consumption at 21 kg was calculated for urban dwellers in 1996 with a value of K34 million, while comparable annual per capita consumption for rural villagers was only 8 kg, valued at K26 million.

In 1996, tinned fish was consumed at 13 kg per capita, valued at K63 million on average (Gillett 2009). Urban dwellers consumed 7 kg per capita compared with only 2 kg per capita for rural villagers. Other estimates show fish and seafood consumption at around 18.2–24.9 kg per year (Preston 2000) if seafood imports and exports are taken into account. Although consumption of fresh and tinned fish is relatively small in PNG, it is an important source of high-quality protein. Papua New Guineans' caloric intakes have been estimated to include around 1.1% fresh fish and 0.6% tinned fish (Gibson 2000).

Fisheries and the National Economy

PNG's rich marine resources provide important contributions to the country's economy through GDP, exports, government fees, and employment (Gillett 2009).

Contribution to GDP

The contribution of the fisheries sector to GDP is presented in Table A3.22. Its share of GDP increased from 2% in 2000 to 2.7% in 2007 (Gillett 2009).

Exports

PNG exports fisheries products to neighboring Solomon Islands, Australia, Southeast Asia, Europe, and the United States (Table A3.23).

Government Access Fees

PNG has negotiated numerous access agreements to its fishing grounds. Bilateral agreements exist with the People's Republic of China, the Republic of Korea, Taipei,China, several Philippine companies, the Federated States of Micronesia, and the United States through a multilateral treaty. Concessionary arrangements also exist with locally based foreign vessels (Gillett 2009).

Employment

The fisheries sector in PNG provides employment both through subsistence and commercial fishing. Subsistence coastal fisheries engage 250,000 to 500,000 people (Gillett 2009). A 1990 census calculated that around 23% (130,963)

Table A3.22 Value of Output and Percentage Share of Fisheries Sector in GDP, Papua New Guinea, 2000–2006

Category	2000	2001	2002	2003	2004	2005	2006
Total value of output of fisheries sector (Kina million)	198.6	272.0	260.2	287.2	308.4	358.1	456.8
GDP (Kina million)	9,735.8	10,996.3	11,872.0	13,241.5	13,459.4	15,094.7	16,896.6
Percentage share of fisheries sector in GDP (%)	2.0	2.5	2.2	2.2	2.3	2.4	2.7

GDP = gross domestic product.
Source: National Statistics Office in Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB.

Table A3.23 Fisheries-Based Commodity Exports, Papua New Guinea

Product	Export countries
Frozen lobster tails and barramundi fillets	Australia
Sashimi grade tuna (chilled airfreight)	Japan, US, Australia, Southeast Asia
Canned tuna	Europe, Philippines, US
Canned fish (using imported mackerel)	Solomon Islands
Fresh (chilled) fish	US
Frozen snapper fillets, mud crabs, lobster tails, Spanish mackerel by sea freight	Australia
Frozen tuna loins	Europe (this trade has terminated)
Live food fish, crabs, lobsters	Australia, Southeast Asia
Processed and unprocessed bivalve shellfish and their meat	Southeast Asia, Australia
Fishmeal	Southeast Asia

US = United States.
Source: Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB.

of the rural households involved in freshwater and marine fishing utilize 60% of their caught fish for consumption, while 40% utilize their caught fish both for consumption and sale (Gillett 2009). Preston (2001) reported that fishing households are dominant in Milne Bay (14.3% of households), East Sepik (11.3%), and Madang (10%). Avalos (1995) noted the important role of women in subsistence fisheries. At least 25% were involved in subsistence catch (possibly higher, if crab were included). They also play a leading role in processing in small-scale fisheries and in the marketing of fish.

Commercial fisheries generate substantial employment for the PNG people. In 2000, around 2,344,734 people were employed, almost half of whom were female (48.7%), or 1,141,501 women (Gillett 2009). The Secretariat of the Pacific Community (2008) estimated that there were 10,000–15,000 fish farmers in PNG; Smith (2007) estimated that in 2001 there 5,418 people from 19 provinces were fish farmers.

Local employment in the tuna industry has grown. Gillett (2008) estimated that 3,167 people were engaged in tuna fisheries in 2002, rising to 4,110 people in 2006, and to 8,990 people in 2008. Sullivan and Ram-Bidesi (2008) reported that about 7,000 women were involved in PNG's tuna industry through onshore handling, loining, or canning, as well as in technical and administrative positions.

Impacts of Climate Change on Fisheries

With or without climate change, the quantity and quality of fisheries resources will be influenced by rising population, urban and infrastructure development, and environmental management. This holds true for any developing country, but is especially important for countries that are highly dependent on fisheries resources for the economy, livelihoods, and food security.

PNG will need to examine the factors influencing the quality and quantity of fisheries harvests from their fishing zones (Allen, Bourke, and McGregor

2009). Some of the physical and biological parameters influenced by climatic changes that affect the fisheries resources are discussed below.

Sea-Surface Temperature

The Papua New Guinea National Weather Service (PNGNWS), Australian Bureau of Meteorology (AMB), and Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2011) reported a steady increase in water temperature since the 1950s, calculating a rate of 0.11°C warming per decade from the 1970s. Variation in sea-surface temperature may be due to natural variability at the regional scale, making it challenging to classify long-term changes (ABM and CSIRO 2011).

Ocean Acidification

A buildup in the level of ocean acidification has been observed in the waters of PNG since the 18th century (ABM and CSIRO 2011). In the PNG region, aragonite saturation has declined from about 4.5 in the late 18th century to an observed value of about 3.9 ± 0.1 as of 2000 (ABM and CSIRO 2011). Using the Coupled Model Intercomparison Project Phase 3 (CMIP3), values below 3.5 maximum aragonite saturation were projected to occur about the year 2040 (ABM and CSIRO 2011). These results have moderate confidence because estimations were based on climate models without explicit representation of the carbon cycle, relatively low resolution, and were subject to regional biases (ABM and CSIRO 2011).

Sea Level

Sea-level rise measured using satellite altimeters around PNG was approximated to be about 7 mm/year since 1993 (ABM and CSIRO 2011). This value is higher than the global average of 3.2± 0.4 mm/year (ABM and CSIRO 2011).

Daily sea levels are measured at hourly intervals using tide gauges located in Lombrum (Manus province) and Rabaul (East New Britain province). Highest tides were determined in both locations during the solstices with a maximum rise in December in Rabaul. La Niña years triggered significantly higher seasonal water levels between November and February in Lombrum, and during November to February and April in Rabaul (ABM and CSIRO 2011). Lower water levels were calculated during the El Niño years in both locations.

Extreme sea-level events have occurred in Lombrum and Rabaul. During January or early February, 10 highest-recorded water levels were evident in Lombrum during La Niña years (ABM and CSIRO 2011). From November to March, 7 of the top 10 severe sea-level events were recorded in Rabaul during La Niña years. Note, however, that tide measurements in these two areas are not indicative of the tide behavior in the coastal areas of PNG, such as in the Gulf of Papua.

ABM and CSIRO (2011) estimated a rise of 4cm–15cm in sea level in 2030 based on a high-emissions scenario (Table A3.24). In addition, natural year-to-year variations heighten the impact of storm surges and coastal flooding. Predictions regarding sea-level rise, however, should be treated with caution because much remains to be learned about melting ice sheets in Antarctica and Greenland, which will contribute to rising levels.

Table A3.24 Projected Sea-Level Rise in Papua New Guinea Under Three Emission Scenarios, 2030, 2055, and 2090

Scenario	Sea-Level Rise (cm)		
	2030	2055	2090
Low-emissions scenario	4–14	10–26	17–46
Medium-emissions scenario	5–14	9–30	20–58
High-emissions scenario	4–15	10–29	22–60

cm = centimeters.
Note: Values represent 90% of the range of the modeling results. Changes presented are relative to average values for the period 1980–1999.
Source: AMB and CSIRO 2011.

References

Allen, B. 2009. Agricultural Development, Policies and Governance. In Bourke, R.M., and T. Harwood, eds. *Food and Agriculture in Papua New Guinea.* Canberra: The Australian National University Press.

Allen, M., and R.M. Bourke. 2009. People, Land and Environment. In R.M. Bourke and T. Harwood, eds. *Food and Agriculture in Papua New Guinea.* Canberra: The Australian National University Press.

Allen, M., R.M. Bourke, and A. McGregor. 2009. Part 5: Cash Income from Agriculture. In Bourke, R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea.* Canberra: The Australian National University Press.

Asian Development Bank (ADB). 2011a. Food Security and Climate Change in the Pacific: Rethinking the Options. *Pacific Studies Series.* Manila.

______. 2011b. *Key Indicators for Asia and the Pacific 2011*. Manila.

Australian Bureau of Meteorology (ABM) and Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2011. *Climate Change in the Pacific: Scientific Assessment and New Research.* Volume 1. Regional overview. Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organization, Canberra http://www.pacificclimatechangescience.org/wp-content/uploads/2013/08/Climate-Change-in-the-Pacific.-Scientific-Assessment-and-New-Research-Volume-1.-Regional-Overview.pdf .

Avalos, B. 1995. Women and Development in PNG. National Centre for Development Studies, Research School for Pacific and Asian Studies. Australian National University, Canberra. Pacific Economic Bulletin 10 (1): 73–83.

Bell, J.D. et al. 2009. Planning the Use of Fish for Food Security in the Pacific. *Marine Policy*. 33. pp. 64–76.

Blakeney, M., and R. Clough. 2001. An Assessment of Grain Production and Imports in PNG, 1975–2000. In Bourke, R.M., M.G. Allen, and J.G. Salisbury, eds. *Food Security for Papua New Guinea*. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. ACIAR Proceedings No. 99. Canberra: Australian Centre for International Agricultural Research. pp. 23–29.

Bourke, R.M. 1985. Sweet Potato (*Ipomoea batatas*) Production and Research in Papua New Guinea. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries.* 33(3–4). pp. 89–108.

______. 2001. Intensification of Agricultural Systems in Papua New Guinea. *Asia Pacific Viewpoint*. 42(2/3). pp. 219–235.

______. 2009. Sweet Potato in Oceania. In Loebenstein, G. and G. Thottappilly, eds. *Sweet Potato.* The Netherlands: Springer.

Bourke, R. et al. 2006. *Solomon Islands Smallholder Agriculture Study Volume 1: Main Findings and Recommendations*. Canberra: Australian Agency for International Development (Australian Aid).

Bourke, R.M. and B. Allen. 2009. Village Food Production Systems. In Bourke, R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea.* Canberra: The Australian National University Press.

Bourke. R.M. et al. 2009. Food Production, Consumption and Imports. In Bourke, R.M. and T. Harwood, eds. *Food and Agriculture in Papua New Guinea.* Canberra: The Australian National University Press.

Bourke, R.M., and V. Vlassak. 2004. *Estimates of Food Crop Production in Papua New Guinea*. Land Management Group, Research School of Pacific and Asian Studies. Canberra: The Australian National University.

Coates, D. 1996. Review of the Present Status of, and Constraints to, Inland Fisheries Development: the Pacific Island counties. *IPFC Working Party of Experts on Island Fisheries.* RAPA, Bangkok.

Dalzell, P., T.J.H. Adams, and N.V.C. Polunin. 1996. Coastal Fisheries in the Pacific Islands. *Oceanography and Marine Biology*. 34. pp. 395–531.

Ero, M., et al. 2011. Impact of Climate Change on Agriculture and Fisheries: Case Study in Papua New Guinea. Draft country report.

Food and Agriculture Organization (FAO). 2007. Selected Indicators of Food and Agricultural Development in the Asia–Pacific Region 1996–2006. Rap Publication 2007/15. Bangkok: Regional Office for Asia and the Pacific.

______. 2009. *Climate Change and Food Security in the Pacific.* Rome. ftp://ftp.fao.org/docrep/fao/012/i1262e/i1262e00.pdf

______. 2010. FishStatJ database. Date accessed: May 2010; March–July 2011.

______. 2011. FAOSTAT. http://faostat.fao.org/

FAO, National Agricultural Research Institute (NARI), and the World Bank. 2002. Strategies for Agricultural and Rural Development in Papua New Guinea. Proceedings of the National Consultative Workshop on Agriculture and Rural Development: Issues and Strategies, Volume II.

Forum Fisheries Agency (FFA). 2008. The Value of Western and Central Pacific Fisheries Commission (WCPFC) Tuna Fisheries. Honiara, Solomon Islands. Unpublished report.

Gibson, J. 1992. *Rice Self-Sufficiency and the Terms of Trade*. Policy Working Paper No. 2. Port Moresby: Department of Agriculture and Livestock.

______. 2000. The Papua New Guinea Household Survey. *The Australian Economic Review*. 33(4). pp. 377–380.

______. 2001a. Food Demand in the Rural and Urban Sectors of PNG. In Bourke, R.M., M.G. Allen, and J.G. Salisbury, eds. *Food Security for Papua New Guinea*. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, PNG University of Technology, Lae, 26–30 June 2000. ACIAR Proceedings No. 99.

______. 2001b. The Nutritional Status of PNG's Population. In Bourke, R.M., M.G. Allen, and J.G. Salisbury, eds. *Food Security for Papua New Guinea.* Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, PNG University of Technology, Lae, 26–30 June 2000. ACIAR Proceedings No. 99, xviii and p. 892.

Gibson, J. and S. Rozelle. 1998. Results of the Household Survey Component of the 1996 Poverty Assessment for Papua New Guinea. Poverty and Human Resources Division. Washington, DC: World Bank. Mimeo.

Gillett, R. 2008. *A Study of Tuna Industry Development Aspirations of FFA Member Countries*. Forum Fisheries Agency. Honiara. 70 pages.

Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB.

Gillett, R., and C. Lightfoot. 2002. The Contribution of Fisheries to the Economies of Pacific Island Countries. *Pacific Studies Series.* Manila: ADB.

Grieve, R.B. 1986. The Oil Palm Industry of Papua New Guinea. *Australian Geographer.* 17. pp. 72–76.

Hartemink, A.E. et al. 2000. Yield Decline of Sweet Potato in the Humid Lowlands of Papua New Guinea. *Agriculture, Ecosystems and Environment*. 79(2000). pp. 259–269.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: Synthesis Report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC.

International Bank for Reconstruction and Development (IBRD). 1965. *The Economic Development of the Territory of Papua New Guinea.* Baltimore: Johns Hopkins Press.

International Federation of Red Cross and Red Crescent Societies (IFRC). 2009. *Papua New Guinea: Cyclone Guba. Final Report*. www.ifrc.org/docs/appeals/07/MDRPG002FR.pdf

Koczberski, G., G.N. Curry, and K. Gibson. 2001. *Improving Productivity of the Smallholder Oil Palm Sector in Papua New Guinea.* RSPAS. Canberra: Australian National University.

Kumoru, L. 2008. *Papua New Guinea.* Working Paper 23. Fourth Regular Session of the Scientific Committee of the Western and Central Pacific Fisheries Commission, Port Moresby, Papua New Guinea, 11–22 August 2008.

Landell Mills Ltd. 1991. Smallholder Oil Palm Productivity Study, Volume 1: Main Report. Bath, United Kingdom.

Mueller, I. 2001. The Spatial Pattern of Child Growth in PNG. In Bourke, R.M., M.G. Allen, and J.G. Salisbury, eds. *Food Security for Papua New Guinea.* Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, PNG University of Technology, Lae, 26–30 June 2000. ACIAR Proceedings No. 99, xviii and pp. 892.

National Agricultural Research Institute (NARI). 2010. Recently Released Technologies for Papua New Guinea Farmers. Morobe, Papua New Guinea.

O'Sullivan, J.N., C.J. Asher, and F.P.C. Blamey. 1997. *Nutrient Disorders of Sweet Potato.* ACIAR Monograph No. 48. Canberra: Australian Centre for International Agricultural Research.

Papua New Guinea Department of Commerce and Industry. 2008. *Statistical Digest*. pp. 1–125.

Papua New Guinea Ministry of Agriculture and Livestock (PNG MAL). 2007a. *National Agriculture Development Plan 2007–2016. Policies and Strategies. Volume 1: Growing the Economy through Agriculture. *

______. 2007b. National Agriculture Development Plan 2007–2016. Implementation Plan. Volume 2, Growing the Economy through Agriculture. Independent State of Papua New Guinea.

Preston, G. 1996. Evaluation of the Potential for Commercialization of Small-Scale Fisheries. TCP/PNG/6611. Food and Agriculture Organization of the United Nations, Rome, Italy.

Preston, G. 2000. *Managing the Ocean.* Report prepared for the World Bank. Washington, DC.

Preston, G. 2001. Review of the PNG Fisheries Sector. PNG Fisheries Development Project TA No. 2832. Manila: Asian Development Bank.

Saweri, W. 2004. *Papua New Guinea: Nutrition Overview* http://www.wpro.who.int/internet/resources.ashx/NUT/png.pdf

Secretariat of the Pacific Commission (SPC). 2002. Obesity in the Pacific: Too Big to Ignore. Noumea.

______. 2008. Fish for Food Security in the Pacific. Working Paper 5. Marine Resources Division. Noumea, New Caledonia.

Smith, P., et al. 2007. Chapter 1 Summary in P.T. Smith P.T., ed. *Aquaculture in Papua New Guinea: Status of Freshwater Fish Farming*. ACIAR Monograph No. 125. Canberra: Australian Centre for International Agricultural Research.

Sullivan, N. and V. Ram-Bidesi. 2008. Gender Issues in Tuna Fisheries – Case Studies in Papua New Guinea, Fiji and Kiribati. DevFish Programme, Forum Fisheries Agency, Honiara.

Trukai Industries. 1998. *The Rice Relay International.* 3(6). Lae, Papua New Guinea.

United Nations Development Programme (UNDP). 2010. *Human Development Report 2010. The Real Wealth of Nations: Pathways to Human Development*. Washington, DC.

Woodward, A. et al. 2000. Protecting Human Health in a Changing World: The Role of Social and Economic Development. *Bulletin of the World Health Organization*. 78(9).

World Bank. 2011. *Data on Papua New Guinea.* http://data.worldbank.org/country/papua-new-guinea

World Bank and International Finance Corporation. 2010. *Improving the Livelihoods of Palm Oil Smallholders: the Role of the Private Sector.* Available: http://www.ifc.org/ifcext/agriconsultation.nsf/AttachmentsByTitle/FSG+Report/$FILE/FSG+report_formatted.pdf

World Health Organization (WHO). 2005. *Papua New Guinea. Country Cooperation Strategy at a Glance.* www.who.int/countryfocus/cooperation_strategy/ccsbrief_png_en.pdf

APPENDIX 4

Agriculture and Fisheries Sectors in Solomon Islands

Overview

Solomon Islands is located between longitudes 175° east and 178° west, and latitudes 15° and 22° south. Located about 1,900 kilometers (km) northeast of Australia, Solomon Islands is an archipelago comprising a double chain of six large islands (Guadalcanal, Malaita, Makira, Isabel, Choiseul, and New Georgia) and approximately 1,000 smaller islands stretching some 1,600 km across the southwestern Pacific Ocean. With a total land area of 28,336 square km (km^2), Solomon Islands consists mainly of mountainous, heavily forested, volcanic islands and a few low-lying coral atolls. Only 23% of its land is classified as agricultural, and only 0.62% is arable (World Bank 2007).

Climatic Conditions

Since Solomon Islands is close to the equator, it has a high and rather uniform temperature. Its climate is humid and warm, with a mean daily maximum temperature of about 30°C and a mean daily minimum temperature of about 23°C. Rainfall distribution is not uniform due to topographical effects that cause significant variations between locations. Annual rainfall ranges between 3,000 millimeters (mm) and 5,000 mm per year; the total amount of rainfall is approximately 21 mm per day. Generally, rainfall is higher in the wet (monsoon) season (SICFCS 2002), which normally lasts from November to April. The dry season occurs from April to November. Because of the country's low latitude, it is less subject to the damaging effects of tropical cyclones than elsewhere in the Southwest Pacific. Nevertheless, cyclones still pose a serious threat each year, particularly during the summer months of December to February. The frequency of cyclone incidence averages one to two per year, tending to increase southward. Solomon Islands is also vulnerable to unusually long dry spells associated with the warm phase of the El Niño Southern Oscillation (ENSO) phenomenon (GEF, UNDP, and SPREP undated). A typical El Niño event impacts the country every 4 to 7 years.

Share of Agriculture in Gross Domestic Product

Agriculture is the dominant and most important activity in Solomon Islands. As of 2010, 68% of the country's economically active population was involved in agriculture (FAO 2011). The majority of the population, particularly in rural areas, derives its livelihoods from a combination of subsistence agriculture and small-scale, income-generating activities, particularly export cash cropping and fresh produce marketing. Agricultural gross domestic product (GDP), as well as its share in total GDP, generally showed a declining trend from 1995 to 2002 (Table A4.1). The performance of the agriculture sector suffered during this period, particularly due to civil unrest known as "ethnic tension,"[1] which occurred from late-1998 to mid-2003. The main agricultural export crops are copra, coconut oil, palm oil, palm kernel, and cocoa. Ethnic tension badly affected these primary export commodities, bringing about the collapse of palm oil production, and contributing to a decline in production of copra and cocoa (Bourke et al. 2006). During this period, the oil palm plantation on the Guadalcanal Plains was closed, and its offices and mill were destroyed. Ethnic tension also disrupted agricultural marketing channels and seriously affected the agriculture sector: the National Agricultural Research Station at Dodo Creek was destroyed, resulting in the displacement of skilled people and the loss of research facilities and equipment, the library, and other important information resources (Bourke et al. 2006). Moreover, the food and tree crop collection at Tenaru, and the livestock breeding stock and cocoa seed garden at Tenavatu on Guadalcanal were abandoned and looted. Most facilities at the National Agricultural Training Institute at Fote on Malaita were also destroyed or looted during the ethnic tension. All of these consequences of the civil conflict contributed to a decline in agricultural activity. The recovery started in 2003.

Since 2003, agriculture[2] has contributed more than 50% to Solomon Islands' GDP (Table A4.1). This growth in the share of agriculture was due to favorable macroeconomic conditions such as strong international commodity prices fueled by demand from the global recovery, and low inflation among trading partners, which set the backdrop for domestic production (CBSI 2010). But the relative growth in the share of agriculture is also due to slow growth in other sectors. Notably, growth in agriculture has been driven by a small number of primary export products that are highly influenced by world market prices. This, in addition to adverse weather conditions and cyclones, makes the agriculture sector of Solomon Islands highly vulnerable. To minimize vulnerabilities to commodity price shocks and ensure balanced and sustained long-term growth, the sector needs to develop nontraditional agricultural exports and other cash crops to diversify its economic base.

While real GDP has grown since 1995, agricultural production declined until 2002 (MAL 2009b). Main hindrances to agricultural growth are the geographic distances between islands and isolation of farmers from the main urban centers (MAL 2008). Hundreds of islands are spread across a large area with poor transport and communications infrastructure. Lack of adequate domestic transport infrastructure, together with lack of credit, and the high transaction costs of securing leases on communal land severely all constrain agricultural output (IMF 2004).

In addition, limited access to world markets for most agricultural products—based on their low quality and and an overall inability to meet quarantine requirements—limits the country's agricultural export sector.

1 The roots of ethnic tension were longstanding unresolved issues, such as land ownership and control of resources. Ethnic tension was exacerbated by interisland migration, in particular to Guadalcanal Province (UN Chronicle 1999).

2 Agriculture in Solomon Islands includes forestry, hunting, and fishing, as well as cultivation of crops, and livestock production.

Table A4.1 Real GDP at Factor Cost and Agricultural GDP, Solomon Islands, 1995–2010 (SI$ million)

Year	Real GDP at Factor Cost (SI$ million)	Agricultural GDP (SI$ million)	Percentage Share of Agricultural GDP in Real GDP (%)
1995	335	163	49
1996	340	158	46
1997	334	160	48
1998	345	160	46
1999	339	148	44
2000	291	123	42
2001	268	119	44
2002	261	125	48
2003	277	148	53
2004	300	165	55
2005	315	174	55
2006	334	183	55
2007	370	205	56
2008	397	219	55
2009	392	203	52
2010	420	224	53

GDP = gross domestic product.
Source: Asian Development Bank (ADB). 2011. Food Security and Climate Change in the Pacific: Rethinking the Options. *Pacific Studies Series.* Manila.

There is also lack of agricultural market information, which constrains potential suppliers from entering both domestic and international markets (MAL 2009b). For instance, demand for agricultural products may exist in urban areas. Suppliers from rural areas, however, may not be aware of them. The international markets face a similar situation. Moreover, lack of improved production technologies in the farming system, increasing pest and diseases, soil degradation, lack of production incentives, declining export prices, limited market opportunities and access to land, and a lack of private and public investments in the agriculture sector have contributed to declining agricultural production (MAL 2009b). Almost nonexistent marketing systems for inputs have also led to poor agricultural performance. The timely availability of agricultural inputs is a major problem in remote areas. In many instances, supplies of farm inputs are not readily available or are not affordable (MAL 2009b). Agricultural extension services have also been inadequate for many decades. Linkages between research, extension, and farmers have been weak due to lack of funding for extension (MAL 2009b). The government spends less than 1% of its budget on agriculture (Evans 2006). Finally, instability in the political and economic environment has further impeded agricultural development.

Population and Human Development

As of 2010, the population of Solomon Islands was 528,000, with an annual growth rate of 2.3% and a density of 19 people per km^2 (ADB 2011).

Table A4.2 Total Population, Rural Population, and Average Population Density by Province, Solomon Islands, 1999

Province	Population		
	Total Population	Percentage Share of Rural Population in Total Population (%)	Average Population Density (persons/km^2)
Malaita	122,620	34	29
Western	62,739	17	11
Guadalcanal	60,275	17	11
Makira/Ulawa	31,006	9	10
Central	21,577	6	35
Isabel	20,421	6	5
Choiseul	20,008	6	6
Temotu	18,912	5	22
Rennell and Belloma	2,377	1	4
Honiara town	49,107	0	–
Total	**409,042**	**100**	**15**

km^2 = square kilometer.

Source: Bourke, R. et al. 2006. *Solomon Islands Smallholder Agriculture Study Volume 1: Main Findings and Recommendations.* Canberra: Australian Agency for International Development (Australian Aid).

The country comprises nine provinces. Based on the 1999 population of 409,297, the province of Malaita has the highest population, (122,620), and the provinces of Rennell and Belloma together have the lowest (2,377) (Table A4.2; Allen et al. 2006).

In 2009, around 80% of the total population (528,000) lived in the rural areas (GSI 2010, World Bank 2011). Rural dwellers lead a subsistence lifestyle where agriculture (basically gardening), fishing, and hunting are the main sources of food and economic activity (SICFCS 2002). Given the importance of subsistence agriculture, land is an important asset. In the context of Solomon Islanders, poverty is defined as lack of land, sea resources, and opportunities to improve quality of life (UN 2002). When it was in place, the *wantok* system (of kinship ties) kept the country free of extreme poverty (UN 2002).

A large number of younger members of the population are migrating from rural to urban centers seeking a better quality of life, which is resulting in higher population density in coastal and urban areas (Table A4.2), in turn creating greater competition for basic services.

Solomon Islands' human development index (HDI) ranking was 123 out of 169 countries, and it was categorized as having medium human development (UNDP 2010).

Health

The Solomon Islands Demographic and Health Survey (SIDHS) was conducted by the Solomon Islands Statistics Office in 2006–2007 (GSI 2010). Results were astonishing: more than 30% of children under 5 years old were stunted, and 8.5% were severely stunted. Of these stunted children, 47% were 18–23 months old, and older in rural areas. Children under 5 years were also observed to be underweight (11.8%), and 2.4% were severely underweight. Children who were 9–11 months old were found to have high levels of malnourishment. Other findings indicated that girls, rural children, and children from the Western Province were underweight. Anemia was a dominant disease for children under 5 years (almost 50%). More than 25% had mild anemia, and less than 1% had severe anemia. In a 1989 United Nations (UN) study (2002), 23% of 15-year-old children in Solomon Islands were malnourished. Similarly, women suffered from anemia. SIDHS showed that around 44.3% of women aged 15–49 years were ill with anemia, and 8.2% had moderate or severe anemia (GSI 2010).

The shift from the traditional diet of taro, yams, and sweet potato to processed food and foods high in sugar has weakened the nutritional value of the Solomon Islands' diet. Findings from SIDHS raised concerns on weight. Body mass index (BMI) was high for men and women, at 30.8% and 44% respectively (GSI 2010). Around 29.9% of women were classified as overweight and 14.5% were considered obese. In addition, the incidence of diabetes had significantly increased in urban communities (UN 2002).

