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Prospects and Adaptation Strategies for the Fisheries Sector under Climate Change in Pacific Coral Triangle Countries

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ABBREVIATIONS

ADB	Asian Development Bank
AQ	aquaculture development
ATSEF	Arafura and Timor Seas Expert Forum
CAC	Coastal Aquaculture Centre
CCA	community conserved area
CT	coral triangle
CTI	Coral Triangle Initiative
CZM	coastal zone management
DOF	Department of Fisheries (Fiji Islands)
DP1	Government of the Republic of Vanuatu *First National Development Plan*
DP2	Government of the Republic of Vanuatu *Second National Development Plan*
DP3	Government of the Republic of Vanuatu *Third National Development Plan*
EBMP	Ecosystem Based Management Plan
EEZ	exclusive economic zone
EIA	environmental impact assessment
EMCA	Environmental Management and Conservation Act (Vanuatu)
EMA	Environment Management Act (Fiji)
ENSO	El Niño Southern Oscillation
EOS	expert opinion survey
EPTD	Environment and Production Technology Division
FAD	fish aggregating device
FAO	Food and Agriculture Organization of the United Nations
FFA	Forum Fisheries Agency
FGD	focus group discussion
FLMMA	Fiji locally managed marine area
FSPI	Foundation of the Peoples of the South Pacific International
FSPV	Foundation of the Peoples of South Pacific Vanuatu
GDP	gross domestic product
GHG	greenhouse gas
GOF	Government of the Republic of Fiji
HDI	human development index
IAS	Institute of Applied Science (University of South Pacific)
ICM	Integrated Coastal Management
IFPRI	International Food Policy Research Institute
kg	kilogram
km	kilometer
km^2	square kilometer
LMMA	locally managed marine area
MAF	Ministry of Agriculture and Fisheries (Timor-Leste)

MECDM	Ministry of Environment, Climate Change, Disaster Management and Meteorology (Solomon Islands)
MECM	Ministry of Environment, Conservation and Management (Solomon Islands)
MED	Ministry of Economy and Development (Timor-Leste)
MFF	Ministry of Fisheries and Forestry (Fiji)
MFMR	Ministry of Fisheries and Marine Resources (Solomon Islands)
MMA	managed marine area
MPA	marine protected area
mt	metric ton
NACCC	National Advisory Committee on Climate Change
NADS	National Aquaculture Development Strategy
NAP	National Action Plan
NAPA	National Adaptation Programme of Action (Fijj)
NAPA	National Adaptation Programme of Action (Vanuatu)
NAPA	National Adaptation Programme of Action on Climate Change (Timor-Leste)
NAPA	National Adaptation Programmes of Action (Solomon Islands)
NBSAP	National Biodiversity Strategy and Action Plan
NCCAS	National Climate Change Adaptation Strategy
NCTICCTL	National Coral Triangle Initiative Coordinating Committee of Timor-Leste
NDFA	National Directorate of Fisheries and Aquaculture (Timor-Leste)
NDS	National Development Strategies
NGO	nongovernment organization
NPoA-CTI	National Plan of Action for Coral Triangle Initiative
NRM	natural resource management
NRP	national research partners
NSDP	National Strategic Development Plan (Timor-Leste)
NTZ	no-take zone
PFO	Provincial Fisheries Office (Vanuatu)
PICT	Pacific Island Coral Triangle
PNA	Parties to Nauru Agreement
PRA	participatory rural appraisal
SEAPODYM	Spatial Ecosystem and Population Dynamics Model
SIG	Solomon Islands Government
SILMMA	Solomon Islands locally managed marine area
SPC	Secretariat of the Pacific Community
SSAF	Secretary of State for Fisheries and Aquaculture
SSE	Secretary of State of Environment (Timor-Leste)
TNC	The Nature Conservancy
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UQ	University of Queensland

VDOF	Vanuatu Department of Fisheries
VLMMA	Vanuatu locally managed marine area
WFC	WorldFish Center
WWF	World Wildlife Foundation