The above indications of malnourishment and disease signify the challenges facing Solomon Islanders in terms of the availability, accessibility, and affordability of nutritious food, especially for children. People in the urban areas may have the same issues, but they are not as severe. Local food production is insufficient to meet domestic demand. More importantly, the production of local crops is influenced by biophysical and institutional factors, such as soil quality, water availability, pest and diseases, seed quality, subsidies to other agricultural inputs, technological knowledge, and others. Subsistence farming is highly dependent on climatic conditions, such as drought, extreme heat, and flooding.

Education

The World Bank (2011) described education as one of the most powerful instruments for reducing poverty and inequality and laying the foundation for sustained economic growth. In Solomon Islands, there are two important areas of traditional education: kinship in relation to ownership and access rights to land, sea, and language (UN 2002). Regrettably, these areas have been neglected and lost in the past and current generations. In addition, formal schooling was seen as a pathway to employment in the formal sector and out of rural life; it was not seen as an opportunity for building relationships in the village or strengthening its culture (UN 2002).

The Solomon Islands' education system requires 7 years of primary schooling, including a preparatory year of kindergarten. Some nongovernment organisations (NGOs) and communities provide early childhood education (UN 2002). The Community High School, a secondary school established through a public initiative, was a welcome educational development after the country's 1978 independence. The Community High School uses the primary school teachers (whose work day ends at lunchtime) to teach secondary-level students who are unable to enroll in established secondary schools (UN 2002). A decline in the quality of education was observed in 1996, at which time over 80% of primary school teachers had only reached Grade 9, and 26% did not have teacher training (UN 2002). Teachers are faced with a number of challenges in their attempts to provide students with a high-quality education. These difficulties include the lack of teaching materials, heavy reliance on expensive residential facilities, and limited resources for imparting universal basic education (UN 2002). In 1991, the Solomon Island's adult literacy rate of 30% (for those older than 15 years) was found to be the lowest in the Pacific Islands (UN 2002).

The World Bank (2011) compiled the country's education data. School enrollment has improved: preschool enrollments rose from 35% in 1999 to 42% in 2003; primary enrollments rose from 88% to 95%; and secondary enrollments rose from 25% to 31%. In 1999, the literacy rate was 85% for youth (15–24 years old) and 77% for adults (15 years and above). A recent study of demographic and health surveys by the SPC (2007) showed that the majority of 8–9 year-old children attend primary school, but enrollments drop when children turn 13 years old. Although primary schooling is free, it is not compulsory in Solomon Islands. Enrollments for 6–12 year-old-children were only 72% and 64% in urban and rural areas respectively (SPC 2007).

Living Standards

Around 23% of the total population has access to improved toilet facilities, 69% of the rural population has access to clean water, and 86% and 21% of housing is permanent in urban and rural areas respectively (UN 2002). Around 94% of urban dwellers and 82% of rural villagers have access to improved water sources, and 72% of urban households, but only 8% of rural people, have access to improved (and not shared) sanitation facilities (SPC 2007).

Healthcare infrastructure in rural areas is impressive; however, the challenge of maintaining clinic staff and health supplies is a persistent problem. The use of traditional medicines and practices is common, especially since official health service providers are difficult to reach. Traditional medicine practitioners operate as a back-up system for modern healthcare facilities (UN 2002).

In 2002, the ratio of healthcare services to population was one doctor to 5,382 people. Advances in the quality and accessibility of healthcare services were observed after the Independence period. From 1978 until 1999, life expectancy at birth improved with a significant decline in the national infant mortality rate from 129 to 66 deaths per 1,000 live births (UN 2002). Leprosy immunization was given to children, and tuberculosis was diagnosed ahead of time. Malaria remains a major public health issue in Solomon Islands, however. Intensive reduction efforts have been initiated since 1965, leading to a drop in malaria cases (80% reduction in Honiara).

Food Production

More than 80% of Solomon Islands land is classified as customary land (Kauhiona 2011 *pers comm*). Of that, only 12% is considered agricultural and only 1% is arable (GSI 2007). Given this situation, large-scale crop cultivation is a not possible, so most Solomon Islanders practice subsistence farming.

The people of Solomon Islands subsist mainly on a diet of root crops, the main staples being sweet potato, cassava (*Manihot esculenta*), taro, yams (*Dioscorea alata*), and *pana* (*D. esculenta*). On some of islands, bananas are also considered a staple food (Table A4.3). This was particularly the case during the ethnic tensions of 1998–1999 that led to shortages of main food crops (Allen et al. 2006).

Table A4.3 Types of Staple Foods Consumed by Province, Solomon Islands, 1999

Province	Major staple foods	Other cultivated crops
Central Province	*Pana (Dioscorea esculenta),* yam *(D. alata)* **Importance:** Cultural and nutritional importance. Exchanged at *kastom* ceremonies such as weddings and funerals	**Root vegetables:** Sweet potato, cassava. taro *(Colocasia esculenta),* kongkong taro *(Xanthosoma),* swamp taro *(Cyrtosperma)*, giant taro *(Alocasia)* **Leafy green vegetables:** Pumpkin tips, taro leaf, various bush greens including "sand paper" *(Ficus spp)* and ferns, kangkong *(Ipomoea aquatic),* slippery cabbage **Other vegetables:** Cucumber, tomatoes, corn, shallots, snake bean, green bean, capsicum, Chinese cabbage **Fruits:** Banana, pineapple, watermelon **Common tree fruits:** Mango, pawpaw, Malay apple **Indigenous fruits and nuts:** Cutnut *(Barringtonia spp),* ngali nut, Terminalia and Inocarpus, breadfruit, sago palm (eaten in times of food scarcity), betel nut, rice
Choiseul	Taro *(Colocasia esculenta)* (significant cultural value), sweet potato (dominant staple crop)	Rice, banana, cassava, taro, yam, pana, sago **Leafy green vegetables:** Slippery cabbage, large variety of bush ferns **Other vegetables:** Cucumber, tomatoes, corn, shallots, snake bean, green bean, capsicum, Chinese cabbage **Trees:** Ngali nut trees (high level of cultural significance; thin shells, high percentage of kernel [26% by weight], ideal for culinary and commercial purposes), cutnut
Guadalcanal	Sweet potato (*Ipomoea batatas),* cassava, banana *(Musa spp),* taro, yam, *pana*	**Fruit and nuts:** Ngali nut, cutnut, oranges, pineapple **Leafy vegetables:** Selfsown ferns, slippery cabbage, sandpaper cabbage **Other foods:** Breadfruit, cutnut, eggplant, snake bean, peanuts **Fruits:** Pineapple, pawpaw, orange, watermelon, betel nut
Isabel	Taro, sweet potato, cassava *(Manihot esculenta), pana,* yams	**Other important crops:** Coconut, banana, slippery cabbage, Chinese cabbage **Other vegetables:** Beans, tomatoes, eggplants, shallots **Food-producing trees:** Ngali nut, cutnut, **Fruits (seasonal):** Mango, pineapple, orange, local apple
Makira/Ulawa	Sweet potato, banana/plantain	**Minor staple food crops:** Cassava, pana, yam, kongkong taro *(Xanthosoma),* swamp taro *(Cyrtosperma chamissonis),* giant taro *(Alocasia)* **Green vegetables:** Slippery cabbage **Food-producing trees:** Ngali nut, cutnut, pawpaw, mango, breadfruit, Malay apple, betel nut, betel pepper

continued on next page

Table A4.3 *continued*

Province	Major staple foods	Other cultivated crops
Malaita	Sweet potato, cassava, taro, banana	**Minor staple foods:** Yam, pana, kongkong taro, swamp taro, giant taro **Major green vegetables:** Slippery cabbage **Food-producing trees:** Ngali nut, cutnut, pawpaw, mango, betel nut, betel pepper
Rennell and Bellona	Rice, taro, sweet potato, yams/*pana,* banana	**Other important foods:** Coconut, pawpaws, slippery cabbage, pineapples, citrus, pumpkin, eggplant, tomatoes, Chinese cabbage, ferns, sweet potato leaves, sandpaper cabbage *(Ficus sp.)*, cassava (minor crop) **Seasonally important fruits:** Mango, breadfruit, Polynesian chestnut *(Inocarpus fagifer),* sea almond or alite *(Terminalia catappa)*, cutnut
Temotu	Sweet potato, bananas/plantains	**Other staple foods:** cassava *(Manihot esculenta),* fruit trees (breadfruit, *Artocarpus altilis)*, Santa Cruz ngali nut, pana, yam, taro, swamp taro *(Cyrtosperma chamissonis)* **Green vegetable:** Slippery cabbage **Food-producing trees and legumes:** Cutnut, sea almond *(Terminalia catappa),* Tahitian chestnut *(Inocarpus fagifer),* peanut, betel nut, betel pepper
Western	Rice (purchased), cassava sweet potato, yams, *pana* (seasonally), taro	Banana **Tree cash crops:** Coconut, cocoa

Source: Allen, M., Bourke, R., Evans, B., Iramu, E., Maemouri, R., Mullen, B, Pollard, A. Wairiu, M., Watoto, C., Zotalis, S. 2006. Solomon Islands Smallholder Agriculture Study. Volume 4: Provincial reports. Australian Government Australian Aid. Provincial Reports Volume 4.

In the 1980s, consumption of imported rice increased, as did consumption of flour-based foods and canned tuna. Choiseul Province was reported to have high levels of imported rice consumption, particularly in the 1990s in areas where people received royalty payments from commercial logging activities (Allen et al. 2006). Rice was introduced by Taipei,China for cultivation in the early 1990s. The Republic of China Agricultural Mission [of Taipei,China] (ROCAM) provided funding support in the form of agricultural extension, seed, fertilizer, pesticide, and farm tools. Smallholder farming of rice was initiated in all provinces in the 1990s. Allen et al. (2006) reported that in the late-1990s, around 20 farmers cultivated rice in Central Province. The number of rice farmers declined to 10 or even fewer thereafter because the farm land is not flat enough for rice cultivation, and farmers cannot acess the required agricultural inputs (seed, equipment, milling machineries); in particular, the costs of pesticide and fertilizer are especially daunting. Moreover, aside from these high production costs, the incidence and inability to control pests and diseases are major constraints to production, and have led to loss of interest by farmers.

Table A4.4 illustrates the estimated production of staple food crops in Solomon Islands in 2004. Sweet potato accounted for approximately 65% of major staple food production in 2004. A comparison of provincial-level

Table A4.4 Estimated Output and Percentage Share in Total Output of Major Staple Food Crops, Solomon Islands, 2004 (ton)

Commodity	Estimated Output (ton)	Percentage Share in Total
Sweet potatoes	280,000	65
Cassava	51,000	12
Bananas	34,000	8
Taro and kangkong taro	32,000	7
Coconut	26,000	6
Pana and yams	7,000	2
Others	2,000	0
Total	**432,000**	**100**

Source: Bourke, R. et al. 2006. *Solomon Islands Smallholder Agriculture Study Volume 1: Main Findings and Recommendations.* Canberra: Australian Agency for International Development (Australian Aid).

staple food crops in 1999, and countrywide food crops in 2004 indicates a shift in production and consumption from taro and yams initially, to sweet potato, cassava, and bananas. Sweet potato and cassava can tolerate lower soil fertility—a condition becoming common in Solomon Islands (Allen et al. 2006). Shorter fallow periods prevent the recovery of soil nutrients, resulting in declining soil fertility. In addition, the short duration of sweet potato cultivation, as discussed in earlier sections of this report, is an important advantage over *pana* and yams, which are harvested at 8–14 months.

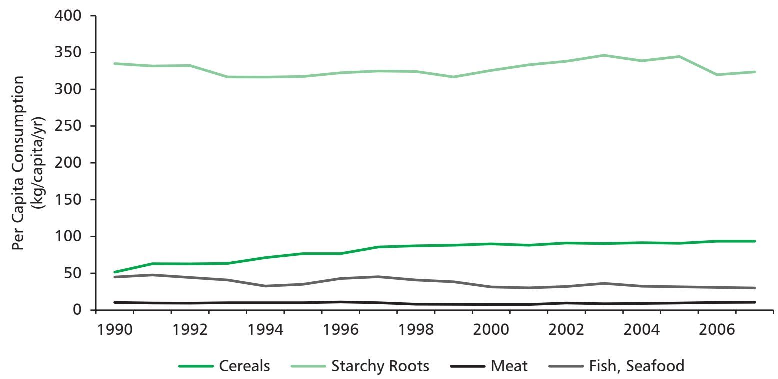
Food Consumption

The World Bank (2011) estimated the food production index of Solomon Islands during 2006–2009. The index represents net food production from agriculture with a base period of 1999–2001. Records showed that the index increased from 114 in 2006, to 117 in 2007, to 118 in 2008, and 119 in 2009. With the population rising from 314,000 in 1990 to 498,000 in 2007 (FAO 2011), Solomon Islands urgently needs to produce enough high-quality food to meet the demands of its population. Figure A4.1 shows annual per capita consumption of key food groups during the period 1990–2007 (World Bank 2011). Root crops have the highest food demand, at more than 300 kilograms (kg). That trend was decreasing, however, indicating a shift in the average Solomon Islands diet. Per capita consumption of root crops fell at 0.17% per year during 1990–2007. In contrast, annual per capita cereal consumption increased from 50 kg in 1990 to 90 kg in 2007 (Figure A4.1, Table A4.5). Estimated per capita consumption of cereals rose at a rate of 3.73% per year during 1990–2007. Interestingly, annual per capita consumption of fish and seafood dropped from 44.9 kg in 1990 to 30 kg in 2007, representing a drop of 1.73% per year in 1990–2007.

Trade

Solomon Islands produces a number of cash crops tradable in local and international markets. Palm oil, palm kernel, copra, coconut oil, and cocoa were the main agricultural commodities for export until 1998, prior to the ethnic tension in 1999 (SICFCS 2002). These cash crops are primarily

Figure A4.1 Annual Per Capita Consumption of Staple Foods, by Major Food Category, Solomon Islands, 1990–2007 (kg)



kg = kilogram, yr = year.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

cultivated in marginal sloping lands in the provinces. Because of the absence of land conservation measures, soil erosion and deteriorating soil fertility are common under shifting cultivation and in areas of high population density (SICFCS 2002).

The Ministry of Agriculture and Livestock (MAL) (2009a) reported the production level of key agricultural commodities for export in 1985–2000. Among the seven commodities, copra production was the only commodity weakening, from 41,907 metric tons (mt) in 1985 to 19,004 mt in 2000—a 55% drop over a period of 15 years. More recent Food and Agriculture Organization (FAO) data showed that palm oil is the most important export product, with an average value of $14.23 million in 2000–2009, followed by cocoa bean, copra, palm kernel, and coconut oil (Table A4.6).

In 2007, the Central Bank of Solomon Islands (CBSI) reported a significant improvement in the export value of three major commodities, copra and coconut oil, palm products, and copra (Table A4.7) (MAL 2009a). Further, Gold Ridge Mining in Guadalcanal, the country's only mining operation, is another source of export income from gold. Ethnic tension in 1998, however, led to closure of the mining company, but operations have recently resumed.

Aside from the export commodities in Table A4.7, powdered kava, fresh vegetables, fruits, tubers, coconut oil, and palm kernel were likewise exported to Australia and other Pacific countries in 2009 (Table A4.8). FAO (2007) reported agricultural trade exports of $4.5 million; imports were $14.3 million.

The Ministry of Agriculture and Livestock (2009a) indicates a number of agricultural commodities with export potential. These include root crops, nut crops, spices, vegetables, fruits, and animal products. From these major groupings, 10 crops were identified as having potential for export: cassava, taro, yams, and sweet potato (root crops); ngali nut; vanilla (spices); kava, coffee, and cut flowers (other crops); ball cabbage (vegetables); and bush lime

Table A4.5 Estimated Annual per Capita Food Demand by Food Type, Solomon Islands, 1990–2007 (kg)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Population ('000)	314	323	332	342	352	362	372	383	393	404	416	427	438	450	462	474	486	498
Cereals	51.6	62.9	62.8	63.4	71.3	76.6	76.6	85.7	87.3	88.1	90.0	88.2	91.2	90.4	91.5	90.8	93.5	93.5
Starchy roots	334.9	331.6	332.2	316.8	316.6	317.4	322.4	324.8	324.1	316.7	325.6	333.2	338.1	346.1	338.6	344.5	319.7	323.6
Coconuts/copra	76.4	77.4	78.3	78.9	79.5	80.1	78.0	78.3	81.4	74.3	74.5	74.9	75.3	75.6	73.6	73.8	72	70.3
Vegetables	23.1	17.8	18.2	15.9	15.7	16.1	16.2	16.5	16.9	18.4	17.4	17.5	18.0	17.3	17.3	17.9	17.8	17.1
Fruits	47.1	47.0	45.2	40.0	38.6	38.9	39.1	38.1	39.5	38.6	39.1	41.2	43.0	44.4	44.7	47.8	46.8	44.8
Meat	10.5	9.7	9.4	10.1	10.0	10.0	11.1	10.1	8.0	7.7	7.5	7.5	9.6	8.7	9.1	9.6	10.4	10.6
Eggs	0.8	0.9	0.8	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.3	1.0	1.0	1.0	1.0	1.1
Milk	8.2	10.4	10.7	10.3	11.7	13.1	7.4	8.5	9.3	7.5	7.8	5.1	6.4	4.0	5.9	5.9	9.7	7.2
Fish, seafood	44.9	47.8	44.3	40.9	32.6	35.0	42.9	45.2	40.8	38.5	31.4	30.2	32.0	36.2	32.4	31.6	30.9	30.1

kg = kilogram.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Table A4.6 Volume and Value of Top Five Agricultural Commodity Exports, Solomon Islands
(2000–2009 average values)

Commodity	Volume (metric tons)	Value ($ '000s)
Palm oil	26,527	14,229
Cocoa beans	3,581	5,671
Copra	12,379	5,097
Palm kernels	6,770	2,540
Coconut (copra) oil	1,057	935

Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Table A4.7 Value of Major Agricultural Commodity Exports, Solomon Islands, 2006–2007

	Export Value (SI$ million)		Increase (%)
Commodity	2006	2007	
Copra and coconut oil	14.1 ($2 million)	33.5 ($4.8 million)	138
Palm products	30.7 ($4.4 million)	77.5 ($11.1 million)	152
Cocoa	31.4 ($4.5 million)	72.0 ($10.3 million)	129

Source: Ministry of Agriculture and Livestock. 2009a. *National Agriculture and Livestock Sector Policy 2009–2014*. Honiara.

Table A4.8 Volume of Agricultural Commodity Exports to Pacific Countries, Solomon Islands, 2009

Commodity	Importing country	Volume
Powdered kava	Kiribati	20.51 mt
Powdered kava	Nauru	4.26 mt
Powdered kava	Marshall Islands	0.15 mt
Fresh vegetables (Chinese cabbage)	Nauru	0.035 mt
Fresh vegetables, fruits, tubers	Nauru	430 cartons
Coconut oil	Australia	29,000 liters
Palm kernel	Papua New Guinea	3,127.93 mt

mt = metric ton.
Source: Ministry of Agriculture and Livestock. 2009a. *National Agriculture and Livestock Sector Policy 2009–2014*. Honiara.

and pineapple (fruit) (MAL 2009a). Since these crops have export potential, production quantity and quality and other export protocols need to be assured. Moreover, changes in climate conditions will pose risks to the production of these crops.

Despite the progress achieved by Solomon Islands in increasing the total value of exports, food imports have increased from SI$164.6 million in 2006, to SI$239.1 million in 2007—representing a significant 45% (MAL

Table A4.9 Volume of Selected Cereal Imports by Country Source, Solomon Islands, 2009 (metric ton)

Cereal	Country Source	Volume (mt)
Rice	PRC	24,210.65
	Papua New Guinea	16,968.18
	Australia	4,600.78
	Thailand	1,333.27
	Viet Nam	1,018.86
	Fiji	56.10
Popcorn	Australia	33.00
Processed flour	Fiji	56.00
Wheat	Australia	9,591.88

PRC = People's Republic of China.
Source: Ministry of Agriculture and Livestock. 2009a. *National Agriculture and Livestock Sector Policy 2009–2014*. Honiara.

Table A4.10 Volume and Value of Top Five Agricultural Imports, Solomon Islands (2000–2009 average values)

Commodity	Volume (metric ton)	Value ($ '000)
Rice, milled	25,384	15,946
Food, prepared, not otherwise specified	1,429	2,541
Wheat	8,134	2,400
Sugar, refined	2,804	1,417
Bread	750	778

Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

2009a). The top four food commodity imports include rice, wheat, sugar, and bread (Table A4.9). This growth in food importation is attributed to intensified demand for rice, wheat, cooking oil, and canned food. Rice imports contributed 58.6% to total food imports at a value of SI$140 million in 2007 (MAL 2009a). Rice imports were the greatest of all cereal imports at 48,187.84 mt in 2009 (Table A4.10). Other dominant food imports were onions, apples, potatoes, and carrots from Australia and New Zealand (Table A4.11). The high demand for food imports implies a change in consumer preferences away from the traditional diet; population growth also increases pressure on food production.

Major Crops

Coconut

Overview

Coconut is the cash crop in Solomon Islands. It provides a small but relatively reliable source of cash income for rural families throughout the country. This income (mainly from the sale of copra) also enhances food security by allowing people to buy rice or locally grown staples when their subsistence production

Table A4.11 Volume of Solomon Islands' Food Imports from Australia and New Zealand, 2009 (metric ton)

From Australia		From New Zealand	
Commodity	Volume (metric ton)	Commodity	Volume (metric ton)
Onions	64.17	Onions	364.32
Potatoes	18.98	Apples	117.97
Apples	13.00	Potatoes	34.72
Carrots	13.78	Carrots	21.10
Watermelon	5.13	Garlic	15.01
Oranges	4.51	Oranges	6.99
Cabbage	3.92	Cabbage	3.50
Pumpkins	3.82	Celery	2.58
Mandarin	3.75	Grapes	2.35
Pears	3.37	Kiwi Fruits	1.47
Garlic	2.85	Pears	1.26
Lemon	1.50	Cauliflower	1.16
Cauliflower	0.91	Broccoli	1.14
Honeydew melon	0.90	Mandarin	0.78
Grapes	0.80	Pumpkins	0.40
Snow peas	0.68	Watermelon	0.30
Celery	0.28	Tomato	0.13
Peas	0.16	Peas	0.10
Lo Bok	0.15	Capsicum	0.08
Tomato	0.11	Lemons	0.07
Radish	0.05	Mushroom	0.004
Total	**142.20**	**Total**	**575.44**

Source: Ministry of Agriculture and Livestock. 2009b. *Ministry of Agriculture and Livestock Annual Report 2009*. Honiara.

fails. Coconut also makes an important contribution to Solomon Islanders' daily diet. A survey from the 1980s found that the Solomon Islands population consumed 0.7 coconuts per person per day on average (Jones, Fleming, and Hardaker 1988).

Products include whole nuts, copra, coconut oil, and virgin coconut oil. While fresh consumption of coconut is of nutritional importance, coconuts are of commercial value primarily as copra. Minor production of coconut oil and virgin coconut oil often takes place on an ad hoc basis. Copra is the most widely produced because it provides a reliable source of cash income. Even at a low copra price of $600 per metric ton, the return to labor for copra of about $19 per day is acceptable[3] (Bourke et al. 2006). Being relatively nonperishable, copra is also a good commodity to produce given the state of Solomon Islands' transportation infrastructure.

3 There is no established rural wage in Solomon Islands, but $15 per day can be taken as a guide for comparing returns to labor from producing copra.

Smallholders account for more than 80% of the copra produced in Solomon Islands. As such, supporting the industry has more potential to increase the cash income of rural people than any other single activity. Any improvement in copra production has the capacity to positively affect a significant number of villagers. Farm budgets prepared by McGregor (2006) show copra making to be a financially viable enterprise, provided there is an operating marketing system in place. This financial viability also holds true in situations in which farmers are provided with steel pipes for drying, which produces higher quality copra and reduces wastage of firewood in drying. The standard practice of farmers is to dry copra using gallon fuel drums; however, this often produces smoke-damaged copra. With good-quality copra, it was expected that farmers would receive higher prices. Bourke et al. (2006) points out the need to increase the capacity of villagers to process their coconuts into improved-quality copra through provision of key copra dryer components (i.e., steel pipe and chimneys). They also suggest that the coconut industry be encouraged to further engage in production of selected value-added uses for coconuts, such as the production of high-quality virgin coconut oil and biofuel. Results of their financial analysis have shown that both operations are viable at prevailing prices, if they are operated regularly with a high level of throughput. It should be noted, however, that achieving the growth potential of the coconut industry is mainly dependent on improvements in marketing and interisland shipping, as well as support for private sector investments in processing and marketing for new products with a potential for market development (World Bank 2007).

Production

On average, coconut production was 268,433 mt during 1980–2009 (Table A4.12). During that period, area harvested to coconut averaged 38,867 hectares (ha), with an average yield of 6.86 tons (t) per hectare (ha). Coconut production generally posted an upward trend for the period (Figure A4.2), with production growing by 2.16% per year. Coconut yields grew at the low rate of 0.68% per year, while area harvested grew by 1.46% per year. Coconut production in 2009 (at 384,000 mt) was about 78% higher than its 1980 level (215,000 mt).

Coconut production generally declined in Solomon Islands between 1980 and 1990 (at 2.03% per year). Although the area harvested grew by 1.26% per

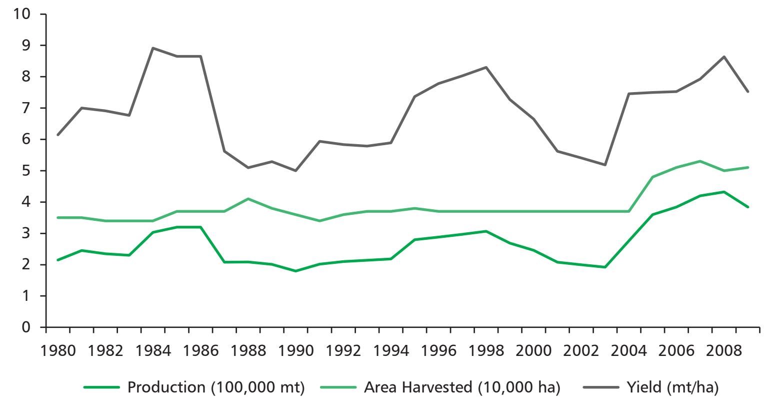
Table A4.12 Growth Rate of Output, Area Harvested, and Yield of Coconut, Solomon Islands, 1980–2009

Item	1980–2009	Growth Rate (%) 1980–1990	1990–2000	2000–2009	1980–2009
Output (metric tons)	268,433	(2.03)	4.19	9.52	2.16
Area (ha)	38,867	1.26	0.58	4.79	1.46
Yield (metric tons/ha)	6.86	(3.26)	3.57	4.52	0.68

ha = hectare, ( ) = negative value.

Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Figure A4.2 Trends in Output, Area Harvested, and Yield of Coconut, Solomon Islands, 1980–2009



ha = hectare, mt = metric ton.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

year over the period, coconut yields fell by 3.26% per year. Cyclone Namu hit the country in 1986, greatly affecting coconut production, and consequences were felt in subsequent years (yields remained low until 1990). Cyclones cause premature nuts to fall and delay the setting of new nuts (trees take years to recover), but it can also cause trees to be knocked down or uprooted.

During 1990–2000, coconut production recovered, growing by 4.19% per year, and yields grew at a rate of 3.57% per year. Growth in area harvested slowed, however (0.58% per year), which can be attributed to disruptions related to ethnic tension. During 2000–2009, coconut production increased rapidly. Coconut output grew at about 9.52% per year, as area harvested to coconut and coconut yields grew at 4.79% and 4.52% per year respectively. As shown in Figure A4.2 coconut production was particularly low during 2000–2003 (averaging 211,500 mt, which is below the 1980 level); it began to pick up in 2004, however. Aside from the ethnic tension in those years, the collapse of the Commodity Export Marketing Authority (CEMA) also significantly affected the coconut industry during that time. CEMA, a parastatal company, had been the sole buyer of copra from producers since 1985. Beginning in 1999, CEMA began to encounter serious cash flow problems,[4] and by 2001 it ran out of cash to purchase copra, causing the industry to collapse (McGregor 2006). CEMA was restructured in 2002 to become a regulatory body. The government removed the CEMA monopoly, so the industry moved to deregulated private sector marketing. Since then, coconut production has begun to recover. Bourke et al. (2006) attribute this resilience to the coincidence of a period of relatively favorable copra prices, the country's fundamental comparative advantage in copra production, the marketing infrastructure network of collection centers previously established by CEMA that could be utilized by private marketers, an availability and

4 For a detailed discussion of the reasons that led to CEMA's collapse, see McGregor (2006, pp.7–8).

Table A4.13 Copra Output by Province, Solomon Islands, 2009

Province	Output (metric ton)	Percentage Share of Total Output (%)
Western	5,470	22
Choiseul	2,378	9
Isabel	1,008	4
Central	2,580	10
Guadalcanal	5,475	22
Malaita	5,764	23
Makira	1,730	7
Temotu	334	1
Bouganville	294	1
Total	**25,033**	**100**

Source:Commodities Export Marketing Authority (CEMA) cited in McGregor, A. 2006. *Solomon Islands Smallholder Agriculture Study.* Volume 3. Markets and Marketing Issues. Australian Govertment/ Australian Aid.http://aid.dfat.gov.au/Publications/Documents/solomon_study_vol3.pdf

willingness of the private sector to trade copra, the ability of coconut palms to survive several years of neglect, and the need of many rural households for a source of cash income.