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EXECUTIVE SUMMARY

The Pacific Islands' agriculture and fisheries sectors are under threat from changing climate. Urbanization, coupled with increases in extreme weather events, erratic rainfall, intense solar radiation, and rising sea levels has caused, among other damaging effects, soil erosion and flooding that contribute to loss of farmlands, resulting in diminishing yields of important local crops, like sugar cane, coconut, cassava, sweet potato, taro, and cocoa beans. At the same time, rising sea surface temperatures and the acidification of oceans are degrading the region's mangrove and coral reef ecosystems and fisheries, and debilitating the production of fish, the region's primary protein source. As a result, the health and livelihoods of rural communities—especially coastal communities—that rely on farming and fishing for subsistence and incomes face serious risks.

The overarching goal of this report is to assess the fisheries development strategies for four Pacific coral triangle (CT) countries—Fiji, Solomon Islands, Timor-Leste, and Vanuatu—in response to the projected impacts of climate change. Specifically, it aims to (1) carry out a study of the economic impacts of climate change adaptation strategies on the fisheries sector, using a model of the fisheries sector of each country; and (2) assess adaptation strategies for coastal communities in the Pacific CT countries, using the results of the economic analysis study. The supply-and-demand model for the fisheries sector developed here covers all fisheries, grouped into six key fisheries subsectors: tuna, other oceanic finfish, coastal finfish, coastal invertebrates, freshwater finfish, and freshwater invertebrates. The model undertakes comparative analysis of alternative fisheries development scenarios for 2035 and 2050, while taking account of the impact of climate change in the fisheries sector.

This study's modeling and scenario analyses have indicated that with rising per capita income and population, fish demand is expected to increase substantially up to 2050. Many Pacific Island countries (Fiji, Solomon Islands, and Vanuatu) are currently net exporters of fish (excluding foreign tuna catch). In contrast to significant growth in fish demand, growth in domestic fish production is projected to be slow due to climate change and other constraints. There is a strong likelihood that some Pacific countries will become net importers of fish under a baseline scenario (i.e., without implementing climate change mitigation and/or adaptation strategies). Likewise, per capita consumption of domestically produced fish is projected to decline under the baseline scenario. Promoting aquaculture can help raise aggregate fish production, consumption, and trade; however, starting from a low base level of production, it is very unlikely that aquaculture alone will be able to meet the growing excess fish demand.

Other climate change adaptation strategies, such as low-cost fish aggregating devices (FADs) and marine protected areas (MPAs), are projected to have positive impacts in the Pacific CT countries (Fiji, Solomon Islands, Timor-Leste, and Vanuatu), expanding the stock and catch of fish. However, the current scale of implementation is too small to have the required impacts to meet demand. Therefore, aggressive—but judicious—increases in investment in aquaculture, low-cost FADs, and MPAs will be important policies to adapt to climate change and to meet the growing demand for fish. It is essential to tailor these policies to the conditions in each of the countries and locations.

1. INTRODUCTION

A. Rationale

Climate change directly affects the economies of developing countries, particularly those highly dependent on agriculture and fisheries. Countries in the Pacific Islands are highly exposed and vulnerable to the impacts of climate change. Floods, rising sea level, frequent and intense cyclones, long-lasting drought, and other natural disasters pose major risks to land and aquatic ecosystems and their natural resources, as well as the health of Pacific Island communities. Even without the hazards of climate change the region is already facing food insecurity and deteriorating coastal and marine biodiversity. Urbanization, coupled with an increase in extreme weather events, has caused, among other effects, soil erosion and flooding that contribute to loss of farmlands, resulting in diminished yields of important local crops, like sugar cane, coconut, cassava, sweet potato, taro, and cocoa beans. At the same time, rising sea surface temperatures and the acidification of oceans are degrading the region's mangrove and coral reef ecosystems and fisheries and debilitating the production of fish—the region's primary source of protein. As a result, the health and livelihoods of rural communities—especially coastal communities—that rely on farming and fishing for subsistence and income are seriously jeopardized.

The agricultural sector is central to Pacific Islanders' livelihoods. Between 2000 and 2009, the sector contributed 33% to Papua New Guinea's total gross domestic product (GDP) and 53% to Solomon Islands' GDP (Rosegrant et al. 2015). Similarly, from 2000 to 2008, the sector contributed 31.1% to Timor-Leste's, 14.9% to Vanuatu's, and 14.2% to Fiji's GDPs (ADB 2009 cited in Ahmed et al. 2011). However, the annual growth rate of agriculture from 2000 to 2008 was –0.9% in Fiji, 0.9% in Timor-Leste, 1.6% in Papua New Guinea, 1.9% in Vanuatu, and 4.9% in Solomon Islands (Ahmed et al. 2011). The slow growth of agriculture will have detrimental effects on food availability, food accessibility, and nutrition security, particularly among rural populations. Hence, there is a dire need for immediate action—especially in the area of food security.

Fish and fisheries have traditionally served as the foundation of food security in the Pacific Islands; however, this is changing. Each year during the 1990s, per capita fish consumption was 44.0–62.0 kilograms (kg) in Fiji, 15.9–25.7 kg in Vanuatu, 18.2–24.9 kg in Papua New Guinea, 32.2–32.7 kg in Solomon Islands, and 5 kg in Timor-Leste (Gillett 2009 in Ahmed et al. 2011). Rural areas have relatively higher fish consumption than urban areas, as exemplified in Fiji (25.3 kg versus (vs.) 15 kg) and Vanuatu (20.6 kg vs. 19.3 kg) (Bell et al. 2009). However, these numbers do not reveal that urbanization and increasingly unstable food production due to climate change have led to the growing consumption of cheap imports, like canned fish and meat, white bread, and soft drinks, in lieu of the traditional diet of root vegetables, fresh fish, and other local food. This was demonstrated in other Melanesian countries, where annual per capita fish consumption in urban areas is higher than in rural areas (e.g., Solomon Islands at 45.5 kg vs. 31.2 kg, and Papua New Guinea at 28.1 kg vs. 10.2 kg) (Bell et al. 2009). Furthermore, as import prices continue their upward trend, not only is this new diet unhealthy and detrimental to local and rural producers and traders, it is also likely to be unsustainable (FAO 2009).

Poverty in Pacific Island countries indicates lack of access to essential basic services, poor education, and the need for a stable source of income (Abbott and Pollard 2004). By contrast, in most developing countries, lack of available food is the prime gauge of poverty. In addition, indicators of poverty vary within the region. For example, lack of knowledge, isolation, disaffected youth, poor communications, and lack of transport are prevalent in Solomon Islands, while improvement in welfare (e.g., access to clean water, education, and other services) is the main issue in Vanuatu. Among the Pacific Island countries, one major issue is the pressure to earn cash income to provide for the basic needs of the family. But declining agricultural and fisheries production makes cash income unsustainable, if at all possible. Most Pacific Islanders lack the skills to diversify and look for other sources of income, plus opportunities to change jobs and earn a stable income are minimal. These circumstances explain the dependence of Pacific Island countries on farming and fishing as primary sources of income.

The overarching goal of this report is to assess the development strategies for the Pacific coral triangle (CT) countries in response to future impacts of climate change on key coastal and marine resources. Specifically, it aims to (1) carry out a study on the economic impacts of climate change adaptation strategies on the fisheries sector, and (2) assess adaptation strategies for coastal communities in the Pacific CT countries using the results of the economic analysis. The remainder of this introduction outlines the conceptual framework for assessing the effects of climate change responses on coastal aquaculture and fisheries in the Pacific CT countries, and summarizes broad socioeconomic trends in the study countries. Section 2 discusses the modeling methodology and description; Sections 3 to 6 deal with country case studies—namely, Fiji, Solomon Islands, Vanuatu, and Timor-Leste; and Section 7 presents the adaptation strategies, supporting national policies, management measures, and implications for the food security and economies of the Pacific CT countries.