Efforts to boost the coconut industry after ethnic tension in 2003 focused on rehabilitating processing and transport infrastructure, encouraging product diversification, and local marketing and value-adding (Evans 2006). In previous years, development of the industry focused more on introducing high-yielding hybrids, but was mostly unsuccessful because of farmer resistance; poor husbandry; and susceptibility to pests, disease, and weed infestation.

Due to the lack of coconut production data by province, data on copra production by province are assessed to provide a geographic picture of the country's coconut industry (Table A4.13). Malaita, Western, and Guadalcanal provinces are the major copra producing areas in Solomon Islands. In 2009, Malaita contributed 23% to total copra production and Guadalcanal and Western province each accounted for 22%. Malaita, the country's most populous island, has large concentrations of coconuts. The northern area, in particular, has a farmers' association involving seven coconut estates of 368 ha each, employing up to 350 farmers and farm laborers.

Consumption

As mentioned earlier, in Solomon Islands, coconut is mainly used for making copra. During 2000–2007, about 18% of the total domestic supply of coconut was available for food on average. Solomon Islanders consume coconut in the form of coconut cream and milk for cooking, and immature nuts for drinking. They are sold as green and dry coconuts in rural and urban markets.

Coconuts contribute an estimated 6% by weight to alllocally grown staple foods (Bourke et al 2006). From 2000 to 2007, annual per capita[5] consumption of coconut averaged 74 kg (Table A4.14). Annual consumption

5 FAO shows this as "Food supply quantity (kg/capita/yr)." The per capita supply of each food item available for human consumption was obtained by dividing the respective quantity by the relevant population data.

Table A4.14 Domestic Supply of Coconut Including Copra and Supply of Coconut Available for Food, Solomon Islands, 2000–2007
(metric tons)

Year	Domestic Supply of Coconut[a] (metric ton '000s)	Supply of Coconut Available for Food (metric ton '000s)	Percent of Total Supply Available for Food (%)	Annual Per Capita Supply (kg)
2000	219	31	14.16	74.5
2001	182	32	17.58	74.9
2002	177	33	18.64	75.3
2003	173	34	19.65	75.6
2004	171	34	19.88	73.6
2005	199	35	17.59	73.8
2006	207	35	16.91	72.0
2007	177	35	19.77	70.3
Average	**188**	**34**	**17.87**	**74.0**
		Annual Change (%)		
2000–01	(16.89)	3.23	24.21	0.54
2001–02	(2.75)	3.13	6.04	0.53
2002–03	(2.26)	3.03	5.41	0.40
2003–04	(1.16)	0.00	1.17	(2.65)
2004–05	16.37	2.94	(11.54)	0.27
2005–06	4.02	0.00	(3.86)	(2.44)
2006–07	(14.49)	0.00	16.95	(2.36)
Average	(2.45)	1.76	5.48	(0.81)

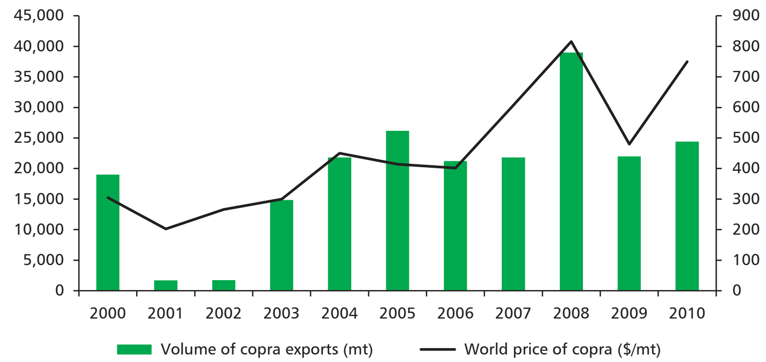
kg = kilogram, ( ) = negative value.
[a] Coconut including copra as indicated by FAOSTAT data.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

per capita exhibited a downward trend during 2000–2007 (0.81% per year), even though available coconut supply for food was increasing at a rate of 1.76% per year; this may be attributable to changing consumption patterns.

Trade

Copra is Solomon Island's main coconut export. Limited volumes of crude coconut oil and virgin oil are also exported. Copra continues to dominate trade, mainly due to better sector coordination for, and a lack of bulking capacity for other commodities, which makes trade even more costly due to prohibitive freight rates. For the copra industry, traders finance the working capital of the value chain through a system of buyers who then finance trucking and shipping. Most coconut products produced in the country are transported to Honiara or Noro for international shipment. Although Solomon Islands mainly (in terms of volume) exports copra, foreign exchange earnings from cocoa exports are higher than from copra exports because cocoa commands

Figure A4.3 Volume of Copra Exported by Solomon Islands and World Price of Copra, 2000–2010



mt = metric ton, $ = US dollar.

Sources: Commodities Export Marketing Authority (CEMA) cited in McGregor, A. 2006. *Solomon Islands Smallholder Agriculture Study*. Volume 3. Markets and Marketing Issues. Australian Goverment/Australian Aid. http://aid.dfat.gov.au/Publications/Documents/solomon_study_vol3.pdf and World Bank.

a higher price (MAL 2009b). Also, with higher values by weight than copra, cocoa obtains better freight value. Still, coconuts directly and indirectly affect a far larger proportion of the population, and hence constitute a potential engine for growth in the national economy.

Between 2000 and 2010, Solomon Islands exported 19,424 mt of copra per year on average. As expected, copra exports were particularly low in 2001 and 2002 due to CEMA's financial problems and ethnic tensions, as previously described (Figure A4.3). In 2008, copra exports reached a decade high of 38,979 mt. This can be attributed to the rise in the international price of copra to $816 per mt in 2008 from $607 per mt in 2007. Copra exports declined again in 2009 (21,973 mt), mainly due to a sharp decline in the world price (to $480 per mt). The senility of coconut trees, which affects about 60% of the country's plantations, also reduced coconut yields and led to the drop in exports (CBSI 2009). Moreover, unreliable shipping and increased coconut oil milling also contributed to declining exports. While the world price of copra rose by 56% in 2010 (to $750/mt), it seems that Solomon Islands was not able to take full advantage of this opportunity because exports only increased by 11% (to 24,395 mt). Copra production has not matched demand as the problems of aging coconut palms and inadequate infrastructure continue to plague the industry (CBSI 2010). Inadequate and unreliable interisland transport services are still major challenges for the copra industry. It is notable that with some donor support, the government has initiated the Franchise Shipping Scheme with the aim of improving the safety, reliability, and frequency of interisland shipping services to rural areas. Its impact, however, has yet to be seen; in the wake of coverage of eight routes having been trialed, concerns remain that this scheme is economically unsustainable (CBSI 2010).

Oil Palm Fruit

Overview and History

Oil palm was introduced in Solomon Islands in the 1970s. The Solomon Islands Plantation Ltd. (SIPL), a 6,000 ha oil palm plantation and mill on the Guadalcanal Plains, was established in 1971. It was a joint venture between the Commonwealth Development Corporation and the Solomon Islands Government. Up until the ethnic tensions, oil palm was the country's most successful agricultural industry in terms of efficiency, international competitiveness, and foreign exchange generation (McGregor 2006). Palm oil and palm kernels were among the nation's primary agricultural exports. In spite of widespread damage caused by Cyclone Namu in 1986, palm oil (and to a lesser extent kernel oil) became an important foreign exchange earner for the government and provided more than 10% of total revenue (Evans 2006). During the 1990s, the country benefited from its strong export performance providing a source of cash to rural communities and thus enhancing food security. However in 2000, the mill and offices of SIPL were destroyed during the ethnic tension. As such, the plantation was abandoned and for several years, Solomon Islands ceased exporting palm products.

In 2006, SIPL reopened under new management—as the Guadalcanal Plains Palm Oil Limited (GPPOL). The New Britain Palm Oil Ltd. (NBPOL), the largest palm oil producer in the South Pacific and a pioneer in the development of innovative approaches for introducing oil palm cultivation on customary land, acquired 80% shareholdings in GPPOL in April 2005. Prior to starting its palm oil operations, GPPOL undertook rehabilitation of processing facilities and completed extensive rehabilitation of the plantations, including replanting of 2,000 ha of palms (CBSI 2006, ADB 2010). The company returned all the land to landowners and then leased it back from them, providing 20% equity to landowners aside from the benefit of giving them royalties (ADB 2010).

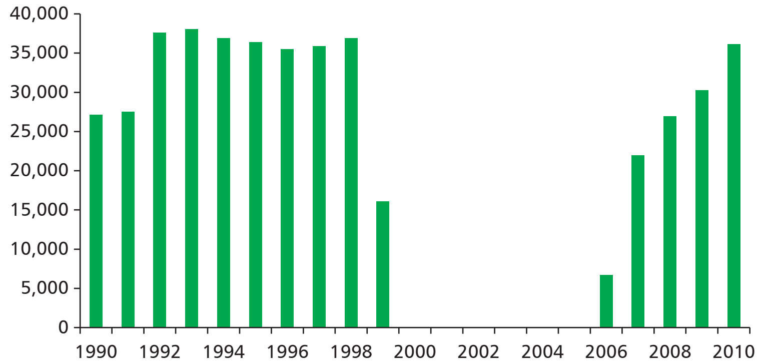
To increase production, GPPOL also implemented an out-growers program, whereby interested landowners manage and harvest their own crops to supply inputs to GPPOL, with technical assistance provided by the company. The company's goal is to increase plantings by around 1,000 ha per year to a total of 12,000–13,000 ha of plantation, along with 3,000–4,000 ha of out-grower plantings. In 2007, GPPOL employed 2,000 workers and engaged about 100 households in its out-grower scheme, managing an estimated area of 500 ha with the potential to expand both production and area planted (MAL 2009a). Since commencement of GPPOL's operations, production of palm oil and palm kernel has been steadily increasing.

Production

Oil palm fruit in Solomon Islands is processed to produce palm oil and palm kernel. These products are the principal commodities of the palm industry and the agriculture sector as a whole. Palm oil and kernel production[6] averaged 21,432 mt per year during 1990–2010 (Figure A4.4, Table A4.15). Specifically,

6 In the absence of reliable data on oil palm fruit production, area, and yield, a discussion on the trends in palm oil and kernel production is provided. FAO data on oil palm fruit production, area, and yield are available, but only as estimates. FAO data for 2000–2005 indicate that oil palm fruit was continually produced and harvested in Solomon Islands. Such data are questionable, since Solomon Islands Plantation Ltd. closed in 2000 because its mills and offices were destroyed during ethnic tension, and the plantation was abandoned. Plantation production only resumed in 2006.

Figure A4.4 Output of Palm Oil and Kernel, Solomon Islands, 1990–2010 (metric ton)



Source: Central Bank of Solomon Islands (CBSI). 2010. *2010 CBSI Annual Report.* Honiara, Solomon Islands.

Table A4.15 Output of Palm Oil and Palm Kernel, Solomon Islands, 1990–2010

Output (metric ton)	**1990–2010**
Palm oil	17,165.05
Palm Kernel	4,188.05
Palm Oil and Kernel	21,431.62
Growth rate in palm oil and kernel production (%)	0.06

Source: Compiled by authors from Central Bank of Solomon Islands Annual Report (various issues).

palm oil production averaged 17,165 mt, while palm kernel production averaged 4,188 mt. From 1990 to 2010, palm oil and kernel production generally increased. On average, palm oil and kernel production only grew by 0.06% annually during that period. The sector was generally growing in the early 1990s, but suffered a setback as production drastically declined in 1999, and eventually ceased from 2000 until 2005 due to the ethnic tension. Palm oil and kernel production in 2010 (36,147 mt) was about 33% higher than the 1990 level (27,155 mt).

Overall, the palm industry continues to recover steadily, given its re-development. In 2007, GPPOL's first full year of operations, palm oil and kernel production markedly increased over 2006 levels due to improved efficiency. The extraction rate for palm oil, which measures the volume of oil extracted as a ratio of the volume of fruit input, rose slightly to 22% from 21.6% in 2006, while the extraction rate for palm kernel rose to 24.5% from 21.6% (CBSI 2007). Palm oil and kernel production also rose due to increased acreage output, as well as increases in international market prices. In 2008, palm oil and kernel production continued to rise despite a decrease in world prices, with continued improvement in efficiency and increased acreage output (CBSI 2008). In 2009 and 2010, the positive output of the sector was due to improved yields of fruit bunches (CBSI 2009; 2010).

Table A4.16 Value of Palm Oil and Kernel Exports from Solomon Islands, and World Price of Palm Oil, 2000–2009

Year	Value of Palm Oil and Kernel Exports (SI$ '000)	World Price of Palm Oil ($/mt)
2000	0	310
2001	0	285
2002	0	390
2003	0	450
2004	0	471
2005	0	422
2006	16,195	477
2007	110,141	780
2008	164,151	1,006
2009	134,604	682
2010	256,246	901

mt = metric ton, SI$ = Solomon Islands dollar, $ = dollar.
Sources: Central Bank of Solomon Islands and World Bank.

Trade

The export volume of palm products has continued to increase since re-development of the industry in 2006 (CBSI 2009). The value of exports of palm products increased between 2006 and 2008, then dropped in 2009 and rose again in 2010 (Table A4.16). Aside from vastly improved domestic production in both the volume of palm oil and palm kernel, the rise in foreign exchange earnings can be attributed to continued rapid increases in international market prices for these commodities. In particular, the world price of palm oil increased from $477 per metric ton (mt) in 2006 to $1,006 per mt in 2008. This sharp increase in the world price of palm oil was primarily due to strong demand, both for edible oil and for use as biofuel (CBSI 2008). Following three consecutive years of increase in the value of palm product exports, this fell in 2009 (to SI$134.6 million), This fall was due to a decline in the international price (to $682 per mt) as a result of a drop in the prices of many substitute goods such as soybean and peanut oils (CBSI 2009). In 2010, export receipts for palm products increased in response to high production volumes and increased global palm oil prices (to $901 per mt). In that year, palm oil exports accounted for 14.4% of total exports (CBSI 2010). Europe is the major destination for Solomon Islands palm oil exports.

Sweet Potato

Overview and History

Sweet potato is Solomon Islands' most important subsistence crop. It is the country's main source of food energy, contributing an estimated 65% by weight of locally grown staple foods (Bourke et al. 2006). Prior to World War II, taro was the most important staple in the country. Sweet potato, however, became widely adopted after World War II, providing a replacement for taro, which was destroyed by taro leaf blight and later, taro beetle. Currently, sweet potato is the most important staple in all provinces of Solomon Islands.

Sweet potato is a productive and resilient root crop that grows in a wide range of soils and conditions. Its diversity at the cultivar level is very high. There is a high turnover of cultivars, with farmers actively sharing and collecting new varieties and discarding old ones, which may be related to yield declines due to buildup of viruses over time (Jansen et al. 2006). Early maturing and high-yielding 3- to 4-month varieties of sweet potatoes are very popular, but are usually complemented with some slower maturing and longer-lasting varieties (e.g., with a longer harvesting period), or with better-tasting cultivars for particular environments and tastes. While sweet potato is the country's major agricultural commodity, it does not register in economic reports because it is not exported, and trade is either in the local cash economy or in the subsistence economy, there being insufficient data relating to both markets. In the New Agricultural and Livestock Policy Matrix of the Solomon Island Government, 2010–2014, various strategies are put forward relating to root crops, including sweet potato. Strategies mentioned are export production support for root crops (production), support for root crop exporters (market facilitation), and root crop development (research). The goal is to develop traditional root crops such as sweet potato for export.

Production

Sweet potato production averaged 67,330 mt per year during 1980–2009 (Table A4.17). In the same period, the area harvested to sweet potato averaged 4,792 ha, providing an average yield of 14.01 t/ha. Sweet potato production generally exhibited an upward trend between 1980 and 2009 (Figure A4.5). Sweet potato production in 2009 (80,391 mt) was about 64% higher than the 1980 level (49,000 mt). Sweet potato production grew by 2.03% per year from 1980 to 2009. Meanwhile, area harvested and yields also increased at rates of 1.53% and 0.51% per year respectively. Growth in sweet potato production can generally be attributed more to area expansion than increases in yields.

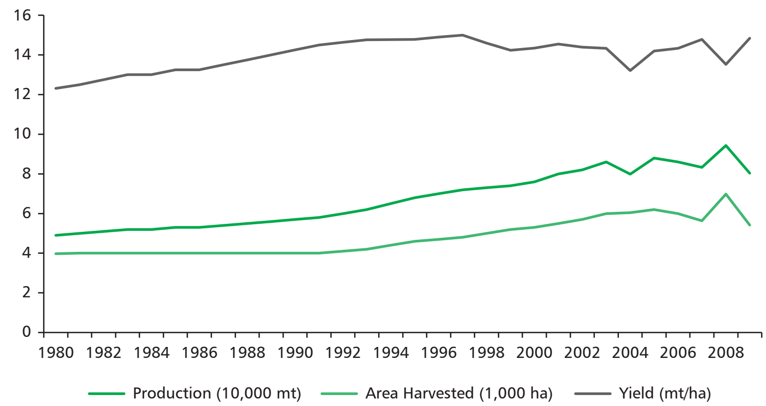
From 1980 to 1990, sweet potato production generally increased at a rate of 1.43% per year. During this period, production growth was mainly due to rising yields (1.41% per year); area harvested only grew at a rate of 0.02% per year. Between 1990 and 2000, sweet potato production grew at a higher rate (3.08% per year). While area harvested to sweet potatoes was

Table A4.17 Average Level and Growth Rate of Output, Area Harvested, and Yield of Sweet Potato, Solomon Islands, 1980–2009

		Growth Rate (%)			
Item	1980–2009	1980–1990	1990–2000	2000–2009	1980–2009
Output (mt)	67,330	1.43	3.08	1.16	2.03
Area harvested (ha)	4,792	0.02	3.14	1.28	1.53
Yield (mt/ha)	14.01	1.41	(0.06)	(0.04)	0.51

Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Figure A4.5 Trends in Output, Area Harvested, and Yield of Sweet Potato, Solomon Islands, 1980–2009



ha = hectare, mt = metric ton.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

increasing by 3.14% per year, yields fell at 0.06% per year. During 2000–2009, sweet potato production continued on a path of positive growth, but at a much slower rate than in the previous decade (1.16% per year). Although area harvested to sweet potato continued to rise (at 1.28% per year), yields continued to decline slowly (at 0.04% per year). In 2004, yields particularly declined due to extended periods of wet weather. Extended periods of very high rainfall during September–October 2004 adversely affected production in some areas—e.g., on the Weather Coast of Guadalcanal—resulting in food shortages. While sweet potato production generally increased over the years, problems are surfacing, such as shortened fallow periods and reduced yields as a result of population pressure, pests, diseases, and destructive logging in some areas (Bourke et al. 2006).

Consumption

Annual sweet potato consumption per capita declined at a rate of 0.77% per year over the period 2000–2007, due to a decrease in the per capita amount of sweet potato available for food (Table A4.18). From rates of 179 kg/capita/year in 2000, consumption fell to 169.2 kg/capita/year in 2007. Average annual per capita consumption for the period was 180 kg. Although production increased in 2000–2007 (1.81% per year), per capita consumption declined. Subsistence production is thus not keeping pace with the steadily rising population. To meet increasing national demand, ADB (2010) suggests the use of superior varieties (mainly sourced from Papua New Guinea), improved husbandry practices, extension services, and research into food production in the wet climatic conditions common in Solomon Islands, particularly in areas such as the coast of Guadalcanal.

The decline in annual per capita consumption of sweet potato may also be associated with changing consumption patterns. About 60% of rural

Table A4.18 Total and Per Capita Domestic Supply of Sweet Potato, Solomon Islands, 2000–2007

Year	Domestic Supply (metric ton '000) (= A + B – C – D)					Utilization (metric ton '000)		Annual Per Capita Amount Available for Food (kg)
	Production (A)	Imports (B)	Stocks (C)	Exports (D)	Total Dmestic Supply	Other Utilization	Amount Available for Food	
2000	76	0	0	0	76	2	74	179.0
2001	80	0	0	0	80	2	78	183.6
2002	82	0	0	0	82	2	80	183.5
2003	86	0	0	0	86	2	84	187.3
2004	86	0	0	0	86	2	84	182.4
2005	88	0	0	0	88	2	86	181.9
2006	86	0	0	0	86	2	84	173.4
2007	86	0	0	0	86	2	84	169.2
Average	**84**	**0**	**0**	**0**	**84**	**2**	**82**	**180.0**
					Annual Change (%)			
2000–01	5.26				5.26		5.41	2.57
2001–02	2.50				2.50		2.56	(0.05)
2002–03	4.88				4.88		5.00	2.07
2003–04	0.00				0.00		0.00	(2.62)
2004–05	2.33				2.33		2.38	(0.27)
2005–06	(2.27)				(2.27)		(2.33)	(4.67)
2006–07	0.00				0.00		0.00	(2.42)
Average	**1.81**				**1.81**		**1.86**	**(0.77)**

kg = kilogram, ( ) = negative value.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

household income is now spent on processed or imported food, which is replacing fresh staple crops such as sweet potato (Jansen et al. 2006). Processed foods are viewed as having high status and being convenient.

Rice Paddy

Overview and History

Recently, rice has become one of the major staple foods for a large majority of the Solomon Islands' populace. The country has the second-highest per capita rice consumption (100 kg) in the Pacific Islands (MAL 2009b). Current rice production levels cannot meet the demand for rice, so the government imports.

Efforts to commercialize rice cultivation in Solomon Islands started in the 1960s. In 1965, large-scale rainfed rice production with highly mechanized and calendar-based aerial application of fertilizers and pesticides began on the plains of Guadalcanal Island by an Australian company, Guadalcanal Plains Limited (MAL 2010). The company faced problems in rice cultivation such as weeds and pest (army worms) infestations (Trukai Industries 1998). The operation was taken over by a United States (US) Company, Mindoro International Corp., but in 1975 they sold to Hawaiian Agronomics International, an entirely owned subsidiary of Hawaii-based multinational

C. Brewer and Co. Ltd. (Moore 2004). In 1978, the Hawaiian group created a new subsidiary, Brewers Solomon Agriculture Ltd., a joint venture with the government, which owned 45% of all shareholdings (Lukhai Industries 1998, Moore 2004). Due to large development costs, serious pest problems (brown planthopper) and highly mechanized production practices that produced yields well below projections, the company experienced successive losses that led the Hawaiian owners to wind up their operations in 1982. The government purchased their shares and continued growing rice, but reduced operations from 2,000 ha to 1,000 ha. In 1986, the company completely closed down its operations due to inability to find new brown planthopper–resistant varieties, and weather disturbances (Lukhai Industries 1998, MAL 2010). In particular, in 1986 Cyclone Namu destroyed the remainder of the rice industry.

Production

Rice production averaged 3,685 mt from 1980 to 2009 (Table A4.19). In the same period, area harvested to rice averaged 1,089 ha for an average yield of 3.15 t/ha. From 1980 to 2009, rice production generally posted a downward trend (Figure 4A.6). On average, rice production fell by 4.74% per year during that time. Both area harvested to rice and rice yields showed a declining trend, but area harvested to rice declined at a faster rate (4.40% per year), while rice yields fell by 0.37% per year. Rice production in 2009 (at 4,434 mt) is significantly lower (69%) than the 1980 level (14,256 mt).

From 1980 to 1990, rice production showed a drastic decline (37.29% per year) as rice area harvested and yield decreased at a rate of 37.48% and 12.54%, respectively. During that period, rice production suffered problems of serious brown planthoppper infestation, and fields were devastated by Cyclone Namu.

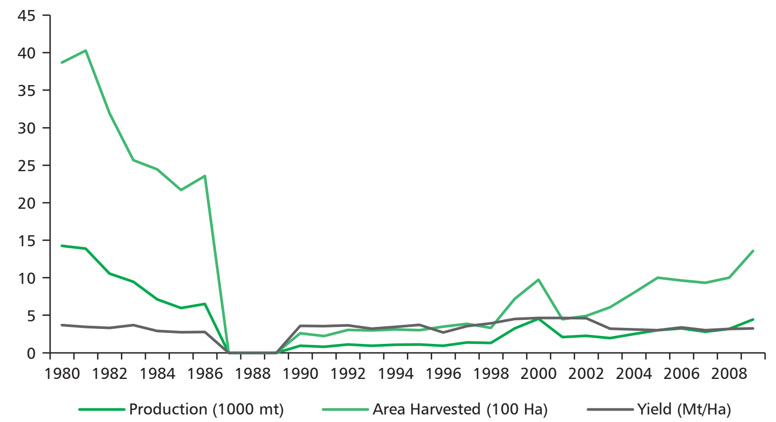
From 1990 to 2000, rice production grew by 15.65% per year as the area harvested to rice and rice yields rose by 12.53% and 2.45% per year respectively (Figure A4.6). Chinese Agriculture Technical Mission of Taipei,China (CATM) began during this period, and its rice program was expanding its operation to more provinces. From 2000 to 2009, rice production grew at a slower rate (2.30% per year) as the area harvested grew by 8.05% per year, but was accompanied by declining yields (5.37% per year).

Table A4.19 Average Level and Growth Rate of Output, Area Harvested, and Yield of Paddy, Solomon Islands, 1980–2009

		Growth Rrate (%)			
Item	1980–2009	1980–1990	1990–2000	2000–2009	1980–2009
Output (metric tons)	3,685	(37.29)	15.65	2.30	(4.74)
Area (ha)	1,089	(37.48)	12.53	8.05	(4.40)
Yield (mt/ha)	3.15	(12.54)	2.45	(5.37)	(0.37)

ha = hectare, mt = metric ton, ( ) = negative value.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Figure A4.6 Trends in Output, Area Harvested, and Yield of Paddy, Solomon Islands, 1980–2009

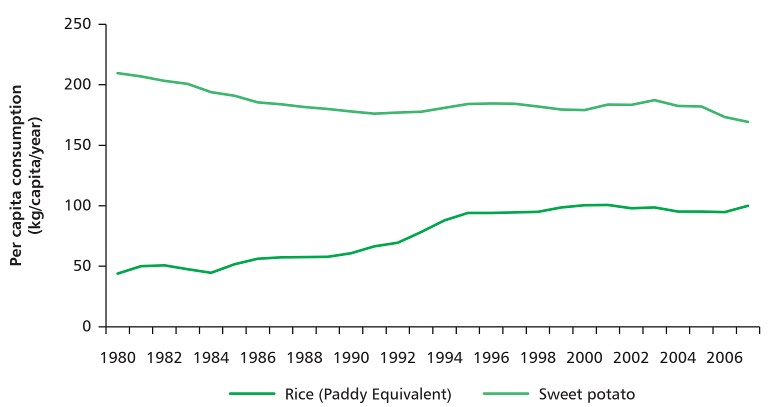


ha = hectare, mt = metric ton.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Consumption

Sweet potato is the most important source of food energy in Solomon Islands, although rice is also becoming an important staple food. Because of its ability to feed more people per kilogram, its qualities of being easy and fast to cook and easy to store for long periods, and its good taste, rice is becoming a normal form of energy intake for most of the Solomon Islanders. As shown in Figure A4.7, annual per capita consumption of sweet potato generally declined during 1980–2007, but annual per capita consumption of rice increased. Notably, annual per capita rice (paddy equivalent) consumption

Figure A4.7 Per Capita Consumption of Sweet Potato and Paddy Equivalent of Rice, Solomon Islands, 1980–2007



kg = kilogram.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

in 2007 (100 kg) was more than 120% higher than the 1980 level (44 kg), whereas annual per capita consumption of sweet potato in 2007 (169 kg) was 19% lower than the 1980 level (210 kg). Solomon Islands' annual per capita consumption of rice is one of the highest in the Pacific (MAL 2009b). Based on the 2005–2006 Household Income and Expenditure Survey, at the national level, households spent about 41% of their food budgets on cereals and cereal products, a category that includes rice. The survey showed that households in rural areas spend almost twice as much on cereals and cereal products as households in urban areas (50% vs. 26%).