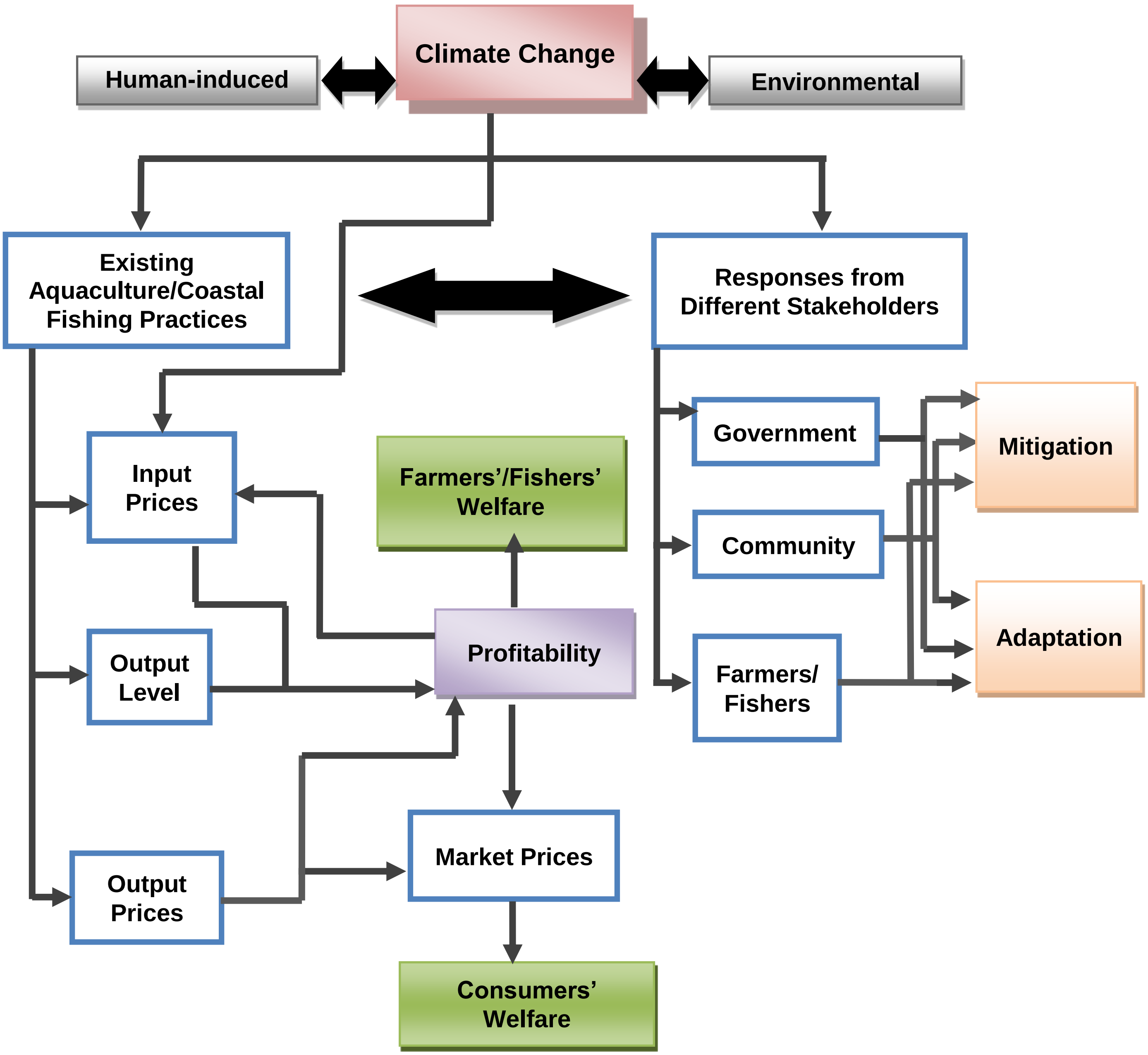
B. Conceptual Framework

There are two broad quantitative approaches for analyzing the impacts of climate change in fisheries and aquaculture: (1) a bioeconomic modeling approach and (2) a market supply–demand approach (Briones, Garces, and Ahmed 2006). Although the bioeconomic modeling approach allows modelers to incorporate climate change scenarios by altering an appropriate set of ecosystem or population parameters, much of the required information on resource and ecosystem interactions is not available in the Pacific CT countries. The market supply–demand approach represents climate change in terms of a supply shock, and works out the economic consequences using the microeconomic tools of supply and demand; Delgado et al. (2003) have effectively used this approach to analyze the "fisheries collapse" scenario. Given the data-scarce situation in biological and physical responses to climate change in the Pacific, this study uses a market fish-supply model to analyze the economic impacts of climate change adaptation strategies on coastal communities in the five selected Pacific CT countries.

Figure 1.1 presents the general framework of the model developed for assessing the effects of climate change adaptation strategies. The model captures the potential effects of alternative adaptation strategies on farmers and fishers, as well as consumers, through changes in input prices, output and market prices, and real per capita income. It considers adaptation strategies followed by national governments, coastal communities, and individual households (farmers and fishers).[1] Some government policies may affect input and output prices. In response, fishers and farmers may adjust their practices and/or input use, which will affect their profitability and welfare, along with the welfare of consumers.

[1] In general, households in coastal communities of the five Pacific CT countries are both subsistence farmers and fishers. Farmers work during the day, while fishers work during the night, assuming favorable weather conditions.