In recent years, annual per capita rice consumption has declined slightly. More specifically, per capita consumption of rice (milled equivalent) decreased by 0.03% per year on average during 2000–2007, due to a decline in the per capita amount of rice available for food (Table A4.20). The quantity of rice imports and domestic rice production were not enough to meet the country's rice demand. Bourke et al. (2006) noted that consumption of rice per person fell due to steadily rising population, as well as both income and price effects. Real disposable income declined during this period, and the price of imported rice increased relative to the prices of locally grown staples. The world price of rice also rose, making imported rice less affordable. With reduced consumer spending power in both rural and urban locations, per capita rice consumption fell.

Table A4.20 Total nd Per Capita Domestic Supply of Milled Equivalent of Rice, Solomon Islands, 2000–2007

Year	Domestic Supply ('000 metric ton) (= A + B – C – D)					Utilization ('000 metric tons)		Annual Per Capita Supply Available for Food (kg)
	Production (A)	Imports (B)	Stocks (C)	Exports (D)	Total Domestic Supply	Other Utilization	Supply Available for Food	
2000	3	24	2	0	29	1	28	67.0
2001	3	33	(7)	0	30	1	29	67.2
2002	3	16	10	0	30	1	29	65.4
2003	3	22	5	0	30	1	30	65.7
2004	4	23	4	0	30	1	29	63.5
2005	4	33	(5)	0	31	1	30	63.4
2006	4	28	0	0	32	1	31	63.3
2007	4	37	(6)	0	34	1	33	66.7
Average	**4**	**27**	**0**	**0**	**31**	**1**	**30**	**65.0**
Annual Change (%)								
2000–01	0.00	37.50			3.45	0.00	3.57	0.30
2001–02	0.00	(51.52)			0.00	0.00	0.00	(2.68)
2002–03	0.00	37.50			0.00	0.00	3.45	0.46
2003–04	33.33	4.55			0.00	0.00	(3.33)	(3.35)
2004–05	0.00	43.48			3.33	0.00	3.45	(0.16)
2005–06	0.00	(15.15)			3.23	0.00	3.33	(0.16)
2006–07	0.00	32.14			6.25	0.00	6.45	5.37
Average	**4.76**	**12.64**			**2.32**	**0.00**	**2.42**	**(0.03)**

kg = kilogram, ( ) = negative value.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

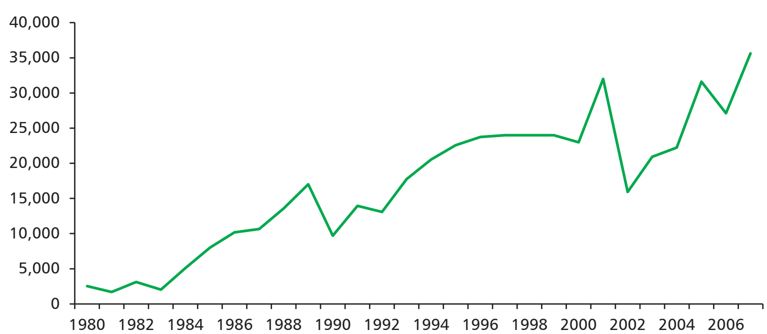
in 2007 (100 kg) was more than 120% higher than the 1980 level (44 kg), whereas annual per capita consumption of sweet potato in 2007 (169 kg) was 19% lower than the 1980 level (210 kg). Solomon Islands' annual per capita consumption of rice is one of the highest in the Pacific (MAL 2009b). Based on the 2005–2006 Household Income and Expenditure Survey, at the national level, households spent about 41% of their food budgets on cereals and cereal products, a category that includes rice. The survey showed that households in rural areas spend almost twice as much on cereals and cereal products as households in urban areas (50% vs. 26%).

In recent years, annual per capita rice consumption has declined slightly. More specifically, per capita consumption of rice (milled equivalent) decreased by 0.03% per year on average during 2000–2007, due to a decline in the per capita amount of rice available for food (Table A4.20). The quantity of rice imports and domestic rice production were not enough to meet the country's rice demand. Bourke et al. (2006) noted that consumption of rice per person fell due to steadily rising population, as well as both income and price effects. Real disposable income declined during this period, and the price of imported rice increased relative to the prices of locally grown staples. The world price of rice also rose, making imported rice less affordable. With reduced consumer spending power in both rural and urban locations, per capita rice consumption fell.

Trade

Solomon Islands does not export rice, given that domestic rice production is not even enough to meet the nation's rice demand. As a result, rice is perpetually imported (Figure A4.8). Rice imports constituted 58.6% of total food imports in 2007, and were valued at SI$ 140 million (MAL 2009a). Solomon Islands imported an average of 27,000 mt of rice annually during 2000–2007. In 2007, the majority of rice milled imports (92.23%) came from Australia (Table A4.21); the People's Republic of China supplied 6%. Solomon Islands also imports rice from Papua New Guinea.

Figure A4.8 Volume of Rice Imports, Solomon Islands, 1980–2007 (metric ton)



Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Table A4.21 Volume of Solomon Islands' Milled Rice Imports by Country Source, 2007 (metric ton)

Source-Country	2007	
	Milled Rice Imports (metric ton)	**Percentage Share in Total** (%)
Australia	32,864	92.23
China, People's Republic of	2,274	6.38
Papua New Guinea	462	1.30
Thailand	26	0.07
Japan	3	0.01
United States	2	0.01
Total	**35,631**	**100.00**

Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

With increasing rice imports, the rising cost of rice, and the burden it places on the import bill, the Solomon Islands government has again recently given priority to rice development and import substitution. The government recognized that a larger percentage of its import bill was spent on rice importation, placing pressure on the national budget. The government views increasing domestic rice production as the most appropriate way to reduce the foreign exchange drain caused by rice imports. Bourke et al. (2006) posits that this premise is flawed, suggesting an alternative approach of encouraging substitution of other locally grown staples. This source notes that increasing local rice production would be economically efficient if more foreign exchange were saved than expended in producing the additional rice. There is a need for a comprehensive study on the comparative advantage of production of rice and other staple food crops in Solomon Islands. Given that the National Rice Sector Policy is promoting a system of rice intensification (SRI), research on the economic efficiency of SRI in Solomon Islands needs to be a priority before further investments are made on expanding rice production.

Fisheries

Solomon Islands is endowed with 1.34 million km^2 of water area, offering rich marine resources (Gillett 2009, FAO 2009). As more than 80% of Solomon Islanders live in rural areas, subsistence fisheries are an important source of food, nutrition, and, to some extent, income. Offshore fisheries comprise most of the commercial fishing industry and provide formal employment, both in the raw and processed tuna subsectors (FAO 2009). Fisheries resources provide food and nutrition security, livelihood, and a source of revenue for the government.

Lawrence and Allen (2006) report the establishment of Rural Fisheries Centres by the Government of Solomon Islands between the 1980s and 1990s. These centers were created to provide services and backup needed by artisanal fishers such as extension services, ice for catch preservation, and assistance to market catches being transported to Honiara markets. The central and provincial governments had difficulty managing the centers, so they leased them to the private sector, but returned them to provincial control in the late-1990s (Lawrence and Allen 2006).

Categories of Fisheries

There are six categories of fisheries in Solomon Islands: (i) coastal commercial fisheries, (ii) coastal subsistence fishing, (iii) offshore locally based fishing, (iv) offshore foreign-based fishing, (v) freshwater fishing, and (vi) aquaculture. Table A4.22 presents a brief description of each category adapted mainly from Gillett (2009). The harvest from coastal commercial fisheries declined from 1,150 mt in 1990s to 800 mt in 2002 (Dalzell, Adams, and Polunin 1996; FAO 2009). In contrast, the catch from coastal subsistence fisheries increased from 6,000 mt to 12,000 mt in 1983 (Cook 1998), to 15,000 mt in 2007 (FAO 2009). Locally based offshore catches also increased from 13,723 mt in 2000 to 23,619 mt in 2007 (FAO 2009). Aquaculture was introduced in 1984, but the political unrest of the late-1990s deterred the industry from fully taking off.

Production

FAO (2010) estimates that total fish production reached 28,106 mt in 2009, which was mainly from capture fisheries from marine waters (Figure A4.9, Table A4.23). Kauhiona and Masolo (2011) similarly reported the advent of aquaculture in 1984, but reliable data are either lacking or unreliable. As a result, this discussion focuses more on marine fisheries and aquaculture rather than on inland fisheries resources.

Total fish production increased on average from 1984 until 1999, but declined considerably from 2000, largely in response to ethnic tension.

Offshore/Coastal Commercial and Coastal Subsistence Fishing

Marine fisheries in Solomon Islands are either offshore/coastal commercial fisheries or coastal subsistence fisheries (FAO 2009). Offshore/coastal commercial fishing involves large-scale tuna fishing activities carried out by domestic fishing vessels and foreign vessels in deep seas. Coastal commercial fishing targets non-tuna fisheries as well, such as finfish and invertebrates. Fishing vessels fish in lagoons, reefs, and coastal pelagic areas by hand line, trolling, use of spear guns, netting, and hand collection (FAO 2009). Trading takes place in urban markets with direct access to transport, as well as in the export market for high-value products such as beche-de-mer (sea cucumber) and trochus. The commercial catch of baitfish in coastal waters is used for offshore tuna fishing.

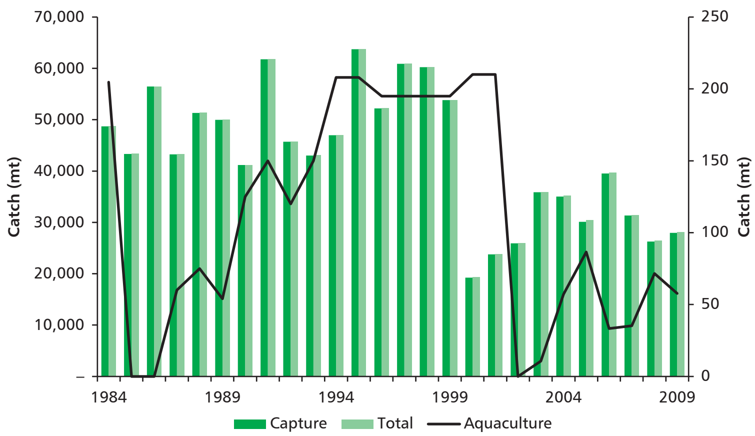
Coastal subsistence fishing is done with nonpowered canoes or simply by swimming from the shore. In 1984–2009, capture fisheries from coastal and offshore marine waters accounted for more than 90% of the total fish harvest in Solomon Islands waters Table A4.23). This indicates the richness of the country's fisheries resources. In fact, SICFS (2002) reveals that the country's tuna fishery is the world's largest because of the country's geographic location (i.e., being located in the Western and Central Pacific). At the same time, Solomon Islands fisheries are confronted by issues such as overcapacity

Table A4.22 Volume and Value of Varieties of Seafood Produced by Solomon Islands' Fisheries, by Subsector

Category	Description	Catch and value
Coastal commercial fisheries	• Mainly in urban areas of Honiara, Auki (Malaita), and Gizo (Western) • Primarily provides finfish to wage earners • Small-scale commercial fisheries (trochus shells, beche-de-mer, shark fins), an important source of cash • Inshore fishery for baitfish for Soltai pole-and-line tuna vessels	• 1990s = 1,150 mt at $4,343,811 (Dalzell, Adams and Polunin 1996) • 1988–2000 = 3,200 mt at SI$9.2 million (Gillett and Lightfoot 2002) • 2002: Tuna bait = 800 mt at SI$800,000 (SI$1/kg)
Coastal subsistence fisheries	• No concrete data has been collected	• 1983 = 6,000–12,000 mt (Cook 1988) • 1990 = 10,000 mt/yr (Skewes 1990) • Late-1990s = 13,564 mt (World Bank 2000) • Late-1990s = 13,000 mt at SI$39 million (Gillett and Lightfoot 2001) • 2006 = 15,000 mt • 2007 = 15,000 mt at SI$184 million
Locally based offshore catches	• Estimates catches of four main commercial tuna species (bigeye, yellowfin tuna, skipjack using national fleet) • By catch, an important component, was not included in estimating locally based offshore catch	• 2000 = 13,723 mt at SI$62.04 million • 2001 = 17,996 mt at SI$75.58 million • 2002 = 19,396 mt at SI$118.68 million • 2003 = 28,618 mt at SI$198.38 million • 2004 = 25,291 mt at SI$188.75 million • 2005 = 21,268 mt at SI$173 million • 2006 = 31,980 mt at SI$256.92 million • 2007 = 23,619 mt at SI$249.86 million
Foreign-based offshore catches	• Tuna catch by foreign vessels fishing in Solomon Island waters • Purse seine catch = 95% • Longline catch = 4.5%	• 2007 = 114,840 mt at $18,064 million
Freshwater catches	• Normally done by inland population with limited access to marine resources • Significant freshwater subsistence for inland population • Flagtails, gobies, freshwater mullets in Choiseul Province (Boseto et al. 2007) • Tilapia • Basically used for subsistence	• Tilapia = >16 mt/yr in Lake Tenaggano, Rennell Island (Nelson and Eldredge 1991) • Production = 2,000 mt at SI$11.2 million
Aquaculture	• Cultured species (giant clams, penaeid shrimps, freshwater prawns, pearl oysters, seaweed, beche-de-mer, hard and soft corals, milkfish, sponges, capture/culture postlarval animals) • Limited contributions to the rural sector due to political unrest • Community-based farms of corals gave small-scale sustained economic benefits for private sector aquarium companies • Seaweeds have potentials and are in the development stage	Postlarvae capture/culture: • 2005 = 1,386 pieces at SI$8,854 • 2006 = 1,202 pieces at SI$7,554 Corals: • 2005 = 1,800 pieces at SI$14,400 • 2006 = 7,000 pieces at SI$56,000 Seaweed: • 2005 = 320 mt at SI$640,000 • 2006 = 165 mt at SI$247,000

kg = kilogram, mt = metric ton.
Source: Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB.

Figure A4.9 Trends in Total Fish Harvests from Capture Fisheries and Aquaculture, Solomon Islands, 1984–2009 (metric ton)



Source: Food and Agriculture Organization (FAO). 2010. FISHSTATJ database. (Accessed in May 2010 and March–July 2011).

and overexploitation, these leading to severe economic and biological consequences not only in the country itself, but also at the global level (SICFS 2002).

Tuna (albacore, bigeye, skipjack, and yellowfin) accounts for 65% of total fish production in Solomon Islands waters (Table A4.24). Because tuna are highly migratory, regional management of this resource is key. As a result, the Forum Fisheries Agency was established, with Solomon Islands being a key participant (UN 2002).

Kauhiona and Masolo (2011) report the tuna catch by fishing gear, and by locally based offshore and foreign-based offshore catches. The catch from locally based offshore vessels followed a rising trend in 2000–2003, after which it steadily declined until 2009. The same trend was observed for foreign-based offshore catches during 2000–2005. Kauhiona and Masolo (2011) report that purse-seine gear contributed the highest average yearly tuna catch (82%), followed by longline gear (10%), and pole-and-line gear (2%) in 2000–2010 regardless of whether the fishing vessel concerned was locally based or foreign-based.

Freshwater Catch

Solomon Islands has many islands with a high inland population with little access to marine resources (Gillett 2009); Hence, inland water resources are heavily used by rural communities for subsistence fishing purpose and for income generation. Common fish species caught in inland waters are flagtails, gobies, and freshwater mullets in Choiseul (Gillett 2009). Production of freshwater fisheries is about 2,000 mt, with a farmgate price of SI$11.2 million (Gillett 2009).

Table A4.23 Total Output of Capture Fisheries and Aquaculture, Solomon Islands, 1984–2009 (metric tons)

Year	**Output** (metric tons)		
	Capture Fisheries	Aquaculture	Total
1984	48,718	205	48,746
1985	43,341	0	43,341
1986	56,477	0	56,477
1987	43,267	60	43,273
1988	51,312	75	51,317
1989	49,975	54	49,978
1990	41,169	125	41,174
1991	61,765	150	61,771
1992	45,723	120	45,731
1993	43,037	150	43,047
1994	46,985	208	46,998
1995	63,743	208	63,756
1996	52,219	195	52,232
1997	60,885	195	60,898
1998	60,222	195	60,235
1999	53,806	195	53,819
2000	19,242	210	19,257
2001	23,788	210	23,803
2002	25,905	0	25,905
2003	35,882	11	35,922
2004	35,012	57	35,226
2005	30,104	87	30,430
2006	39,538	33	39,707
2007	31,322	35	31,431
2008	26,256	72	26,401
2009	27,956	58	28,106

Source: Food and Agriculture Organization (FAO). 2010. FISHSTATJ database. (Accessed in May 2010 and March–July 2011).

Aquaculture

One potential means of lessening pressure on marine fisheries and ensuring availability of animal protein is to pursue aquaculture in freshwater or inland areas. Aside from increasing the availability of food, aquaculture creates opportunities for livelihood and for expanding exports (GSI 2010). The Government of Solomon Islands (2010) designed an Aquaculture Development Plan (2009–2014) that aims to reduce pressure on heavily exploited wild inshore stocks as well as to address food security and livelihood issues.

Lindsay (2007) reports the three basic types of aquaculture operations in Solomon Islands: (i) coral culture involving Acropora and soft corals; (ii) postlarval capture and culture from postlarval lobsters, shrimp, and fish

Table A4.24 Output of Solomon Islands' Marine Fisheries by Major Species, 1980–2009

Year	Albacore	Bigeye tuna	Skipjack Tuna	Yellowfin Tuna	Eucheuma Seaweeds nei	Marine Fishes nei	Sea Cucumbers nei	Sharks, rays, skates nei	Trochus shells
	Output (metric ton)								
1980	25	154	21,908	1,154	–	11,051	37	–	370
1981	2	193	21,106	1,531	–	11,376	8	–	400
1982	8	205	18,062	1,796	–	12,000	17	–	340
1983	19	351	29,828	3,234	–	12,055	9	–	393
1984	19	358	32,591	2,647	–	12,410	44	–	469
1985	12	406	26,568	3,011	–	12,775	14	–	500
1986	–	268	39,426	2,555	–	13,147	134	–	662
1987	–	487	24,144	4,806	–	13,147	146	4	445
1988	–	539	35,080	4,894	–	10,000	147	2	460
1989	–	688	29,191	4,383	–	15,000	87	5	372
1990	–	426	21,844	4,342	–	14,000	119	14	307
1991	–	368	42,296	4,224	–	14,000	622	23	87
1992	–	709	24,219	5,630	–	14,200	715	50	105
1993	–	733	20,080	7,193	–	14,500	316	30	99
1994	–	593	26,661	6,671	–	12,500	285	17	204
1995	24	1,072	40,136	8,433	–	12,000	219	1,513	80
1996	100	1,292	26,485	10,820	–	12,000	113	1,000	31
1997	109	1,611	36,311	9,411	–	12,000	203	1,000	139
1998	370	1,444	38,662	7,902	–	11,000	253	368	58
1999	136	1,270	35,613	8,643	–	7,000	376	475	202
2000	224	706	8,791	3,208	–	6,000	161	19	54
2001	54	810	11,943	4,410	–	6,000	375	10	146
2002	121	889	13,998	3,529	–	7,000	174	5	126
2003	95	1,185	18,653	6,431	40	9,000	409	2	43
2004	207	1,659	14,198	8,840	214	10,000	17	9	18
2005	–	788	12,605	6,630	326	10,000	20	10	18
2006	–	1,355	18,557	9,550	169	10,000	20	10	18
2007	–	955	13,743	6,546	108	10,000	20	10	18
2008	–	869	7,564	7,749	144	10,000	20	10	18
2009	–	193	9,557	8,133	150	10,000	20	10	18

– = data not available, nei = not easily identified.
Source: Food and Agriculture Organization (FAO). 2010. FISHSTATJ database. (Accessed in May 2010 and March–July 2011).

Table A4.25 Volume and Value of Aquaculture Output, Solomon Islands, 2005–2008

Product	2005		2006		2007		2008	
	Volume	Value ($)	Volume	Value ($)	Volume	Value ($)	Volume	Value ($)
Post larval capture/culture	1,400 pcs	1,200	1,200 pcs	1,000	n.a.	n.a.	n.a.	n.a
Coral	1,800 pcs	1,900	7,000 pcs	7,400	n.a.	n.a.	n.a.	n.a.
Giant tiger prawns	n.a.	n.a.	n.a.	n.a.	1 t	14,000	1 t	14,000
Seaweed	326 t	87,000	169 t	33,000	108 t	21,000	144 t	58,000

n.a. = not applicable, t = ton, pcs = pieces.
Source: Food and Agriculture Organization (FAO). 2009. *Climate Change and Food Security in the Pacific.* Rome. ftp://ftp.fao.org/docrep/fao/012/i1262e/i1262e00.pdf.

(coral shrimp (*Stenopus* spp.) and especially spiny lobsters (*Panulirus* spp.); and (iii) seaweed culture that utilizes *Kappaphycus alvarezii*. Table A4.25 reports the volume and value of these aquaculture products produced in Solomon Islands during 2005–2008.

FAO (2009) reports that aquaculture practices had not taken off to the degree planned because of political unrest, which caused commercial operations to close.

The most recent aquaculture and food security project was initiated by the Ministry of Fisheries and Marine Resources (Government of Solomon Islands), Aquaculture Section; Secretariat of the Pacific Commission; and the WorldFish Center in 2010–2011 (SPC 2011, WFC 2011). Major findings of this research suggest the importance of aquaculture to the future food security of Solomon Islands and existing market demand and opportunities in inland aquaculture. The study states that five areas should be addressed, through the involvement of all relevant actors/stakeholders from local communities to the private and public sectors (SPC 2011, WFC 2011). These are as follows: (i) expanding fish yields and productivity; (ii) enhancing skills and organizational arrangements; (iii) improving access to finance, infrastructure, and operations; (iv) providing access to markets; and (v) developing public policy and institutions.

Table A4.26 presents a summary of total capture fisheries production and aquaculture harvest from the six categories of fisheries in Solomon Islands. The results presented show that in 2007, offshore fishing by foreign-based vessels was responsible for the largest fish harvest, at 98,023 mt valued at SI$1.17 trillion (Gillett 2009).

Consumption and Nutrition Security

Around 80% of Solomon Islanders depend on the sea for their animal protein intake (UN 2002). Fish constitutes a key component of their diet, at an annual per capita consumption of 38 kg in 2003 (MAL 2010) and 33 kg in 2009 (Gillett 2009). According to a national survey, annual per capita fish consumption was approximately 33 kg. Further, the survey showed that rural dwellers consume less fish than urban dwellers (31.2 kg/capita/yr compared with 45.5 kg/capita/yr). Based on the survey, coastal communities had the highest fish consumption (118.3 kg/capita/yr). Trends in capita consumption of major food groups are presented in Figure A4.10 (FAO 2011). With population rising from 323,000 in 1991 to 498,000 in

Table A4.26 Output of Fish from Capture Fisheries (2007) and Aquaculture (2006), Solomon Islands

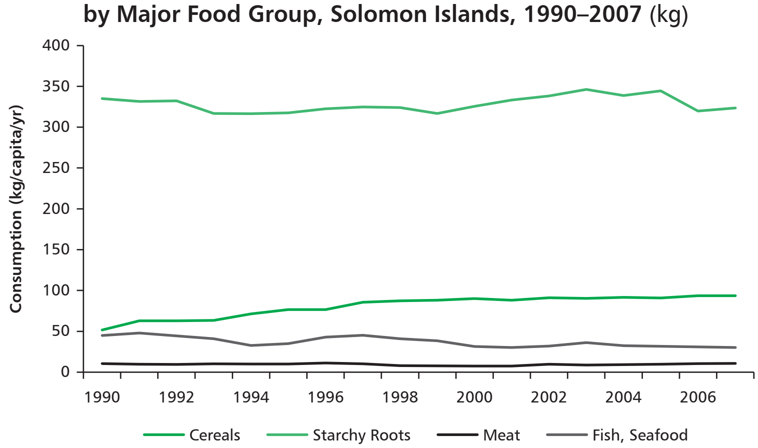
Fisheries Subsector	Volume (metric tons)	Value (SI$)
Coastal commercial	3,250	25,300,000
Coastal subsistence	15,000	84,000,000
Offshore locally based	23,619	249,864,889
Offshore foreign-based	98,023	1,174,648,841
Freshwater	2,000	11,200,000
Aquaculture	8,202 pieces + 165 mt	311,000
Total	**8,202 pieces + 142,057 mt**	**1,545,324,730**

Source: Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB..

2007, or at an average annual rate of 2.75% in 1991–2007, demand for food is also growing. Nevertheless, total consumption of starchy roots declined from 335 kg/capita/year in 1990 to 324 kg/capita/year in 2007, or at around 0.17% per year on average in 1991–2007. Similarly, consumption of fish fell from 45 kg/capita/year to 30 kg/capita/year between 1990 and 2007, and at an estimated annual fall of 1.76%. Cereal consumption, however, rose from 52 kg/capita/year in 1990 to 94 kg/capita/year in 2007, indicating an annual rate of increase at 3.73% from 1990 to 2007. This suggests a change in consumer preferences from root crops to cereals. At the same time, various types of livestock and imported canned meat are slowly increasing, suggesting that as a source of animal protein, these products are competing with fish (FAO 2009).

Of the fish consumed at the national level in Solomon Islands, 64% was from subsistence fishing and 36% was purchased (Bell et al. 2009).

Figure A4.10 Annual Per Capita Food Consumption by Major Food Group, Solomon Islands, 1990–2007 (kg)



kg = kilogram.
Source: Food and Agriculture Organization of the United Nations (FAO). 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Consumption of fish in the rural areas exhibited similar behavior: 73% was contributed by subsistence fishing and 27% was bought from the market. Unsurprisingly, urban dwellers purchase most of their fish products (87%) instead of relying on subsistence fishing (13%).

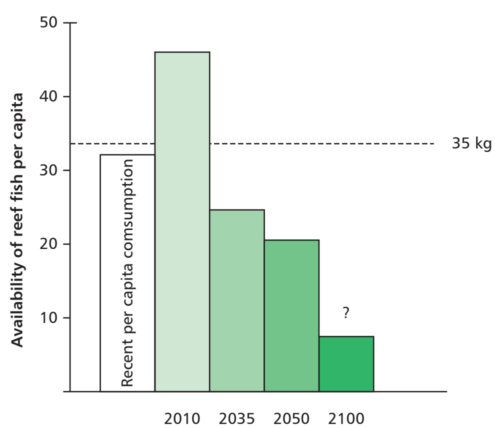
FAO (2009) describes the factors influencing the future demand for fish. These include rising population; rising fish prices (overexploitation of inshore areas, gradual devaluation of the local currency, fuel cost increases); and the relative cost of fish substitutes. Bell et al. (2009) estimate the future fish demand of the rural and urban communities in Solomon Islands in 2020 and 2030 (Table A4.27). These projections help government planners to recognize the amount of fish that should be made available to meet demand. In addition, the forecasts provide information on the amount of fish required by urban dwellers and rural communities. Bell (2010) describes the effect of increasing population on availability of reef fish for consumption. Rising population will intensify the amount of fish needed for food and nutrition, even though the availability of reef fish is declining over time (Figure A4.11).

Table A4.27 Projected Annual Demand for Fish, Solomon Islands, 2010–2030 (metric ton)

Country	2010	2020	2030
Solomon Islands	18,000	25,500	29,900
Urban	3,400	5,400	8,700
Rural	14,600	18,100	21,200

Source:Bell, J.D. et al. 2009. Planning the Use of Fish for Food Security in the Pacific. *Marine Policy*. 33. pp. 64–76.

Figure A4.11 Projected Human Population and Per Capita Availability of Reef Fish, Solomon Islands, 2010–2050



Year	Population
2010	549,000
2035	969,900
2050	1,245,800

kg = kilogram.
Source: Bell, J. 2010. Climate Change, Fisheries and Aquaculture in the Pacific: Adaptations for Food Security, Livelihoods and Economic Growth. Based on presentation made at ICES/PICES/FAO Symposium of the 'Climate change effects on fish and fisheries', Sendai, Japan, April 2010.

Fisheries and the Country's Economy

SICFCS (2002) shows that there are substantial fish resources in Solomon Island's exclusive economic zone, and that the biologically sustainable yearly catch of 120,000 mt had not been attained.

Contribution to GDP

Gillett (2009) reports the percentage share of the fisheries sector in Solomon Islands' GDP (Table A4.28), which ranged from 7.1% in 2003 to 5.9% in 2006, with equivalent values of SI$178 million and SI$208 million respectively.

Fishing Licenses

The sale of fishing licenses to foreign vessels is an important source of revenue for the Solomon Islands government. In 2007, license fees contributed 4% or SI$90 million of the government's total revenue and grants amounting to SI$2,049 million (Gillett 2009).

Employment

Aside from the fishing licenses, the fisheries sector provides employment for the people of Solomon Islands. The International Monetary Fund (2008) calculates total employment in the fishing sector during the period 2001–2004 (Table A4.29). Formal employment was mainly in offshore fisheries (i.e., the tuna industry) (Table A4.30).

Table A4.28 Percentage Share of Fisheries in GDP, Solomon Islands, 2003–2006 (current prices)

Item	2003	2004	2005	2006
Solomon Islands GDP (SI$ million)	2,497.5	2,807.6	3,129.8	3,497.7
Percentage share of fisheries in GDP	7.1	7.3	5.5	5.9
Value of output of fisheries (SI$ million)	177.8	206.0	171.5	208.4

GDP = gross domestic product.
Note: Data for 2005 and 2006 are provisional.
Source: Statistical Office. 2008. Economic Statistics. http://stats.gov.ck/Statistics/Economic in Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB.

Table A4.29 Percentage Share of Fisheries-Sector Formal Employment in Total Formal Employment, Solomon Islands, 2001–2004

Item	2001	2002	2003	2004
Formal-Sector Jobs in Fisheries Sector	5,179	5,030	5,015	5,114
Total Formal-Sector Jobs	42,631	41,067	41,723	42,297
Percentage Share of Formal-Sector Jobs in Fisheries Sector in Total Formal-Sector Jobs	12.1	12.2	12.0	12.1

Source: International Monetary Fund (IMF). 2008. *Solomon Islands: Tax Summary and Statistical Appendix*. IMF Country Report No. 08/359. Washington, DC. in Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB.

Table A4.30 Number of Solomon Islanders Employed in the Solomon Islands Tuna Industry, by Location of Employment, 2002, 2006, and 2008

Type of Employment	2002	2006	2008
Local jobs on vessels	464	66	107
Local jobs in shore facilities	422	330	827
Total	**886**	**396**	**934**

Source: Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB.

Tuna Industry

Solomon Islands supports the world's largest tuna fishery. The challenge facing the region in terms of oceanic environment is to ensure that overcapacity and overexploitation—which have had severe economic and biological consequences worldwide—are not exacerbated.

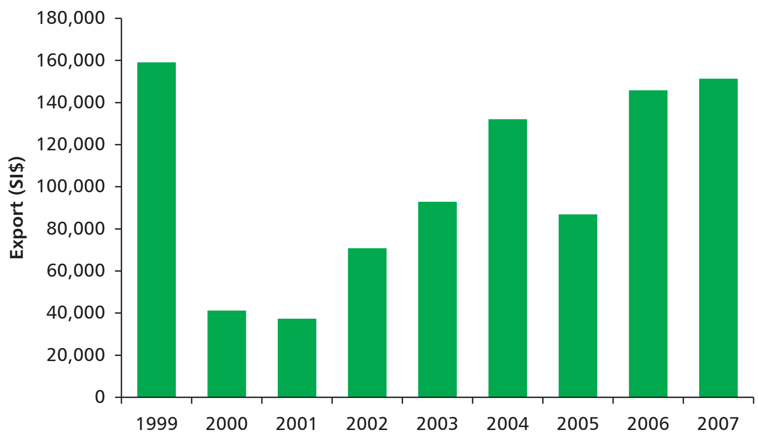
Tuna is a key contributor to Solomon Islands export revenues. FAO (2011) reports a total tuna catch of 48,378 mt in 1998, dropping to 12,929 mt in 2000. A National Tuna Management and Development Plan (known as "Tuna 2000") was initiated by the Government of Solomon Islands to explore the potential of this resource. Plans for aquaculture, game fishing, and reef and lagoon sports fishing were also included in the plan, but poor governance deterred their implementation (FAO 2009).

Three local tuna companies have been operating in Solomon Islands: Soltai Fishing and Processing Company Ltd. (formerly called as Solomon Taiyo), National Fisheries Development (NFD), and Solgreen (UN 2002). Prior to the ethnic tension of 1998, Solomon Taiyo employed around 2,300 cannery workers, the majority of whom were women. The industry was profitable, as it was able to comply with European Union (EU) import quality standards, and its products sold in the United Kingdom commanded attractive prices. Tensions caused Soltai and NFD to move to Western Province, and to reduce the scale of operations. The Government of Solomon Islands owns 51% of Soltai through its investment arm, the Investment Corporation of Solomon Islands, and 49% of Western Province (Macfadyen and Allison 2009). Soltai had 2,300 employees prior to 1998, but only 680 employees in 1999. Operations focused on exports of canned and smoked tuna and fishmeal (UN 2002). However, low international prices during some years discouraged extensive operations in the tuna industry.

Exports

FAO (2009) estimates the value of exports of fishery products from Solomon Islands at SI$168.6 million ($22 million) in 2007, or approximately 13% of total exports in that year. Of this, tuna constituted the majority, while beche-de-mer, trochus, items for the aquarium trade, seaweed, and shark fins comprised the country's non-tuna fishery exports. Gillett (2009) reports the value of exports of fish products from Solomon Islands over the period 1999–2007 (Figure A4.12).

Figure A4.12 Value of Fish Exports, Solomon Islands, 1999–2007 (SI$)



SI$ = Solomon Islands dollars.
Source: Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series*. Manila: ADB.

Impact of Climate Change on Fisheries

As with agriculture, fisheries will in all likelihood be negatively impacted by climate change. Variation in sea-surface temperatures, salinity concentration, water circulation patterns, and rising sea levels will all impact the biology of the aquatic ecosystem.

Sea-Surface Temperature

The Australia Bureau of Meteorology (ABM) and the Commonwealth Scientific and Indusrial Research Organisation (CSIRO 2011), together with the Solomon Islands Meteorological Service, observed increases in sea-surface temperatures in Solomon Islands during the 1950s. In the 1970s, sea-surface temperatures in Solomon Islands rose by an estimated 0.12ºC over the decade. Due to natural variation in sea-surface temperatures in the Pacific, determining long-term trends on sea-surface temperatures on a region-wide basis is a challenging task.

Ocean Acidification

The level of aragonite saturation is reported to have dropped from about 4.5 in the 18th century to 3.9± 0.1 in 2000 (ABM and CSIRO 2011). Projections of ocean acidification using CMIP3 suggest that the maximum annual aragonite saturation value in the year 2045 will be below 3.5, with reductions in subsequent years (ABM and CSIRO 2011). As previously pointed out, such a low level of aragonite saturation cannot support the growth of coral reefs. Other effects of such a low level of aragonite saturation are known to be coral bleaching and storm damage.

Sea-Level Rise

Sea-level rise in Solomon Islands is measured by means of satellite altimeters, which estimate that a 8 mm per year rise in sea level has occurred since 1993 (ABM and CSIRO 2011). While this value exceeds the global average of 3.2±0.4 mm per year, some of the objserved degree of sea-level rise is due to natural climate variability (ABM and CSIRO 2011).

Hourly tidal measurements performed at Honiara, show that high tides are greatest near the equinoxes, i.e., during April–May and November–December. The El Niño Southern Oscillation likewise raises sea levels by about 0.1 m during the La Niña phase of the oscillation, and decreases sea levels by the same amount during the El Niño phase of the oscillation.

CMIP3 projections under the higher emissions scenarios (i.e., the A2 [high-emissions scenario] and the A1B [medium-emissions scenario] indicate sea-level rise of about 5–15 cm by the year 2030, and 20–60 cm by 2090 (Table A4.31).

Table A4.31 Projected Sea-Level Rise in Solomon Islands in 2030, 2055, and 2090 Under Alternative Emissions Scenarios (cm)

Scenario	Projected Sea-Level Rise		
	2030	2055	2090
Low-emissions	4–14	10–26	17–45
Medium-emissions	5–14	8–30	19–58
High-emissions	4–15	8–30	20–60

cm = centimeter.

Note: The values shown represent 90% of the range of sea-level-rise values calculated by the models. All values for the projected rise in sea level reported in the table are relative to the average sea level over the period 1980–1999.

Source: Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2011. *Climate Change in the Pacific: Scientific Assessment and New Research. Vol. 2: Country Reports*. Aspendale, Victoria, Australia.

References

Allen, M., Bourke, R., Evans, B., Iramu, E., Maemouri, R., Mullen, B, Pollard, A. Wairiu, M., Watoto, C., Zotalis, S. 2006. Solomon Islands Smallholder Agriculture Study. Volume 4: Provincial reports. Australian Government Australian Aid.

Asian Development Bank (ADB). 2010. Solomon Islands 2010 Economic Report. *Pacific Studies Series.* Manila.

______. 2011. Food Security and Climate Change in the Pacific: Rethinking the Options. *Pacific Studies Series.* Manila.

Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2011. *Climate Change in the Pacific: Scientific Assessment and New Research. Vol. 2: Country Reports*. Aspendale, Victoria, Australia.

Bell, J. 2010. Climate Change, Fisheries and Aquaculture in the Pacific: Adaptations for Food Security, Livelihoods and Economic Growth. Based on presentation made at ICES/PICES/FAO Symposium of the 'Climate change effects on fish and fisheries', Sendai, Japan, April 2010.

Bell, J.D. et al. 2009. Planning the Use of Fish for Food Security in the Pacific. *Marine Policy*. 33. pp. 64–76.

Bourke, R. et al. 2006. *Solomon Islands Smallholder Agriculture Study Volume 1: Main Findings and Recommendations.* Canberra: Australian Agency for International Development (Australian Aid).

Central Bank of Solomon Islands (CBSI). 2006. *2006 CBSI Annual Report.* Honiara, Solomon Islands.

______. 2007. *2007 CBSI Annual Report.* Honiara, Solomon Islands.

______. 2008. *2008 CBSI Annual Report.* Honiara, Solomon Islands.

______. 2009. *2009 CBSI Annual Report.* Honiara, Solomon Islands.

______. 2010. *2010 CBSI Annual Report*. Honiara, Solomon Islands.

Cook, J. 1988. A Review of the Solomon Islands Fisheries Statistics Program. *Fisheries Statistical Bulletin Number 1*. Honiara: Fisheries Division, Ministry of Natural Resources.

Dalzell, P., T.J.H. Adams, and N.V.C. Polunin. 1996. Coastal Fisheries in the Pacific Islands. *Oceanography and Marine Biology*. 34. pp. 395–531.

Evans, B.R. 2006. *Solomon Islands Smallholder Agriculture Study. Volume 5: Literature Review: A Brief National Assessment of the Agriculture Sector*. Canberra: Australian Aid.

Food and Agriculture Organization (FAO). 2007. *Selected Indicators of Food and Agricultural Development in the Asia–Pacific Region 1996– 2006*. Rap Publication 2007/15. Bangkok: FAO Regional Office for Asia and the Pacific.

______. 2009. *Climate Change and Food Security in the Pacific.* Rome. ftp://ftp.fao.org/docrep/fao/012/i1262e/i1262e00.pdf

______. 2010. FISHSTATJ database. (Accessed in May 2010 and March–July 2011).

______. 2011. FAOSTAT. Statistical Database. Rome. Available: http://faostat.fao.org/

Gillett, R. 2009. Fisheries in the Economies of the Pacific Island Countries and Territories. *Pacific Studies Series.* Manila: ADB.

Gillett, R. and C. Lightfoot. 2002. The Contribution of Fisheries to the Economies of Pacific Island Countries. *Pacific Studies Series.* Manila: ADB.

GSI. 2007.

GSI. 2010.

Global Environment Facility, United Nations Development Programme, and Secretariat of the Pacific Regional Environment Programme. 2009. *Pacific Adaptation to Climate Change Solomon Islands Report of In-Country Consultations*.

International Bank for Reconstruction and Development (IBRD). 1965. *The Economic Development of the Territory of Papua and New Guinea.* Baltimore: Johns Hopkins Press.

International Monetary Fund (IMF). 2004. *Solomon Islands: Selected Issues and Statistical Appendix*. Country Report No. 04/255. Washington, DC.

______. 2008. *Solomon Islands: Tax Summary and Statistical Appendix.* IMF Country Report No. 08/359. Washington, DC.

Jansen, T. et al. 2006. S*olomon Islands Smallholder Agriculture Study: Vol 2. Subsistence Production, Livestock and Social Analysis*. Canberra: Australian Aid.

Jones, S., E.M. Fleming, and J.B. Hardaker. 1988. *Smallholder Agriculture in Solomon Islands: Report of the South Pacific Smallholder Project in the Solomon Islands, 1985–86*. South Pacific Smallholder Project. University of New England, New South Wales.

Kauhiona, H. and T. Masolo. 2011. Climate Change and Food Security: Adaptation Mechanisms and Policy Recommendations for Solomon Islanders. Unpublished report.

Lawrence, D. and M. Allen. 2006. Community Sector Program. Report of the CSP Community Snapshot. Volume 2: Analysis of the Data. CSP Milestone 13.

Lindsay, S. 2007. Aquaculture Sector Assessment, Solomon Islands. Lincoln International Pty Ltd., Marine Resource Organizational Strengthening Project Solomon Islands.

Macfadyen, G. and E. Allison. 2009. *Climate Change, Fisheries, Trade and Competitiveness: Understanding Impacts and Formulating Responses for Commonwealth Small States.* London: Commonwealth Secretariat.

McGregor, A. 2006. *Solomon Islands Smallholder Agriculture Study. Volume 3: Markets and Marketing Issues*. Canberra: Australian Aid.

Ministry of Agriculture and Livestock (MAL). 2008. *Ministry of Agriculture and Livestock Annual Report 2008*. Honiara.

______. 2009a. *National Agriculture and Livestock Sector Policy 2009–2014*. Honiara.

______. 2009b. *Ministry of Agriculture and Livestock Annual Report 2009*. Honiara.

______. 2010. *National Rice Sector Policy (2010–2015)*. Honiara.

Moore, C. 2004. *Happy Isles in Crisis: The Historical Causes for a Failing State in Solomon Islands, 1998–2004*. Canberra: Asia Pacific Press.

Nelson, S. and L. Eldredge. 1991. Distribution and Status of Introduced Cichlid Fishes of the Genera Oreochromis and Tilapia in the Islands of the South Pacific and Micronesia. *Asian Fisheries Science*. 4. pp. 11–22.

Secretariat of the Pacific Commission (SPC). 2007. S*olomon Islands 2007 Demographic and Health Survey. Facts and Figures at Your Fingertips.* New Caledonia.

______. 2008. *Fish for Food Security in the Pacific.* Working Paper 5. Marine Resources Division, Noumea, New Caledonia.

______. 2011. Aquaculture and Food Security in Solomon Islands. *SPC Fisheries Newsletter.* 134 (January–April 2011).

Solomon Islands Coastal Marine Resources Consultancy Services (SICFCS). 2002. Synopsis of Issues, Activities, Needs, and Constraints: Sustainable Development 1992–2002. Solomon Islands.

Solomon Islands Government. 2007. *Agriculture and Rural Development Strategy*. Ministry of Planning and Aid Coordination, Honiara, Solomon Islands.

Statistical Office. 2008. Economic Statistics. http://stats.gov.ck/Statistics/Economic.

Trukai Industries. 1998. *The Rice Relay International.* 3(6).

United Nations (UN). 2002. Common Country Assessment Solomon Islands. Suva, Fiji: Office of the United Nations Resident Coordinator.

United Nations Development Programme (UNDP). 2010. *The Real Wealth of Nations: Pathways to Human Development.* New York: Oxford University Press. http://hdr.undp.org/en/reports/global/hdr2010/

World Bank. 2007. *Solomon Islands Agriculture and Rural Development Strategy: Building Local Foundations for Rural Development*. Washington, DC.

______. 2011. *World Development Indicators.* Washington, DC. http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

World Bank and International Finance Corporation. 2010. *Improving the Livelihoods of Palm Oil Smallholders: The Role of the Private Sector.* http://www.ifc.org/ifcext/agriconsultation.nsf/AttachmentsByTitle/FSG+Report/$FILE/FSG+report_formatted.pdf

WorldFish Center (WFC). 2011. Aquaculture and Food Security in Solomon Islands. *Policy Brief 2011-08*.

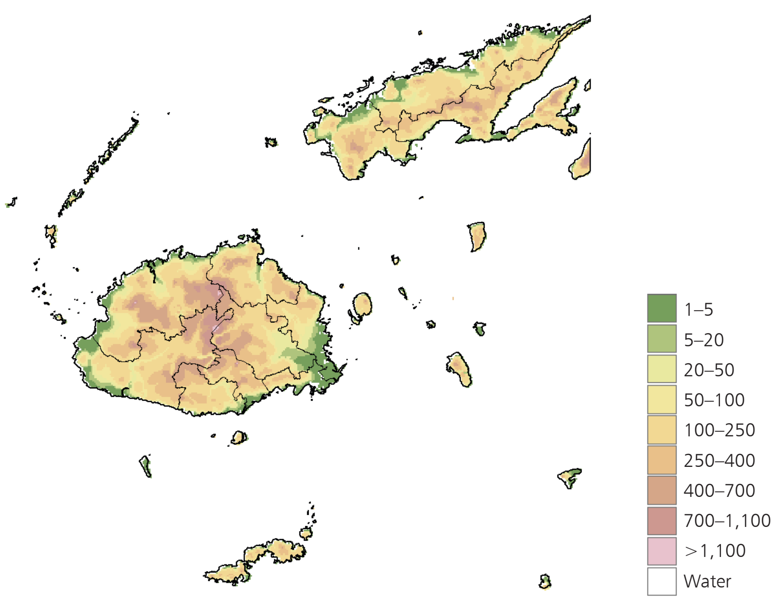
APPENDIX 5

Impacts of Climate Change on Agriculture and Food Security: Models Used and Analysis of Results for Fiji

Baseline Climate and Environment

Fiji is flatter along some of the coasts that would potentially be good for cultivation (Figure A5.1). The central parts of both Viti Levu and Vanua Levu, the two large islands, also have some steeper slopes, which are also generally poor for use as cropland (unless terraced), but can often be productive for livestock or forestry.

Figure A5.1 Elevation in Meters (GLOBE), Fiji



Source: GLOBE Task Team and others (Hastings, D.A., P.K. Dunbar, G.M. Elphingstone, M. Bootz, H. Murakami, H. Maruyama, H. Masaharu, P. Holland, J. Payne, N.A. Bryant, T.L. Logan, J.-P. Muller, G. Schreier, and J.S. MacDonald), eds., 1999. The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center. Colorado, US. Available from http://www.ngdc.noaa.gov/mgg/topo/globe.html.

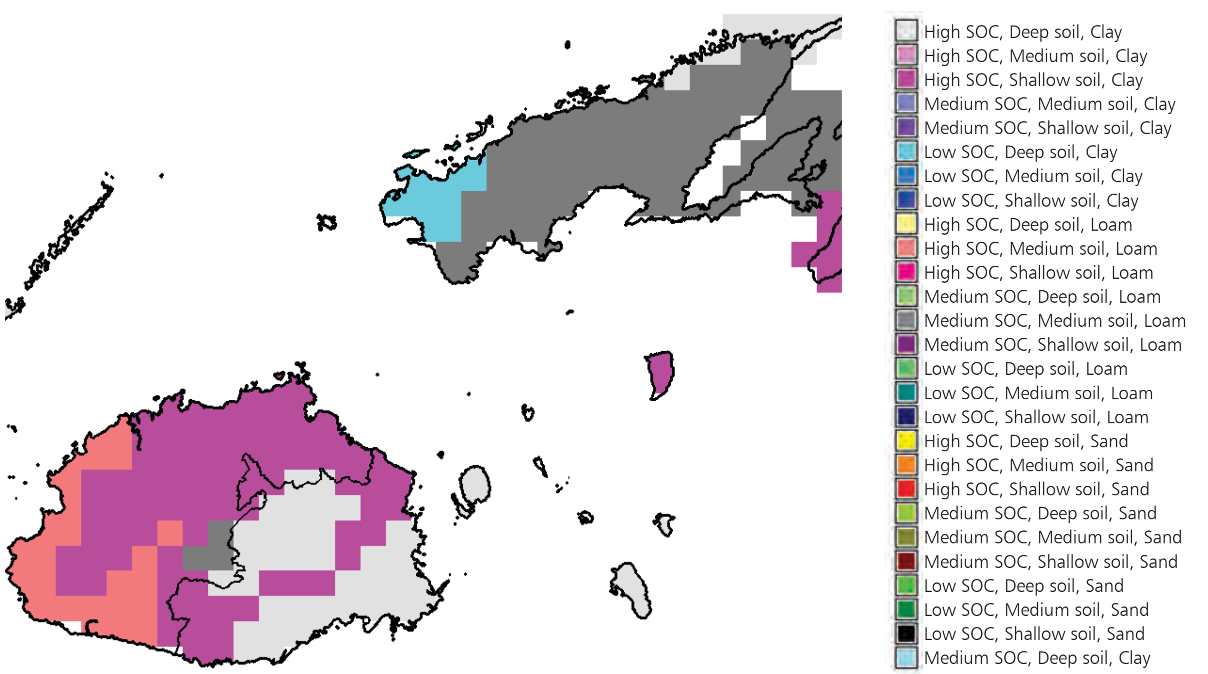
Figure A5.2 shows the soil database of Fiji used inside Decision Support System for Agrotechnology Transfer (DSSAT). The Western Division has mostly high soil organic carbon (SOC), shallow clay soils; the Northern Division has mostly medium SOC, medium-depth loams soils; and both the Eastern and Central divisions mostly have high SOC, deep clay soils, although Central Division also has high organic matter, shallow clay soils. Soils with high organic matter are generally more fertile, so areas in the Western and Central divisions, and smaller areas in the Eastern and Northern divisions, are potentially very fertile. Some of these areas, however, appear to be in areas with a moderate to high slope, but many are in flatter areas.

Shallow soils can limit the type of crops planted, excluding those that have deeper roots. Most of the shallow soils appear to be in higher elevations with steep slopes, while some of the deeper soils appear to be in flatter areas.

Historically, rainfall has been lowest on the western portion of Viti Levu, and highest in the central portion of the island, where the highlands are located (Figure A5.3). Vanua Levu does not appear to have as much rainfall variation, but appears to have a similar pattern where higher rainfall is observed in the elevated areas in the center of the island. Highest annual rainfall in Central Division is around 3,000 millimeters (mm) per year. Parts of Western Division receive less than 2,000 mm per year.

February generally appears to be the hottest month in Fiji, with daily high temperatures of up to 32°C in some places, but only 26°C in high elevation areas (Figure A5.4).

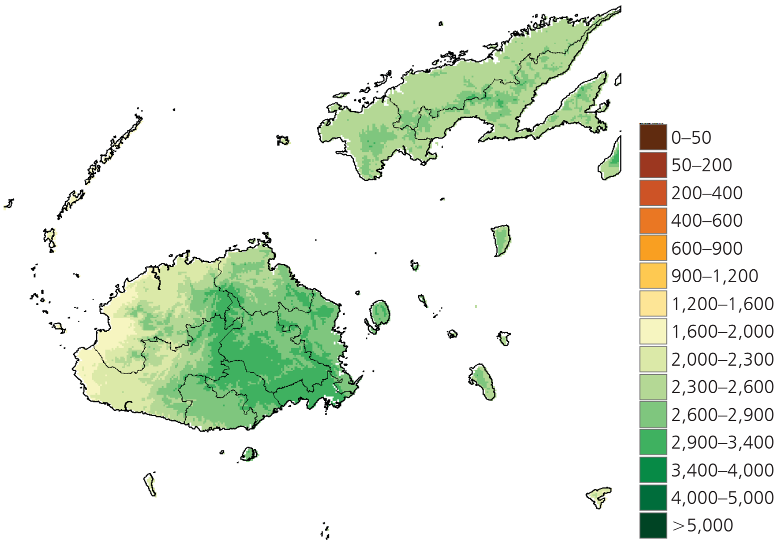
Figure A5.2 Soil Types, Fiji



SOC = soil organic carbon.

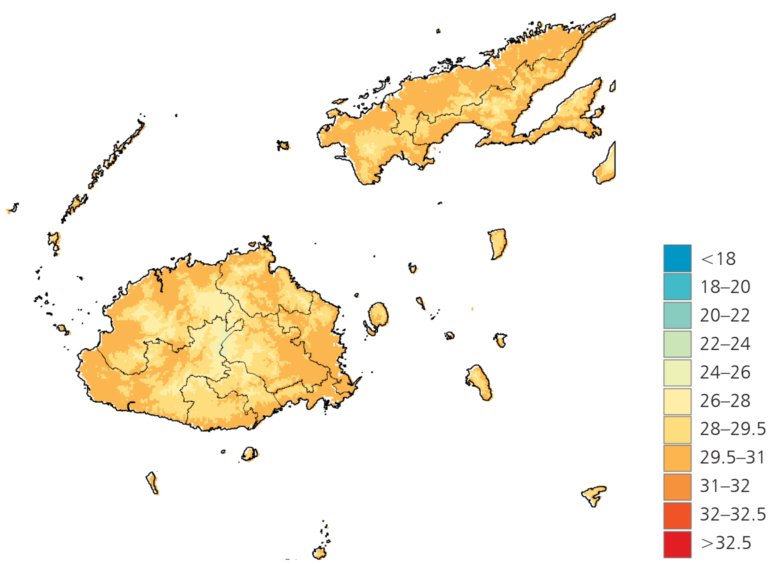
Source: Koo, J., and J. Dimes. 2010. HC27 Generic Soil Profile Database. Version 1, July. International Food Policy Research Institute, Washington, DC. http://hdl.handle.net/1902.1/20299 from the Harmonized World Soil DataBase (HWSD ver. 1.1) by Batjes, N., K. Dijkshoorn, V. Van Engelen, G. Fischer, A. Jones, L. Montanarella, M. Petri, et al. 2009. Harmonized world soil database. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Figure A5.3 Mean Annual Precipitation (mm), Fiji, 1950–2000



mm = millimeter.
Source: WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org).

Figure A5.4 Maximum Temperature (°C) During the Warmest Month, Fiji



°C = degree Celsius.
Source: WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org).

Overview of Results from Climate Models

Figures A5.5–A5.8 present climate change results for Fiji from the four global climate models (GCMs)—CNRM, CSIRO, ECHAM, and MIROC[1]—based on Scenario A1B for 2000–2050, including changes in annual precipitation, changes in precipitation during the wettest three months, and changes in normal daily maximum temperature during the warmest month.

DSSAT Results

Rainfed Sugarcane

Figure A5.9 shows yield changes between the baseline and 2050 climates for each of the four GCMs. CSIRO results stand out as predicting increased yields. Results of the other three models are in close agreement across most gridcells and show general trends toward yield losses. This is a reminder that climate change does not necessarily have to cause reduced yields, and that changes can sometimes work in the favor of farmers in some locations.

In the worst-case results from the GCMs (which are close to the outcome of three of the four GCMs), the Western Division is likely to suffer greater yield losses than the other divisions, although the Northern Division is not far behind (Table A5.1).

Rainfed Taro

Figure A5.10 shows yield changes in 2050 from the baseline climate for each of the four GCMs in our study. All four models indicate yield losses. The CSIRO results show more moderate losses compared with the significant losses indicated by the other three GCMs, which once again are in close agreement. In these images, there is a strip of five gridcells in the center of Viti Levu show particularly large yields gains relative to the gridcells around them.

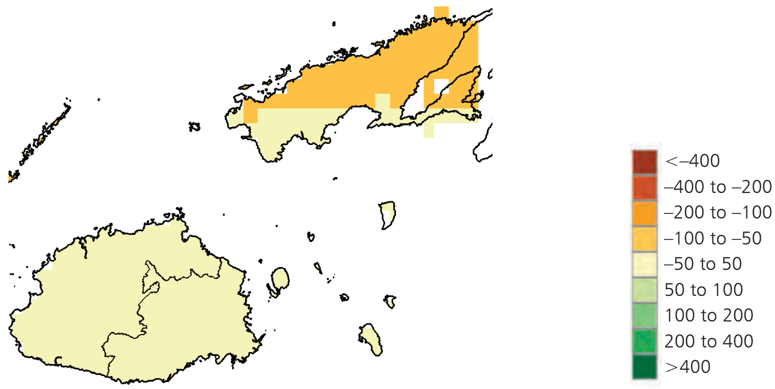
The climate data for the strip show that the current temperature is relatively low, rainfall is relatively high, and the elevation is high. It is possible that one of these factors—probably low temperature—limits production currently, but in the future, the climate conditions will be more favorable to growing taro there. Interestingly, sugarcane yields are consistently boosted in this strip, as well. Cropland is small or nonexistent in these cells, however, so it doesn't significantly affect the yields or yield changes significantly.

Both the Western and Northern divisions experience major losses of taro yield due to climate change (Table A5.2). Taro appears to respond well to higher fertilizer rates. In the low-fertilizer scenario, DSSAT assumes the availability of only 10 kilograms (kg) of nitrogen per hectare (ha), whereas under the high-fertilizer scenario, that increases to 90 kg/ha.

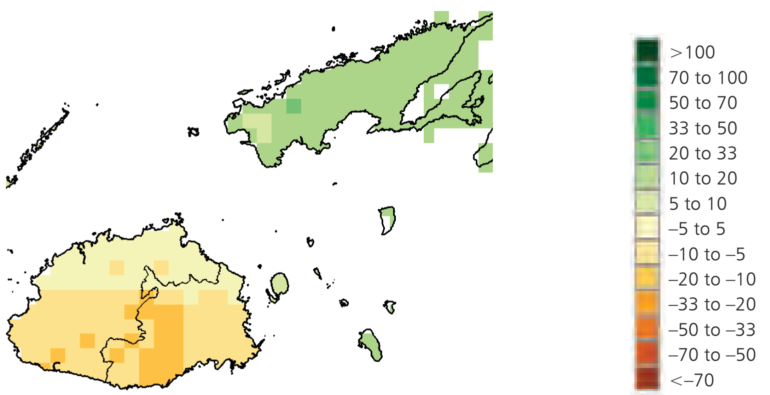
1 CNRM indicates Centre National de Recherches Météorologiques (The National Meteorological Center [of France]); CSIRO indicates the Commonwealth Scientific and Industrial Research Organisation (of Australia); ECHAM indicates the Max Planck Institute for Meteorology at the European Center Hamburg (Germany); and MIROC indicates the Model for Interdisciplinary Research on Climate (Japan).

Figure A5.5 Rainfall and Temperature Changes as Modeled by CNRM–CM3 Global Climate Model under Scenario A1B, Fiji, 2000–2050

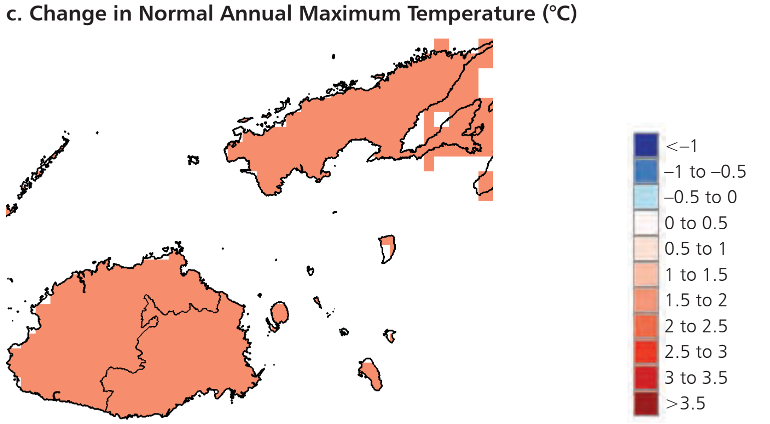
a. Change in Annual Rainfall (mm)



b. Change in Rainfall (mm) during the Wettest 3 Months



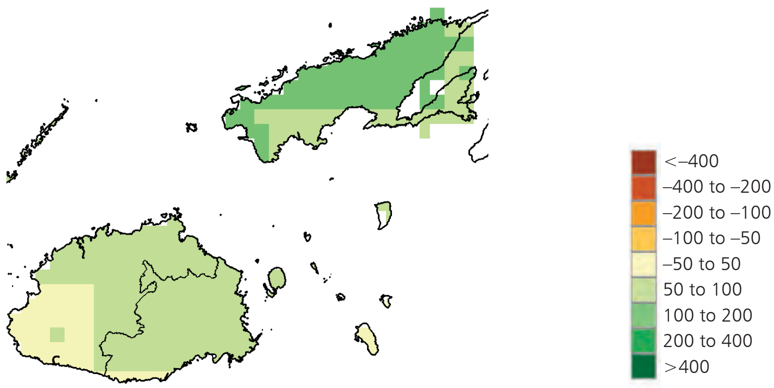
c. Change in Normal Annual Maximum Temperature (°C)



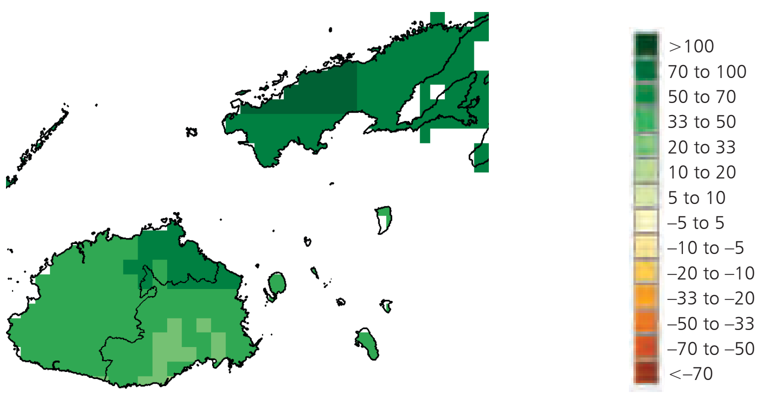
CNRM-CM3 = Centre National de Recherches Météorologiques Coupled global climate model Version 3, °C = degree Celsius, mm = millimeter.
Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3).

Figure A5.6 Rainfall and Temperature Changes as Modeled by CSIRO Mk3 Global Climate Model under Scenario A1B, Fiji, 2000–2050

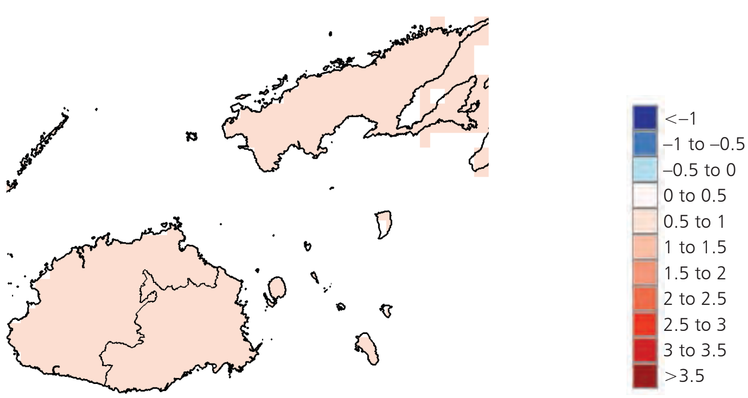
a. Change in Annual Rainfall (mm)



b. Change in Rainfall (mm) during the Wettest 3 Months



c. Change in Normal Annual Maximum Temperature (°C)

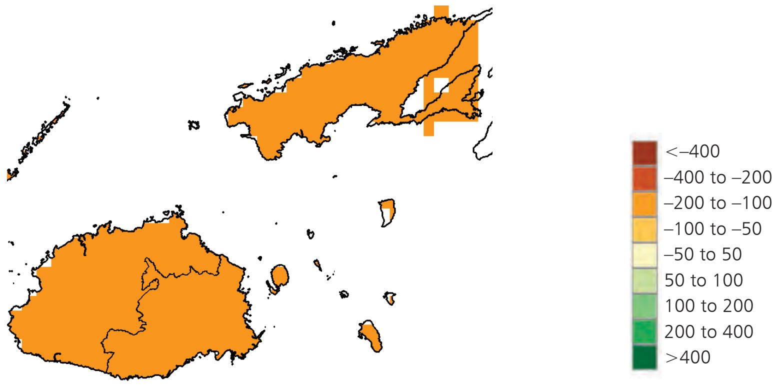


CSIRO Mk3 = Commonwealth Scientific and Industrial Research Organisation Mk3 Version, °C = degree Celsius, mm = millimeter.

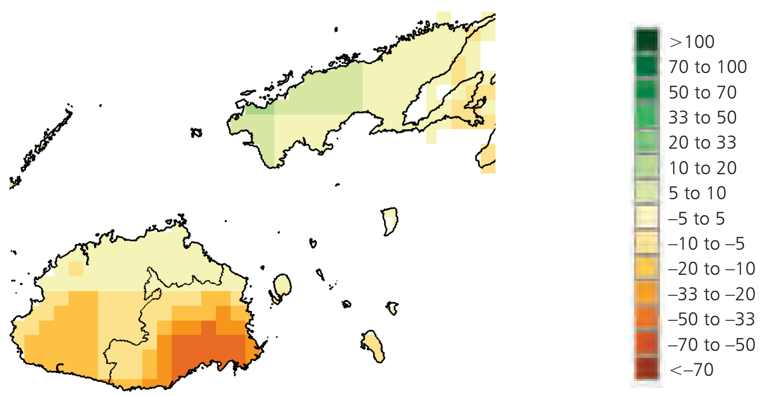
Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3).

Figure A5.7 Rainfall and Temperature Changes as Modeled by ECHAM5 under Scenario A1B, Fiji, 2000–2050

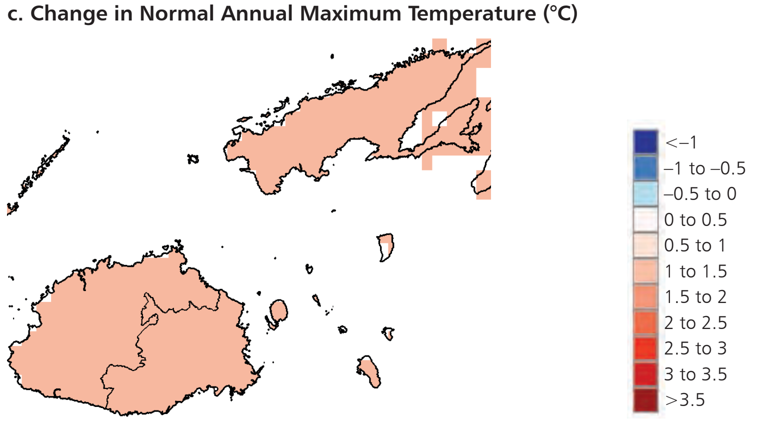
a. Change in Annual Rainfall (mm)



b. Change in Rainfall (mm) during the Wettest 3 Months



c. Change in Normal Annual Maximum Temperature (°C)

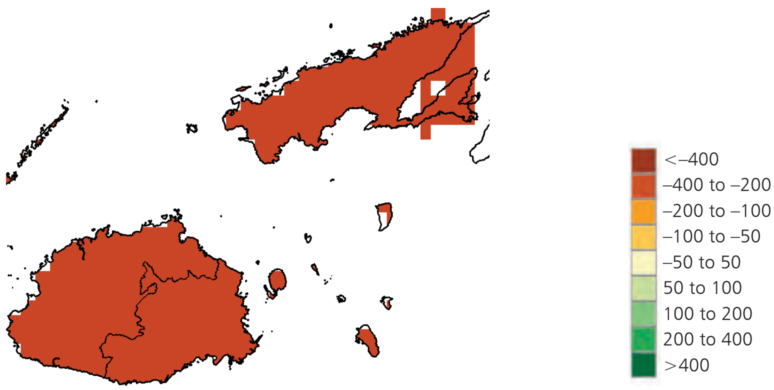


°C = degree Celsius, ECHAM5 = European Center Hamburg , mm = millimeter.

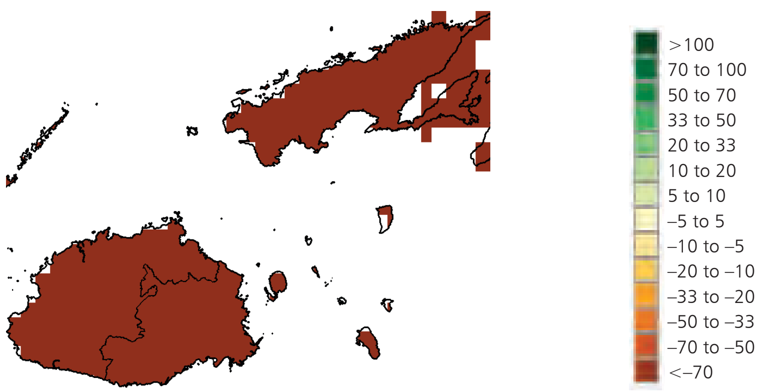
Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3).

Figure A5.8 Rainfall and Temperature Changes as Modeled by MIROC 3.2, Medium Resolution, under Scenario A1B, Fiji, 2000–2050

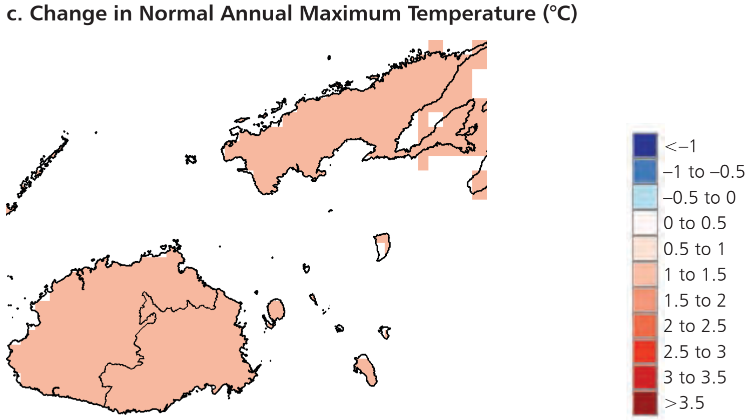
a. Change in Annual Rainfall (mm)



b. Change in Rainfall (mm) during the Wettest 3 Months



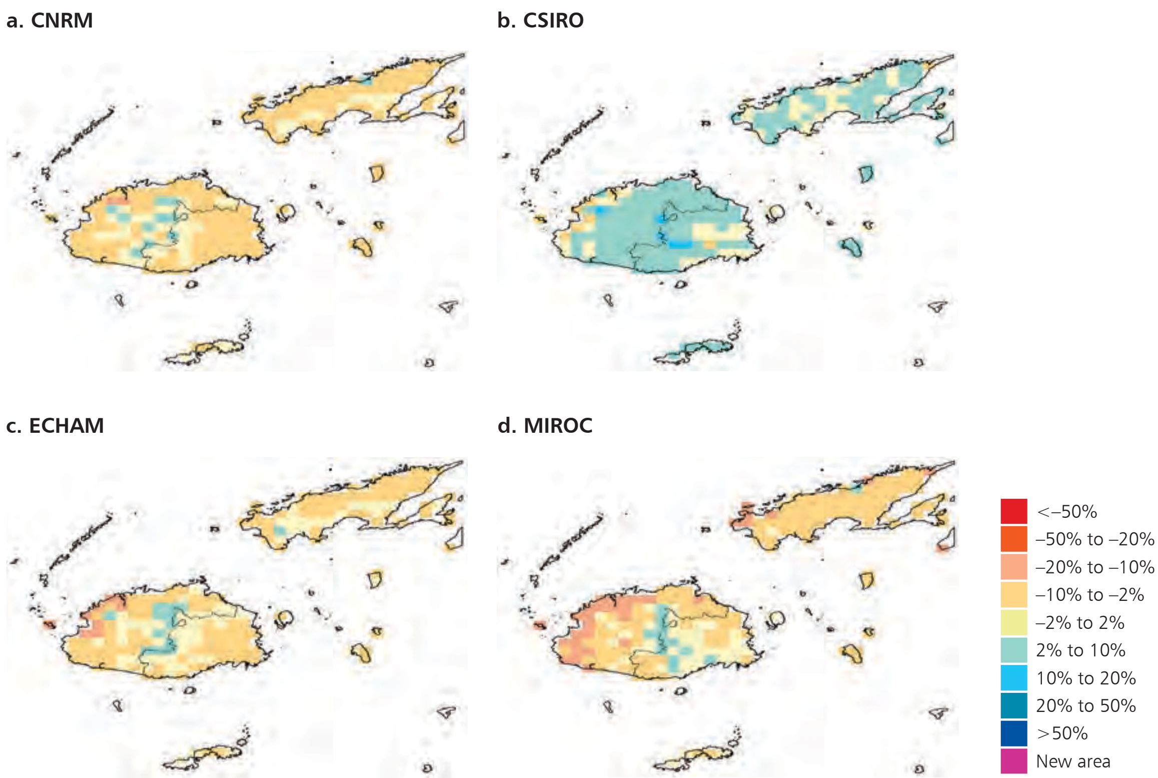
c. Change in Normal Annual Maximum Temperature (°C)



°C = degree Celsius, MIROC 3.2 = Model for Interdisciplinary Research On Climate, mm = millimeter.

Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3).

Figure A5.9 Change in Yield of Rainfed Sugarcane due to Climate Change, Optimal Planting Month and Cultivar for the Year Concerned, Fiji, 2000 and 2050



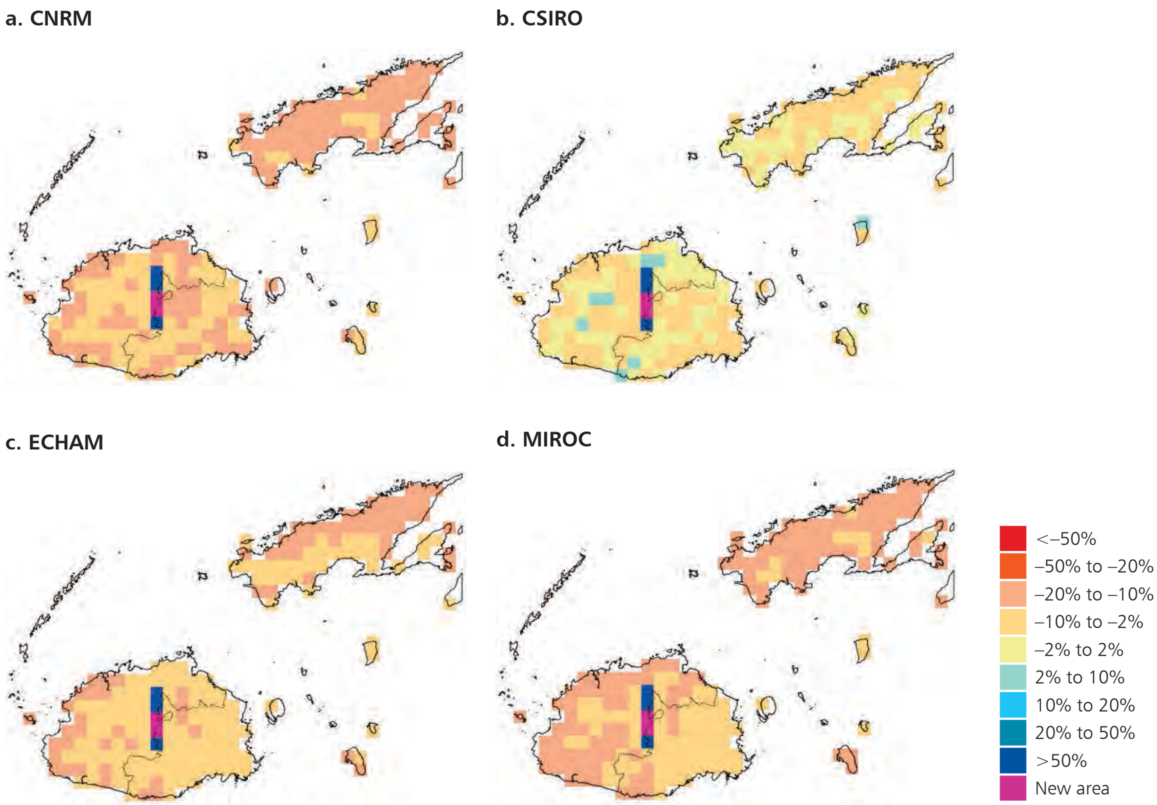
CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

Table A5.1 Regional Impacts of Climate Change on Rainfed Sugarcane, Fiji, 2000 and 2050

	Change in Yield as Compared to Year 2000 (%)							
	Maintaining Cultivar and Planting Month as in Year 2000				Cultivar and Planting Month Optimal for Year 2050			
Region	Worst case		Best Case		Worst Case		Best Case	
Nationwide	(8.3)	MIROC	2.3	CSIRO	(7.6)	MIROC	2.8	CSIRO
Central	(7.0)	CNRM	2.6	CSIRO	(4.9)	CNRM	3.0	CSIRO
Eastern	(6.1)	CNRM	2.1	CSIRO	(4.8)	MIROC	3.2	CSIRO
Northern	(7.5)	MIROC	2.0	CSIRO	(7.2)	MIROC	2.2	CSIRO
Western	(9.4)	MIROC	2.4	CSIRO	(8.6)	MIROC	3.0	CSIRO

CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, MIROC = Model for Interdisciplinary Research On Climate, ( ) = negative value.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

Figure A5.10 Change in Yield of Rainfed Taro due to Climate Change, Optimal Planting Month and Cultivar for the Year Concerned, with High Fertilizer Levels, Fiji, 2000 and 2050



CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

Table A5.2 Regional Impacts of Climate Change on Rainfed Taro with High Fertilizer Levels, Fiji, 2000 and 2050

	Change in Yield as Compared to Year 2000 (%)							
	Maintaining Cultivar and Planting Month as in Year 2000				Cultivar and Planting Month Optimal for Year 2050			
Region	Worst Case		Best Case		Worst Case		Best Case	
Nationwide	(17.5)	MIROC	(3.9)	CSIRO	(12.3)	MIROC	(2.5)	CSIRO
Central	(11.4)	CNRM	(3.3)	CSIRO	(9.0)	CNRM	(2.5)	CSIRO
Eastern	(11.7)	MIROC	(3.6)	CSIRO	(9.6)	CNRM	(2.3)	CSIRO
Northern	(18.6)	MIROC	(3.8)	CSIRO	(13.5)	CNRM	(3.3)	CSIRO
Western	(18.2)	MIROC	(4.1)	CSIRO	(12.6)	MIROC	(2.2)	CSIRO

CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, MIROC = Model for Interdisciplinary Research On Climate, ( ) = negative value.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

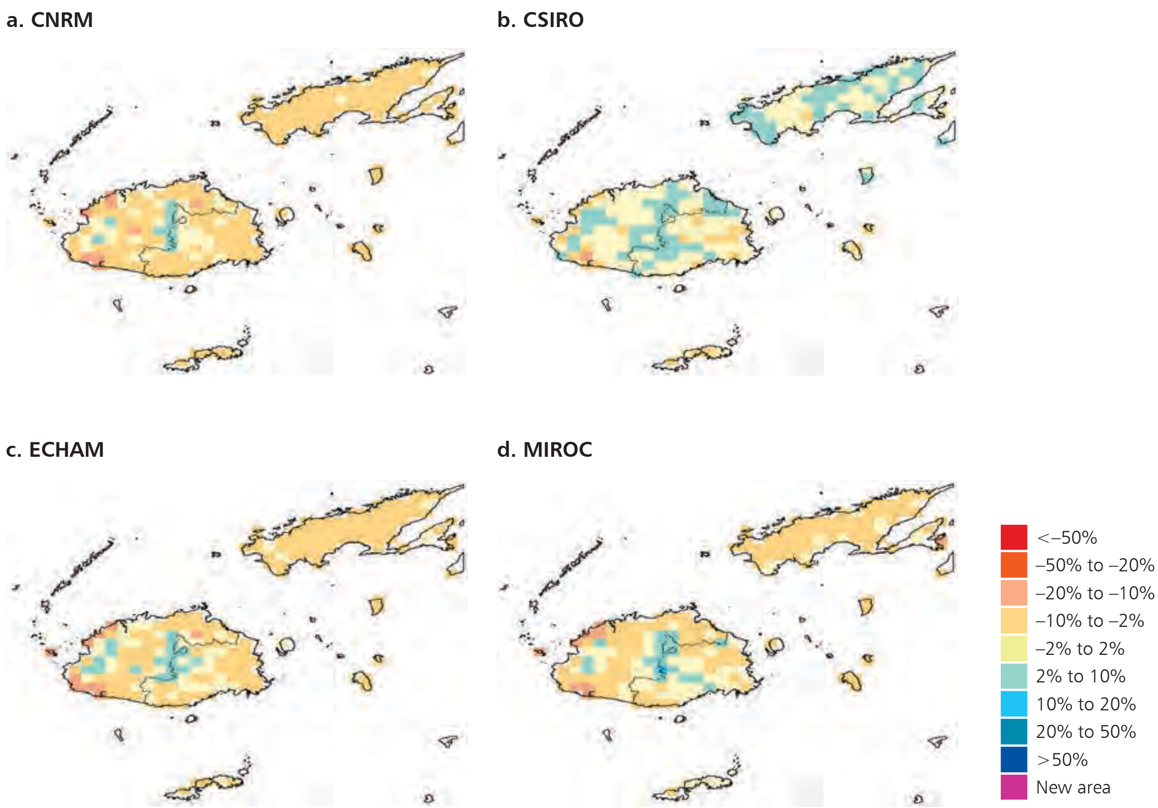
Rainfed Rice

In the baseline climate, rainfed rice yields appear to be relatively high in the Central and Eastern divisions, with moderate yields in the Northern Division, and lower yields in the Western Division.

Results for rainfed rice are qualitatively similar to those for sugarcane and taro: CSIRO stands out as optimistic relative to the other three models, which generally show yield declines to be greatest in the lower elevations (Figure A5.11). (Note that the anomalous strip affecting sugarcane and taro yields is also visible in these results.) For these results, application of nitrogen fertilizer is assumed at a rate of 90 kg/ha.

Results indicate that yield losses due to climate change are not likely to exceed 6%, as long as farmers are able to adapt to the effects of climate change by adjusting their planting months and their cultivar selection (Table A5.3).

Figure A5.11 Change in Yield of Rainfed Rice due to Climate Change, Optimal Planting Month and Cultivar for the Year Concerned, with High Fertilizer Levels, Fiji, 2000 and 2050



CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

Table A5.3 Regional Impacts of Climate Change on Rainfed Rice with High Fertilizer Levels, Fiji, 2000 and 2050

Region	Change in Yield as Compared to Year 2000 (%)							
	Maintaining Cultivar and Planting Month as in Year 2000				Cultivar and Planting Month Optimal for Year 2050			
	Worst Case		Best Case		Worst Case		Best Case	
Nationwide	(11.0)	CNRM	(4.0)	CSIRO	(5.3)	CNRM	0.2	CSIRO
Central	(7.5)	CNRM	(1.3)	CSIRO	(5.5)	CNRM	(0.3)	CSIRO
Eastern	(8.6)	CNRM	(2.0)	CSIRO	(6.3)	CNRM	(1.1)	CSIRO
Northern	(13.4)	CNRM	(3.1)	CSIRO	(5.6)	ECHAM	2.3	CSIRO
Western	(11.3)	ECHAM	(4.6)	CSIRO	(5.4)	CNRM	(0.4)	CSIRO

CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate, ( ) = negative value.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

References

Batjes, N., K. Dijkshoorn, V. Van Engelen, G. Fischer, A. Jones, L. Montanarella, M. Petri, et al. 2009. Harmonized world soil database. Laxenburg, Austria: International Institute for Applied Systems Analysis.

GLOBE Task Team and others (Hastings, D.A., P.K. Dunbar, G.M. Elphingstone, M. Bootz, H. Murakami, H. Maruyama, H. Masaharu, P. Holland, J. Payne, N.A. Bryant, T.L. Logan, J.-P. Muller, G. Schreier, and J.S. MacDonald), eds., 1999. The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model. Version 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center. Colorado, US. Available from http://www.ngdc.noaa.gov/mgg/topo/globe.html

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas". *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org

Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3

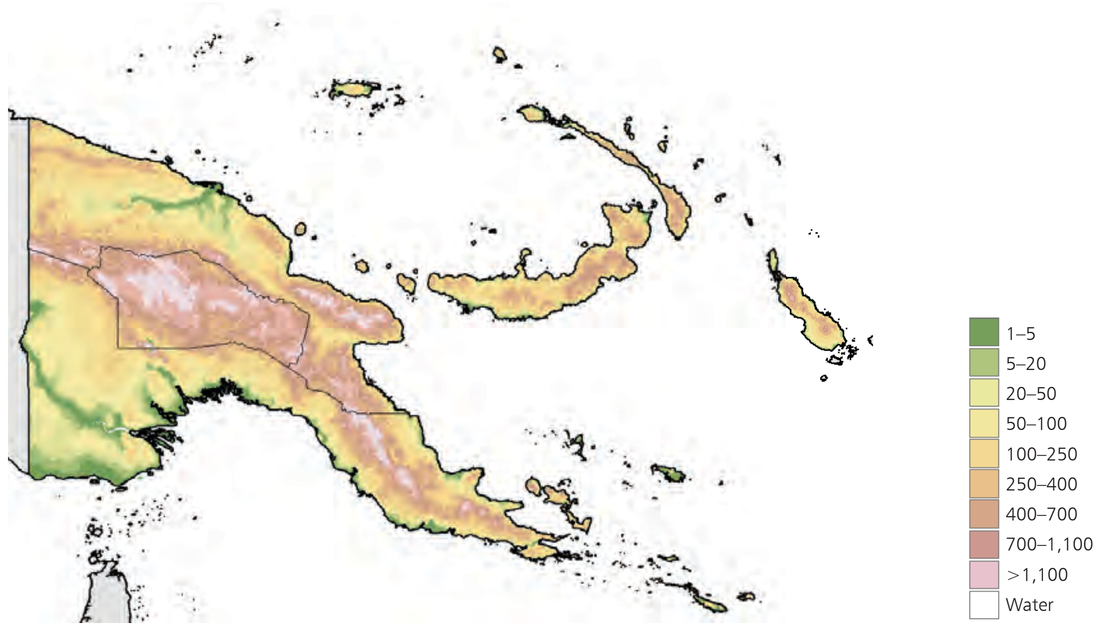
Koo, J., and J. Dimes. 2010. HC27 Generic Soil Profile Database. Version 1, July. International Food Policy Research Institute, Washington, DC. http://hdl.handle.net/1902.1/20299

APPENDIX 6
Impacts of Climate Change on Agriculture and Food Security: Models Used and Analysis of Results for Papua New Guinea

Baseline Climate and Environment

In terms of soil types, the Highlands have mostly high SOC, shallow clay soils, followed by high SOC, medium depth loam soil (Figure A6.2). The Momase region has primarily medium SOC, medium depth loam soil, followed by

Figure A6.1 Elevation in Meters (GLOBE), Papua New Guinea



Source: GLOBE Task Team and others (Hastings, D.A., P.K. Dunbar, G.M. Elphingstone, M. Bootz, H. Murakami, H. Maruyama, H. Masaharu, P. Holland, J. Payne, N.A. Bryant, T.L. Logan, J.-P. Muller, G. Schreier, and J.S. MacDonald), eds., 1999. The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center. Colorado, US. Available from http://www.ngdc.noaa.gov/mgg/topo/globe.html high SOC, medium depth loam soils. The Southern region has 36% each of high SOC, medium depth loam soil and high soil organic carbon (SOC), deep clay soil, whereas the Islands are almost half medium SOC, medium depth loam soil, and high SOC, deep clay soils.

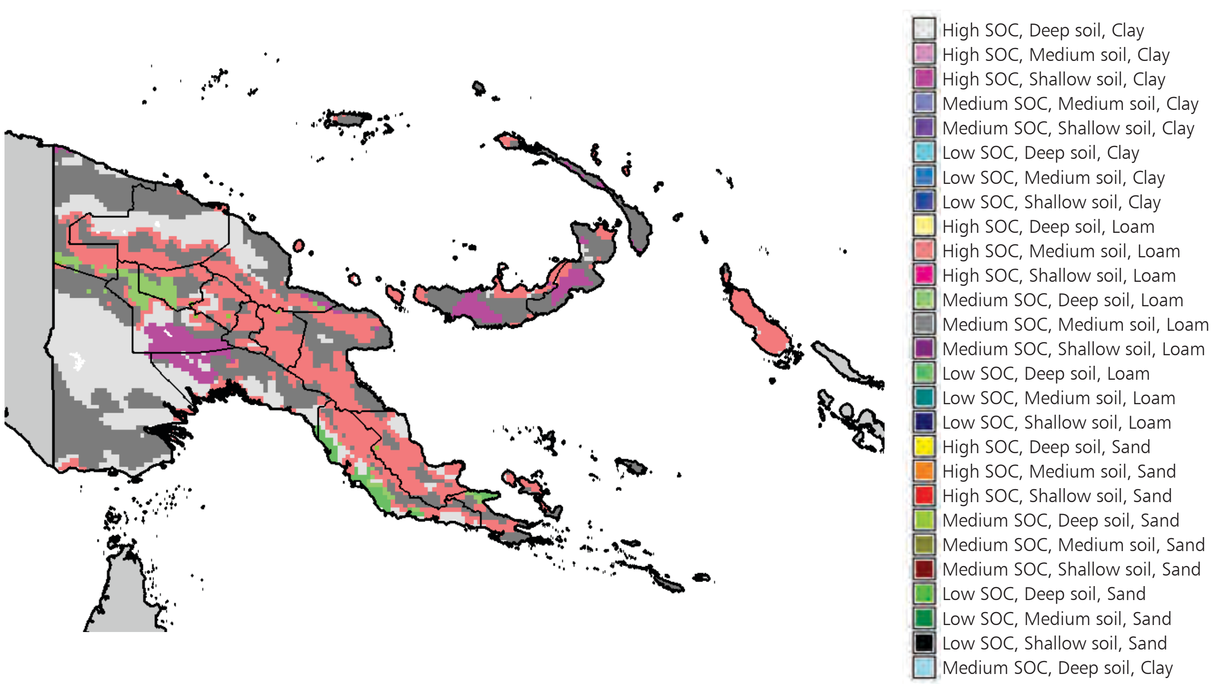
Mean annual rainfall in 1950–2000 appears to be lower on portions of the southern coast and an area on the northern coast (Figure A6.3). The country has very high rainfall in the central eastern region and in areas just south and north of the Highlands region. The Islands region appears to have high rainfall as well.

Based on the maximum temperature of the warmest month, higher elevations are generally much cooler, and the Islands region is generally cooler than mainland coastal areas (Figure A6.4).

Overview of Results from Climate Models

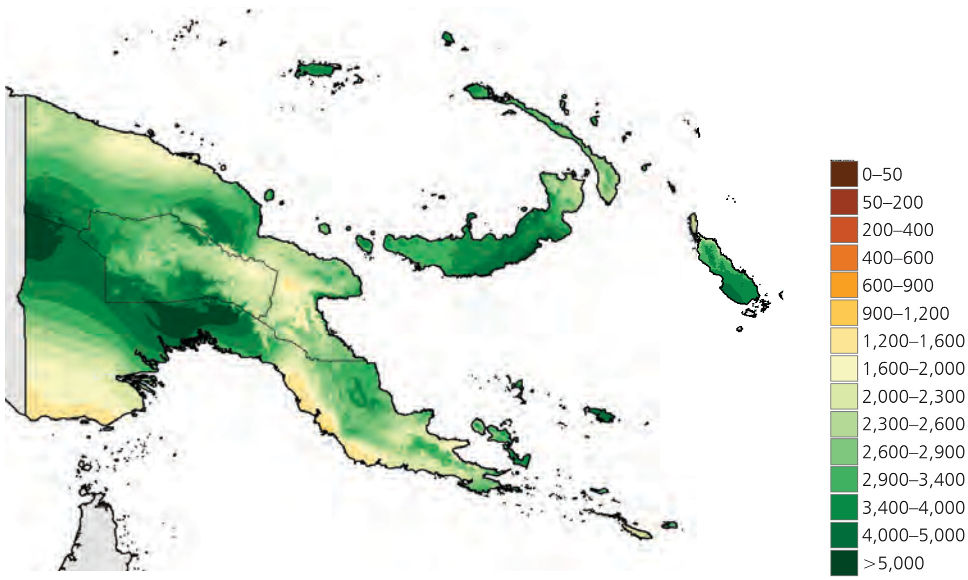
Figures A6.5–A6.9 present climate change results for Papua New Guinea (PNG) from the four GCMs based on Scenario A1B for 2000–2050, including annual precipitation, changes in precipitation during the wettest three months, and changes in highest temperature during the warmest month.

Figure A6.2 Soil Types, Papua New Guinea



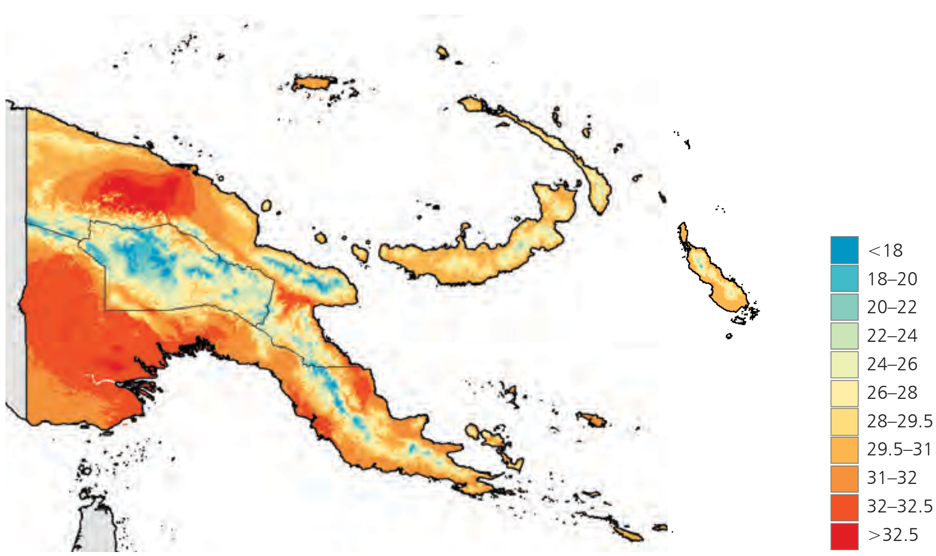
Source: Koo, J., and J. Dimes. 2010. HC27 Generic Soil Profile Database. Version 1, July. International Food Policy Research Institute, Washington, DC. http://hdl.handle.net/1902.1/20299 from the Harmonized World Soil DataBase (HWSD ver. 1.1) by Batjes, N., K. Dijkshoorn, V. Van Engelen, G. Fischer, A. Jones, L. Montanarella, M. Petri, et al. 2009. Harmonized world soil database. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Figure A6.3 Mean Annual Precipitation (mm), Papua New Guinea, 1950–2000



mm = millimeter.
Source: WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas". *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org).

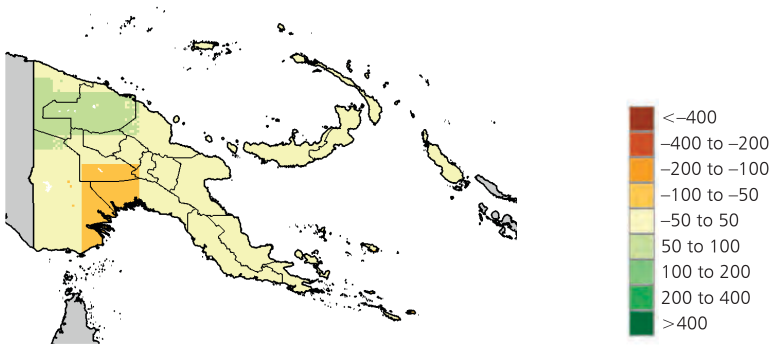
Figure A6.4 Maximum Temperature (°C) During the Warmest Month, Papua New Guinea



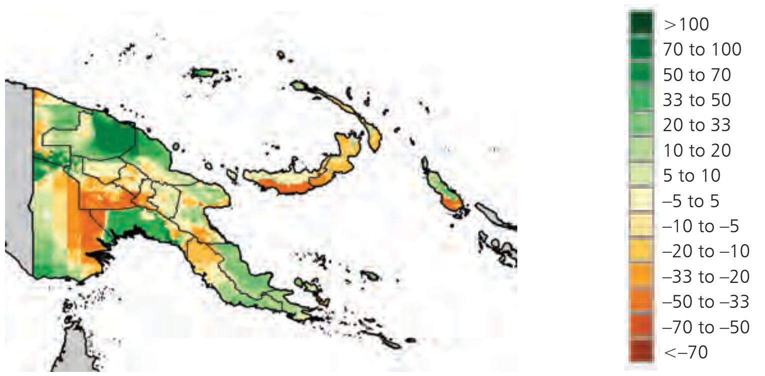
°C = degree Celsius.
Source: WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas". *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org).

Figure A6.5 Rainfall and Temperature Changes as Modeled by CNRM–CM3 Global Climate Model under Scenario A1B, Papua New Guinea, 2000–2050

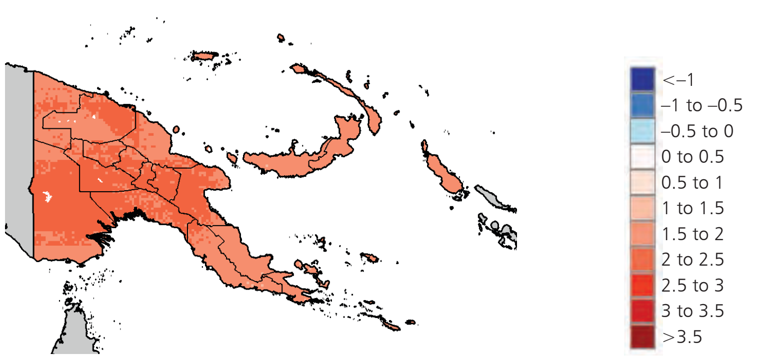
a. Change in Annual Rainfall (mm)



b. Change in Rainfall (mm) during the Wettest 3 Months



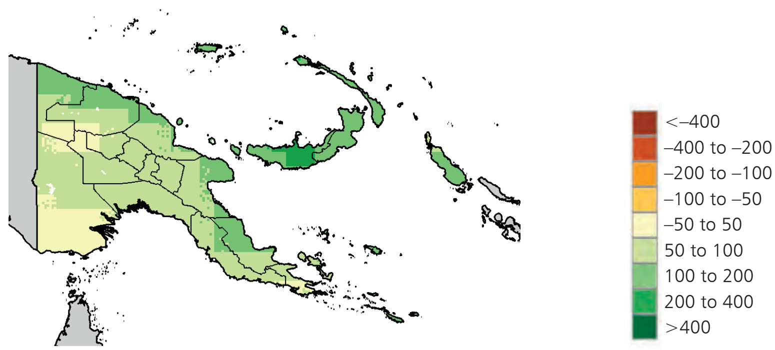
c. Change in Normal Annual Maximum Temperature (°C)



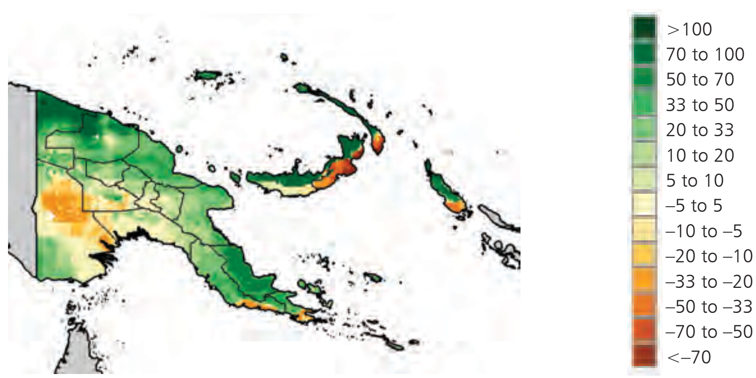
CNRM-CM3 = Centre National de Recherches Météorologiques Coupled global climate model Version 3, °C = degree Celsius, mm = millimeter.
Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3)).

Figure A6.6 Rainfall and Temperature Changes as Modeled by CSIRO Mk3 Global Climate Model under Scenario A1B, Papua New Guinea, 2000–2050

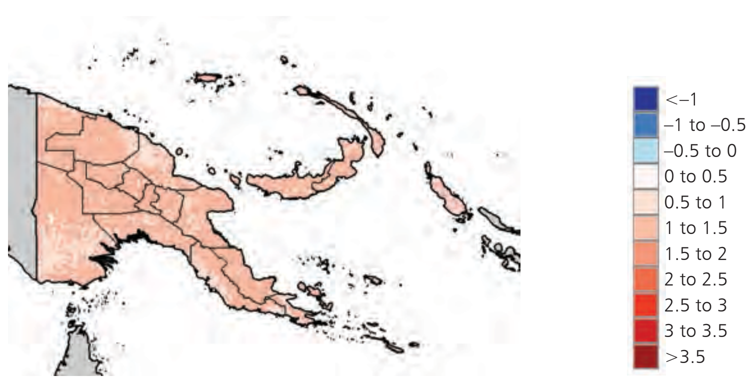
a. Change in Annual Rainfall (mm)



b. Change in Rainfall (mm) during the Wettest 3 Months



c. Change in Normal Annual Maximum Temperature (°C)

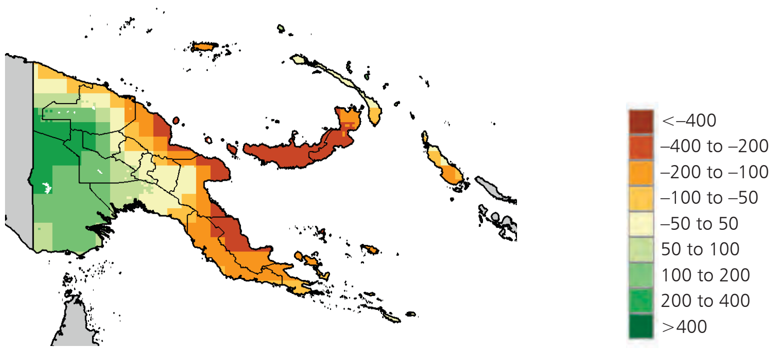


CSIRO Mk3 = Commonwealth Scientific and Industrial Research Oganisation Mk3 Version, °C = degree Celsius, mm = millimeter.

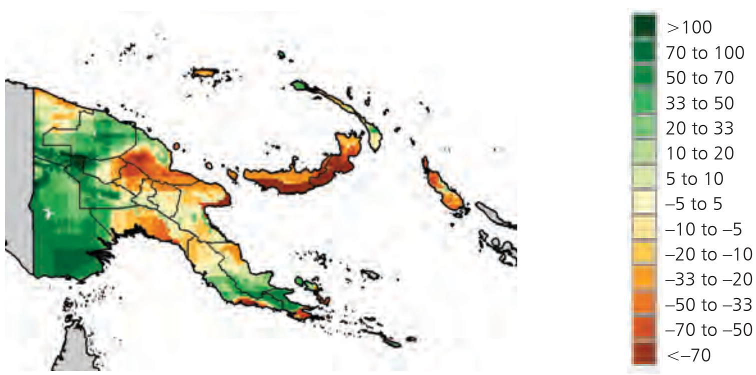
Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3).

Figure A6.7 Rainfall and Temperature Changes as Modeled by ECHAM5 under Scenario A1B, Papua New Guinea, 2000–2050

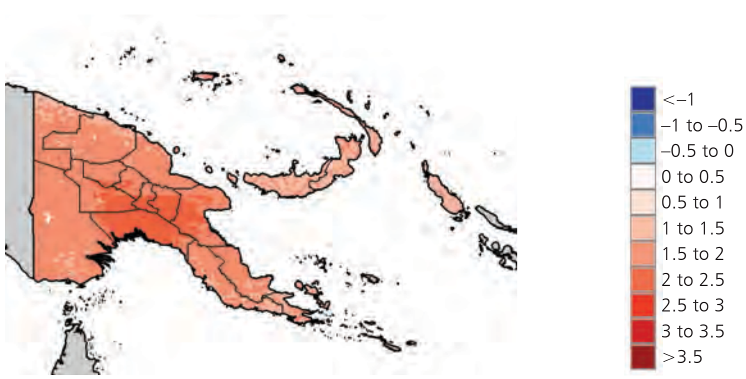
a. Change in Annual Rainfall (mm)



b. Change in Rainfall (mm) during the Wettest 3 Months



c. Change in Normal Annual Maximum Temperature (°C)

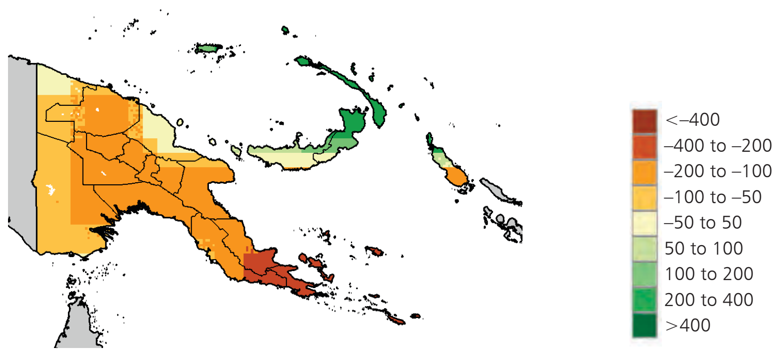


°C = degree Celsius, ECHAM5 = European Center Hamburg, mm = millimeter.

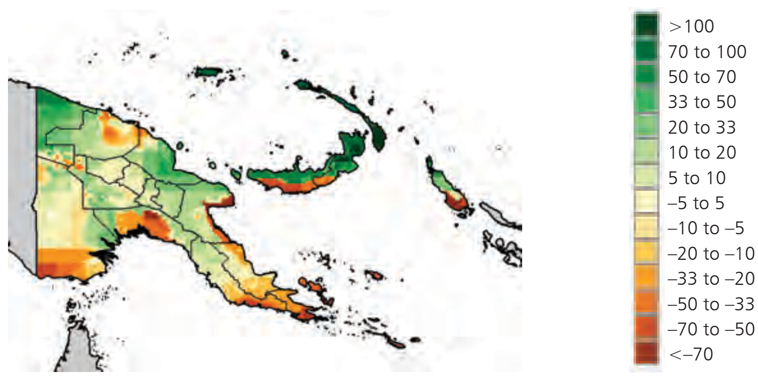
Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3).

Figure A6.8 Rainfall and Temperature Changes as Modeled by MIROC 3.2, Medium Resolution, under Scenario A1B, Papua New Guinea, 2000–2050

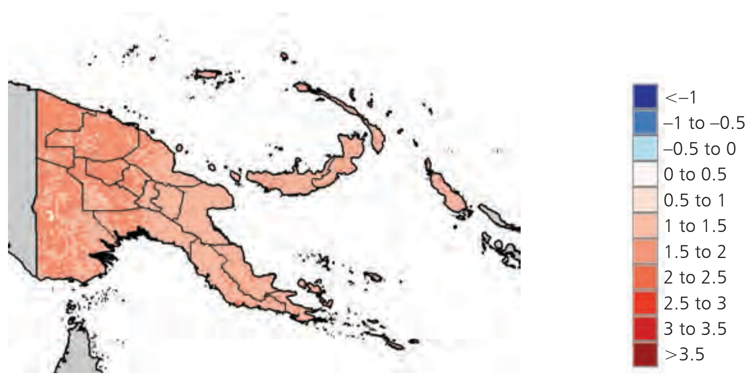
a. Change in Annual Rainfall (mm)



b. Change in Rainfall (mm) during the Wettest 3 Months



c. Change in Normal Annual Maximum Temperature (°C)



°C = degree Celsius, MIROC 3.2 = Model for Interdisciplinary Research On Climate, mm = millimeter.

Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3).

DSSAT Results

Rainfed Taro

Figure A6.9 shows yield changes between the baseline climate and the year-2050 climate for each of the four GCMs. Yield losses are the smallest in the results from the Commonwealth Scientific and Industrial Research Organization (CSIRO) model; the other three GCMs share similar yield declines, all of which significantly exceed those for the CSIRO results. In all four GCMs, taro could not be grown in areas on the fringes of the highlands prior to climate change, but it became possible with climate change, indicating a potential opportunity.

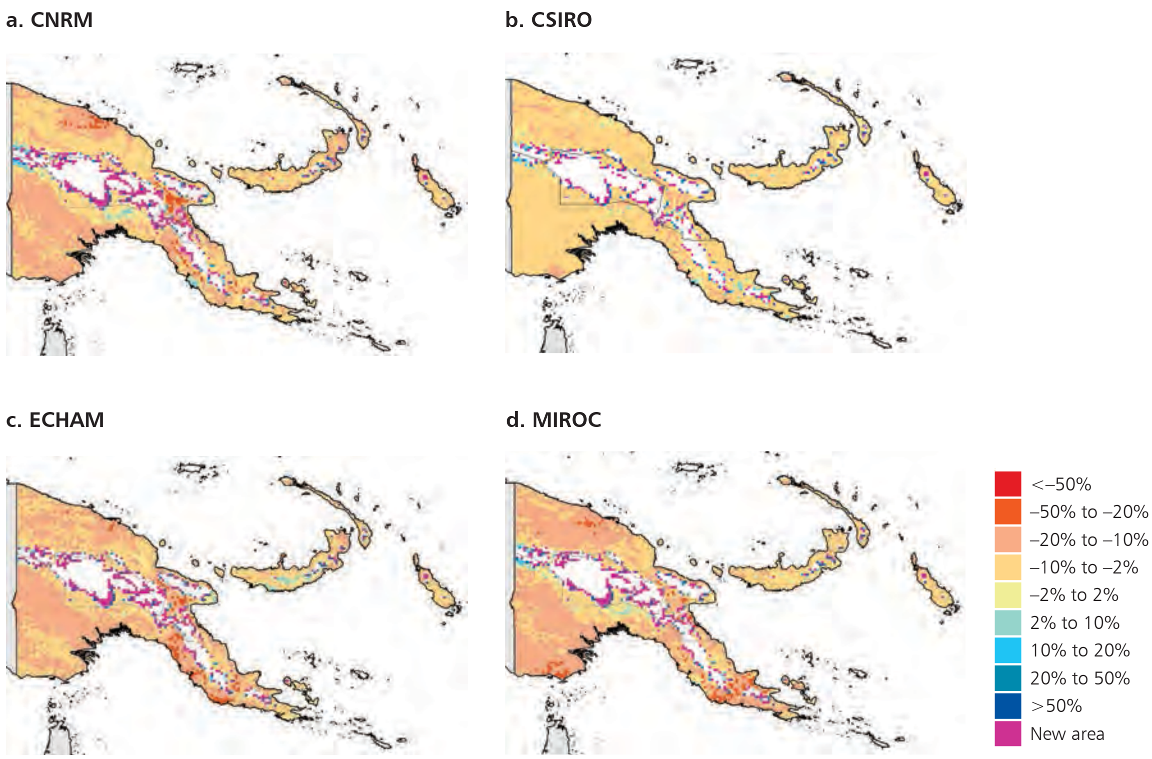
Table A6.1 provides a summary of yield changes by division. We note a decline in taro yield, even in the case where planting month and cultivar are allowed to change. The greatest losses are observed in the southern region.

Rainfed Maize

In the baseline climate, rainfed maize yields appear not to do well in the Highlands. Yields generally appear to be high in most of the rest of the country. Under climate change, maize results indicate yield losses in most of the country, and yield gains in the highlands (Figure A6.10). However, it appears that under the influence of climate change, maize can be grown in 2050 in places where it could not previously be grown. Losses appear to be more moderate based on results from the CSIRO model, which once again is an outlier. The three other GCMs give similar results indicating higher yield losses.

Table A6.2 shows yield changes due to climate change. Yields of rainfed maize appear to increase in the highlands due to climate change, but results indicate either no change or modest losses in the rest of the country, depending on the GCM.

Figure A6.9 Change in Yield of Rainfed Taro due to Climate Change, Optimal Planting Month and Cultivar for the Year Concerned, with High Fertilizer Levels, Papua New Guinea, 2000 and 2050



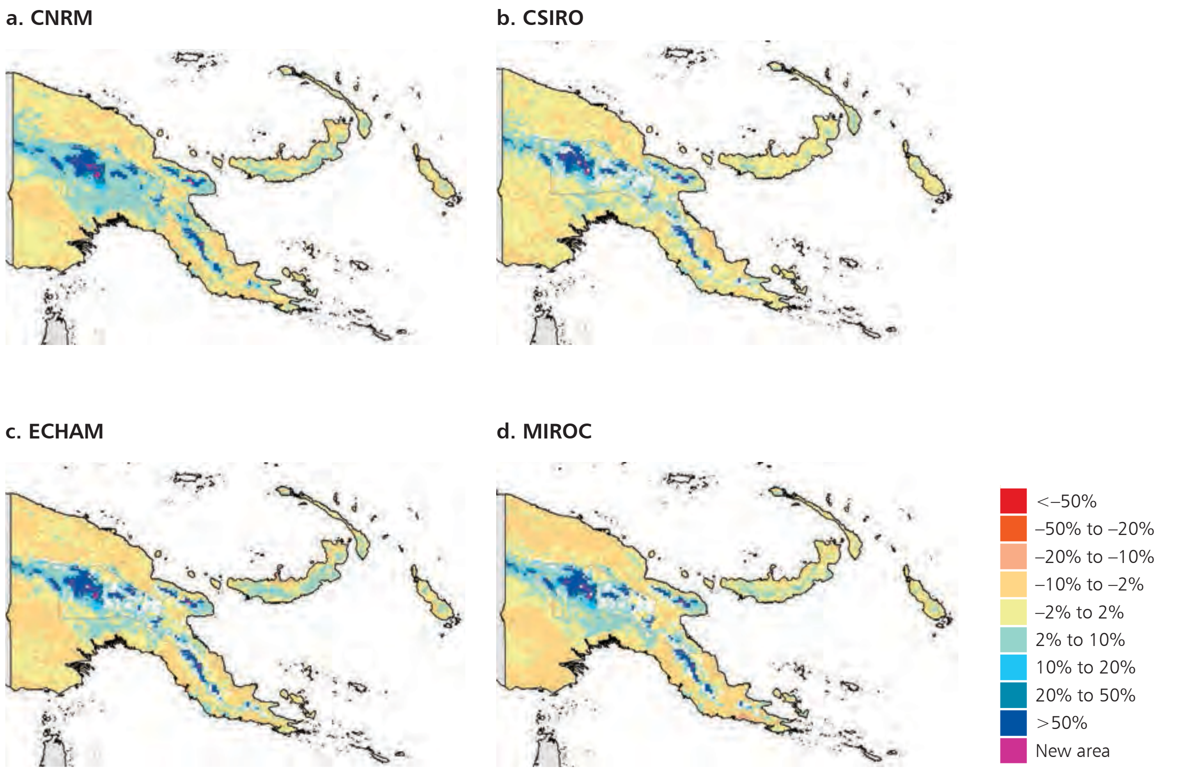
CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

Table A6.1 Regional Impacts of Climate Change on Yields of Rainfed Taro in Papua New Guinea, High Fertilizer Levels

	Change in Yield as Compared to Year 2000 (%)							
	Maintaining Cultivar and Planting Month as in Year 2000				Cultivar and Planting Month Optimal for Year 2050			
Region	Worst Case		Best Case		Worst Case		Best Case	
Nation	(3.0)	MIROC	(6.7)	CSIRO	(4.5)	MIROC	(1.7)	CNRM
Highlands	3.0	CSIRO	26.9	CNRM	45.8	CSIRO	130	CNRM
Islands	(11.0)	ECHAM	(6.5)	CSIRO	(3.6)	CNRM	(1.2)	CSIRO
Momase	(13.9)	MIROC	(7.3)	CSIRO	(5.2)	MIROC	(1.9)	CSIRO
Southern	(15.0)	MIROC	(6.9)	CSIRO	(11.0)	MIROC	(5.0)	CSIRO

CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate, ( ) = negative value.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

Figure A6.10 Change in Yield of Rainfed Maize due to Climate Change, Optimal Planting Month and Cultivar for the Year Concerned, with High Fertilizer Levels, Papua New Guinea, 2000 and 2050



CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

Table A6.2 Change in Yield of Rainfed Maize due to Climate Change, Optimal Planting Month and Cultivar for the Year Concerned, with High Fertilizer Levels, Papua New Guinea, 2000 and 2050

	Change in Yield as Compared with Year 2000 (%)							
	Maintaining Cultivar and Planting Month as in Year 2000				Cultivar and Planting Month Optimal for Year 2050			
Region	Worst Case		Best Case		Worst Case		Best Case	
Nation	(3.8)	MIROC	(1.1)	CSIRO	(1.3)	MIROC	0.2	CNRM
Highlands	3.6	MIROC	5.6	CNRM	5.8	CSIRO	9.4	CNRM
Islands	(5.7)	ECHAM	(1.8)	CSIRO	(2.1)	ECHAM	(0.6)	CSIRO
Momase	(4.8)	MIROC	(1.3)	CSIRO	(1.8)	MIROC	0.0	CNRM
Southern	(4.8)	MIROC	(2.0)	CSIRO	(2.8)	MIROC	(1.1)	CSIRO

CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate, ( ) = negative value.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

References

Batjes, N., K. Dijkshoorn, V. Van Engelen, G. Fischer, A. Jones, L. Montanarella, M. Petri, et al. 2009. Harmonized world soil database. Laxenburg, Austria: International Institute for Applied Systems Analysis.

GLOBE Task Team and others (Hastings, D.A., P.K. Dunbar, G.M. Elphingstone, M. Bootz, H. Murakami, H. Maruyama, H. Masaharu, P. Holland, J. Payne, N.A. Bryant, T.L. Logan, J.-P. Muller, G. Schreier, and J.S. MacDonald), eds., 1999. The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center. Colorado, US. Available from http://www.ngdc.noaa.gov/mgg/topo/globe.html

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas". *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org

Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3

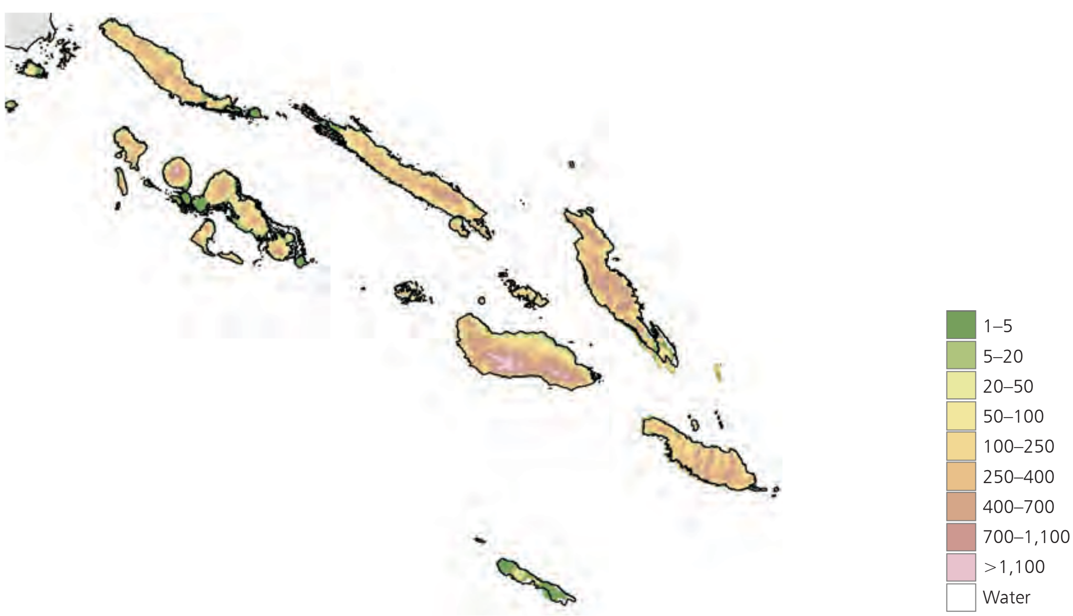
APPENDIX 7

Impacts of Climate Change on Agriculture and Food Security: Models Used and Analysis of Results for Solomon Islands

Baseline Climate and Environment

Figure A7.1 shows the elevation map for Solomon Islands. Guadalcanal has a mountain range with some of the country's highest elevations; some points of higher elevation are also found in the Western province.

Figure A7.1 Elevation in Meters (GLOBE), Solomon Islands



Source: GLOBE Task Team and others (Hastings, D.A., P.K. Dunbar, G.M. Elphingstone, M. Bootz, H. Murakami, H. Maruyama, H. Masaharu, P. Holland, J. Payne, N.A. Bryant, T.L. Logan, J.-P. Muller, G. Schreier, and J.S. MacDonald), eds., 1999. The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center. Colorado, US. Available from http://www.ngdc.noaa.gov/mgg/topo/globe.html

In terms of soil types, Choiseul and Isabel provinces have mostly medium SOC, medium depth loam soils (Figure A7.2). Guadalcanal province has mostly high SOC, deep clay soils; Makira province has mostly high SOC, shallow clay soils; and Malaita province has medium depth loam soils in about equal proportions of medium and high. Finally, Western province has a roughly even distribution of all four soil types.

Mean annual rainfall in 1950–2000 appears to be lowest in Guadalcanal and higher in the westernmost and easternmost provinces (Figure A7.3).

Areas of higher elevation are generally cooler (Figure A7.4).

Overview of Results from Climate Models

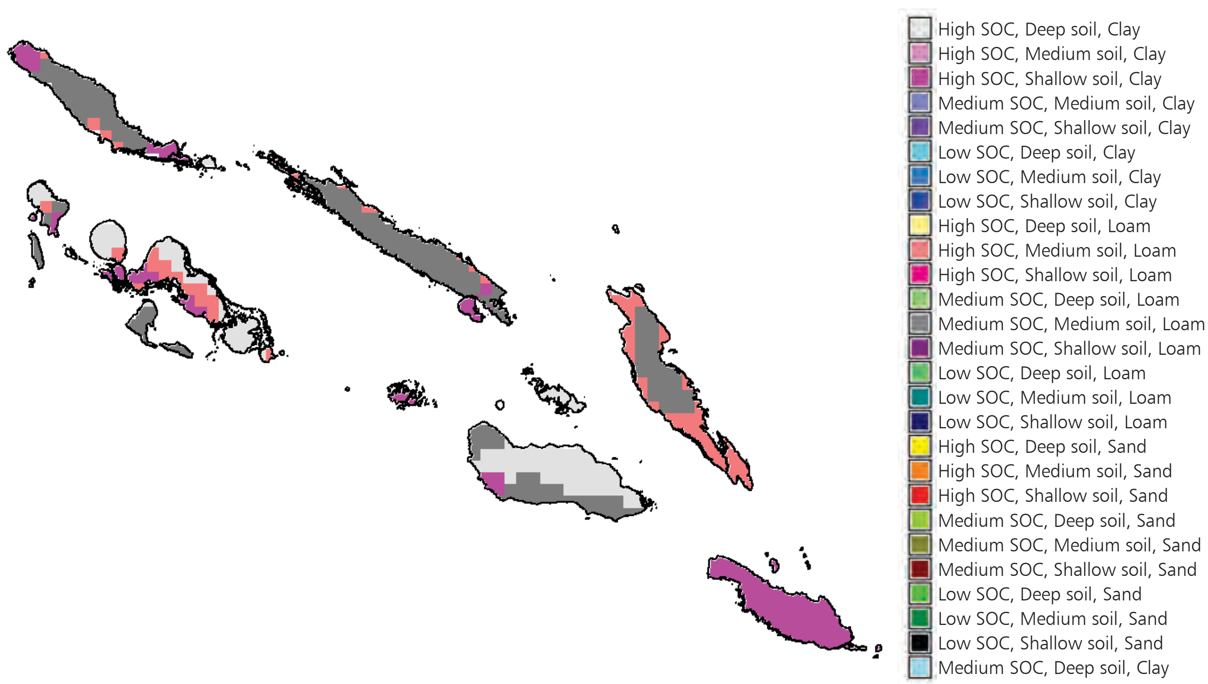
Figures A7.5–A7.8 present climate change results for Solomon Islands from the four GCMs based on Scenario A1B for 2000–2050, including changes in annual precipitation, changes in precipitation during the wettest three months, and changes in maximum temperature during the warmest month.

DSSAT Results

Rainfed Taro

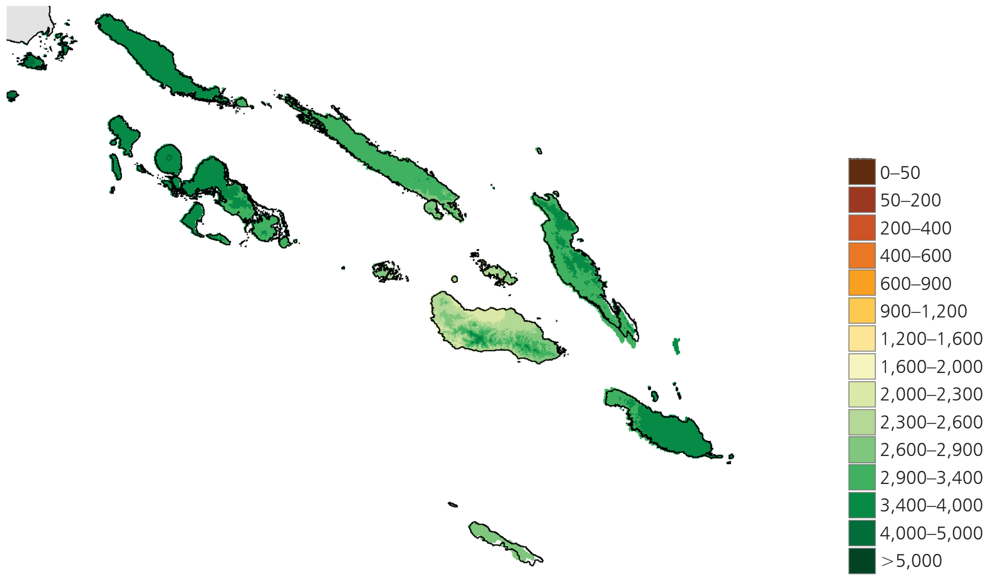
Existing yields of taro are good in most areas of Solomon Islands, except for a small portion of the southern coast of Guadalcanal, where there is currently little or no agriculture.

Figure A7.2 Soil Types, Solomon Islands



Source: Koo, J., and J. Dimes. 2010. HC27 Generic Soil Profile Database. Version 1, July. International Food Policy Research Institute, Washington, DC. http://hdl.handle.net/1902.1/20299 from the Harmonized World Soil DataBase (HWSD ver. 1.1) by Batjes, N., K. Dijkshoorn, V. Van Engelen, G. Fischer, A. Jones, L. Montanarella, M. Petri, et al. 2009. Harmonized world soil database. Laxenburg, Austria: International Institute for Applied Systems Analysis.

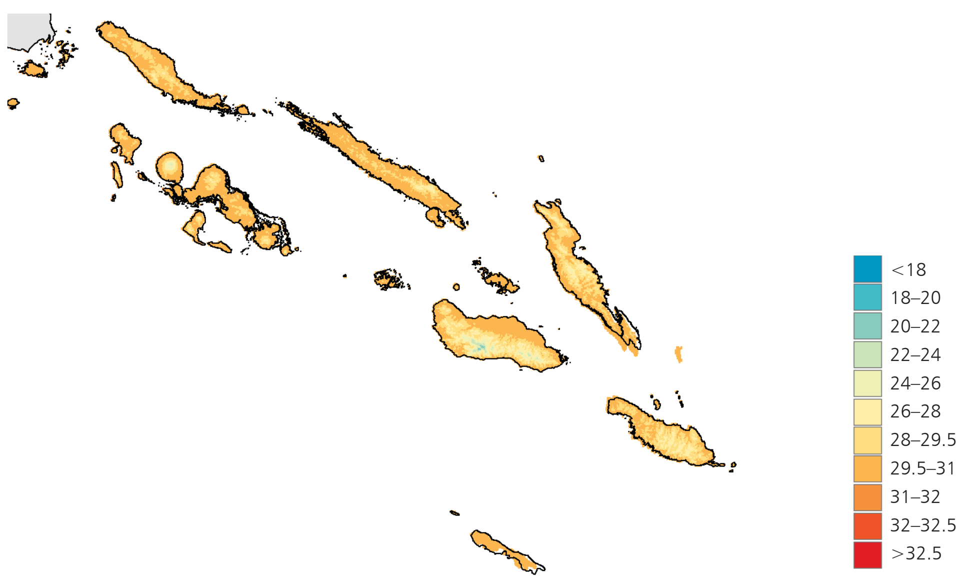
Figure A7.3 Mean Annual Precipitation (mm), Solomon Islands, 1950–2000



mm = millimeter.

Source: WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas". *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org).

Figure A7.4 Maximum Temperature (°C) During the Warmest Month, Soomon Islands



°C = degree Celsius.

Source: WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas". *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org).

Figure A7.5 Rainfall and Temperature Changes as Modeled by CNRM–CM3 Global Climate Model under Scenario A1B, Solomon Islands, 2000–2050

a. Change in Annual Rainfall (mm)

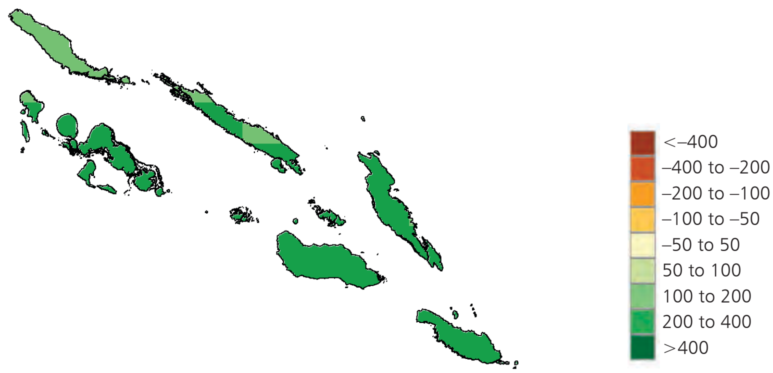
b. Change in Rainfall (mm) during the Wettest 3 Months

c. Change in Normal Annual Maximum Temperature (°C)

CNRM-CM3 = Centre National de Recherches Météorologiques Coupled global climate model Version 3, °C = degree Celsius, mm = millimeter.
Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3)).

Figure A7.6 Rainfall and Temperature Changes as Modeled by CSIRO Mk3 Global Climate Model under Scenario A1B, Solomon Islands, 2000–2050

a. Change in Annual Rainfall (mm)



b. Change in Rainfall (mm) during the Wettest 3 Months

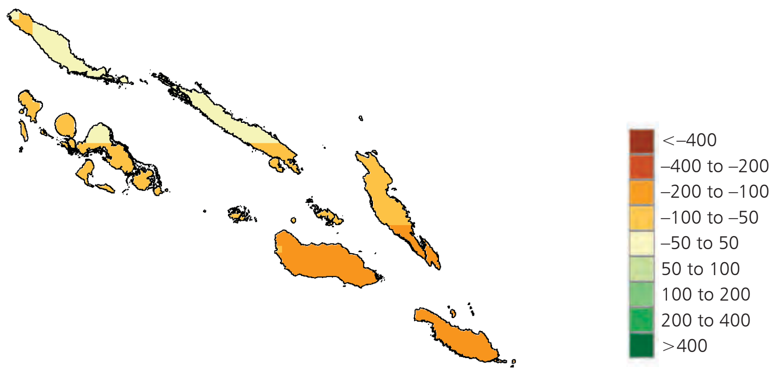
c. Change in Normal Annual Maximum Temperature (°C)

CSIRO Mk3 = Commonwealth Scientific and Industrial Research Organisation Mk3 Version, °C = degree Celsius, mm = millimeter.

Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3).

Figure A7.7 Rainfall and Temperature Changes as Modeled by ECHAM5 under Scenario A1B, Solomon Islands, 2000–2050

a. Change in Annual Rainfall (mm)



b. Change in Rainfall (mm) during the Wettest 3 Months

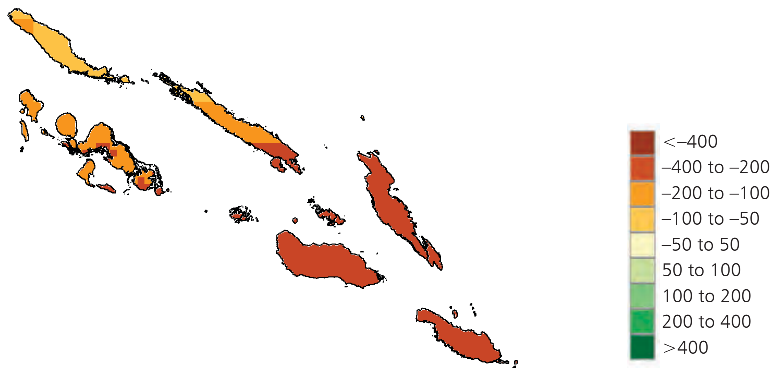
c. Change in Normal Annual Maximum Temperature (°C)

°C = degree Celsius, ECHAM5 = European Center Hamburg, mm = millimeter.

Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3).

Figure A7.8 Rainfall and Temperature Changes as Modeled by MIROC 3.2, Medium Resolution, under Scenario A1B, Solomon Islands, 2000–2050

a. Change in Annual Rainfall (mm)



b. Change in Rainfall (mm) during the Wettest 3 Months

c. Change in Normal Annual Maximum Temperature (°C)

°C = degree Celsius, MIROC 3.2 = Model for Interdisciplinary Research On Climate, mm = millimeter.
Source: Authors' calculations, based on WorldClim 1.4 (Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org; and Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3).

Figure A7.9 shows yield changes between the baseline climate and the year-2050 climate for each of the four GCMs. All models show yield losses (apart from the aforementioned strip). As noted previously, the CSIRO results show lower losses compared to the other GCMs, which are in close agreement in most gridcells, and show significant yield losses.

Table A.1 provides a summary of changes in yield for rainfed taro by province. Yield is least responsive to fertilizer in Guadalcanal, where losses due to climate change are relatively high.

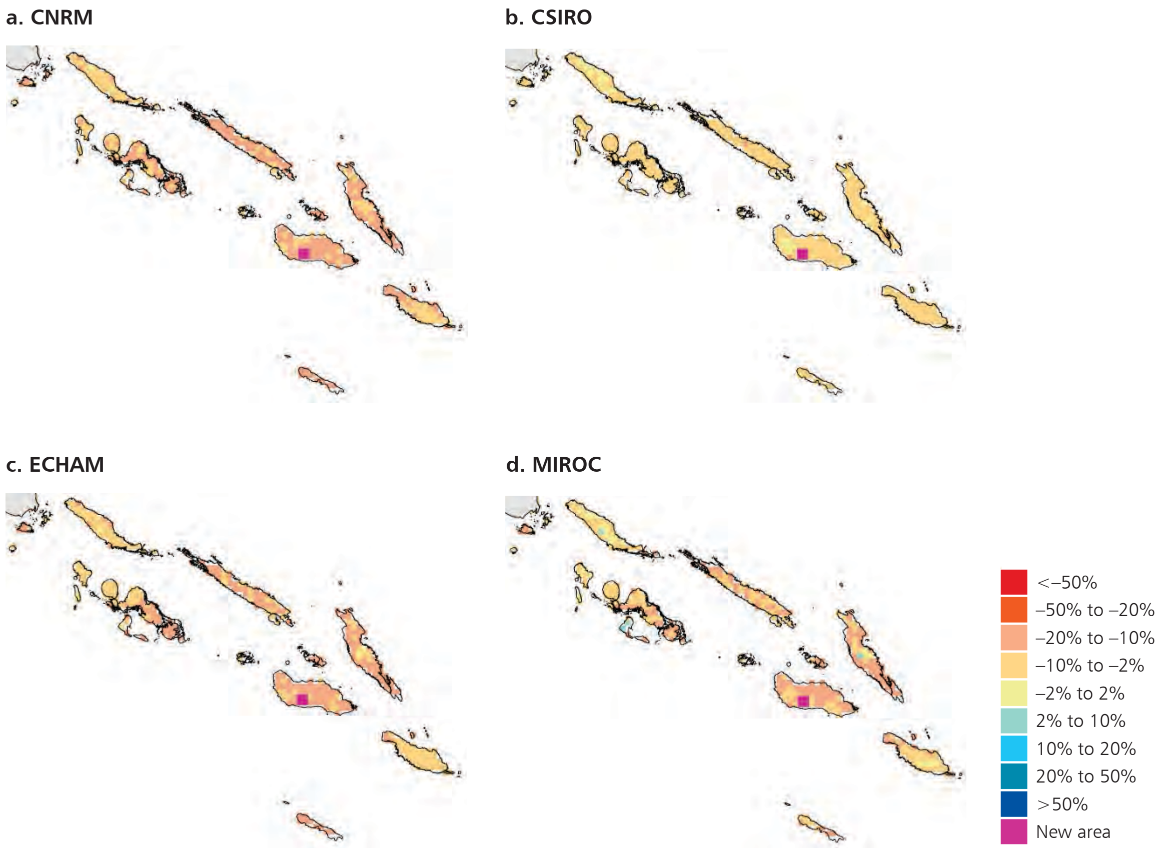
Rainfed Rice

Under the baseline climate, rainfed rice yields are good in Guadalcanal and Western provinces. For all images in Figure A7.10, the application of nitrogen fertilizer is assumed at a rate of 90 kg per hectar.

The number of areas for which yields of rainfed rice increase under climate change (Figure A7.10) exceeds those for taro. As with previous results, the CSIRO model indicates greater yield improvements from climate change than do any of the other GCMs.

The ability of farmers to adjust planting month and cultivar allows them to prevent more than 8% of average yield losses due to climate change in the worst-case, and more than 5% in the best case (Table A7.2).

Figure A7.9 Change in Yield of Rainfed Taro due to Climate Change, Optimal Planting Month and Cultivar for the Year Concerned, with High Fertilizer Levels, Solomon Islands, 2000 and 2050



CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

Table A7.1 Regional Impacts of Climate Change on Rainfed Taro in Solomon Islands, High Fertilizer Levels, 2050 Climate

	Change in Yield as Compared to Year 2000 (%)							
	Maintaining Cultivar and Planting Month as in Year 2000				Cultivar and Planting Ponth Optimal for Year 2050			
Region	Worst Case		Best Case		Worst Case		Best Case	
Nation	(16.1)	MIROC	(7.4)	CSIRO	(12.4)	MIROC	(6.4)	CSIRO
Guadalcanal	(17.8)	MIROC	(7.4)	CSIRO	(13.7)	MIROC	(6.5)	CSIRO
Isabel	(19.6)	CNRM	(12.3)	CSIRO	(12.8)	CNRM	(8.5)	CSIRO
Malaita	(13.1)	ECHAM	(5.5)	CSIRO	(11.7)	CNRM	(4.9)	CSIRO
Western	(11.2)	ECHAM	(7.9)	CSIRO	(9.4)	CNRM	(6.4)	CSIRO

CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate, ( ) = negative value.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

Figure A7.10 Change in Yield of Rainfed Rice due to Climate Change, Optimal Planting Month and Cultivar for the Year Concerned, Solomon Islands, 2000 and 2050

CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

Table A7.2 Regional Impacts of Climate Change on Rainfed Rice in Solomon Islands, High Fertilizer Levels, Year-2050 climate

	Change in Yield as Compared to Year 2000 (%)							
	Maintaining Cultivar and Planting Month as in Year 2000				Cultivar and Planting Month Optimal for 2050			
Region	Worst Case		Best Case		Worst Case		Best Case	
Nation	(15.3)	MIROC	(7.9)	CSIRO	(7.0)	CNRM	(2.5)	CSIRO
Guadalcanal	(18.6)	MIROC	(9.0)	CSIRO	(7.7)	CNRM	(2.5)	CSIRO
Isabel	(12.9)	CNRM	(4.7)	MIROC	(7.1)	ECHAM	(2.4)	CSIRO
Malaita	(9.1)	MIROC	(5.2)	CSIRO	(3.2)	MIROC	(1.7)	CSIRO
Western	(8.0)	CNRM	(4.3)	CSIRO	(6.3)	CNRM	(2.5)	MIROC

CNRM = Centre National de Recherches Météorologiques, CSIRO = Commonwealth Scientific and Industrial Research Organization, ECHAM = European Center Hamburg, MIROC = Model for Interdisciplinary Research On Climate, ( ) = negative value.
Source: Authors' calculations using Decision Support System for Agrotechnology Transfer.

References

Batjes, N., K. Dijkshoorn, V. Van Engelen, G. Fischer, A. Jones, L. Montanarella, M. Petri, et al. 2009. Harmonized world soil database. Laxenburg, Austria: International Institute for Applied Systems Analysis.

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Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. "Very high resolution interpolated climate surfaces for global land areas". *International Journal of Climatology*. 25. pp. 1965–1978. http://www.worldclim.org

Jones, J.W., P. K. Thornton, and Jens Heinke. 2009. Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment, project report for ILRI. International Livestock Research Institute, Nairobi, Kenya. http://cgspace.cgiar.org/bitstream/handle/10568/2482/Jones-Thornton-Heinke-2009.pdf?sequence=3

Koo, J., and J. Dimes. 2010. HC27 Generic Soil Profile Database. Version 1, July. International Food Policy Research Institute, Washington, DC. http://hdl.handle.net/1902.1/20299

Climate Change, Food Security, and Socioeconomic Livelihood in Pacific Islands

This report assesses the impact of climate change on agriculture and fisheries in three Pacific Island countries, including the impacts on agricultural production, economic returns for major crops, and food security. Alternative adaption policies are examined in order to provide policy options that reduce the impact of climate change on food security. The overall intention is to provide a clear message for development practitioners and policymakers about how to cope with the threats, as well as understand the opportunities, surrounding ongoing climate change. Project countries include Fiji, Papua New Guinea and Solomon Islands.

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