Figure 1.1
Conceptual Framework for Assessing the Effects of Climate Change Responses on Coastal Aquaculture and Fisheries in the Pacific CT Countries



C. Overall Environment and Socioeconomic Development Conditions

Of the 7,500 islands in the tropical Pacific Ocean, about 500 are inhabited. The Pacific region has 14 independent nations and 6 French and U.S. territories. The countries are grouped into Melanesian, Micronesian, and Polynesian cultural classes. ADB (2011) has categorized the countries according to their geological conditions—namely, as "high" for mountainous, volcanic states, while the rest are "low" for coral atoll countries. The four study countries—Fiji, Solomon Islands, Timor-Leste, and Vanuatu—belong to the "high" countries and have the largest land areas in the Pacific, other than Papua New Guinea (Table 1.1).

Table 1.1
Cultural Group, Land Area, Sea Area, and Population of Pacific Island Countries

Rank in Terms of Land Area[a]	High (H)/ Low (L)[a]	Cultural Group, Country[a]	Land Area (km^2)[a]	Sea Area (000 km^2)[a]	Population (2012)[b]
		Melanesia:			
1	H	Papua New Guinea	462,840	3,120	7,167,010
2	H	Solomon Islands	30,407	1,340	549,598
3	H	Fiji	18,273	1,290	874,742
4	H	Timor-Leste	14,874		1,210,233
5	H	Vanuatu	12,281	680	247,262
		Polynesia:			
6	H	Samoa	2,785	120	188,889
8	L	Federated States of Micronesia	701	2,978	103,395
9	L	Tonga	650	700	104,941
11	L	Cook Islands	237	1,830	15,708[a]
13	L	Tuvalu	26	900	9,860
		Micronesia:			
7	L	Kiribati	811	3,550	100,786
10	L	Palau	444	629	20,518
12	L	Marshall Islands	181	2,131	52,555
14	L	Nauru	21	320	9,976[a]
		Total Population			10,655,473

[a] Reprinted from Ahmed, M., J. Maclean, R.V. Gerpacio, and M. Sombilla (2011). *Food Security and Climate Change: Rethinking the Options*. Pacific Studies Series. Manila. Table 1. http://www.adb.org/publications/food-security-and-climate-change-pacific-rethinking-options .
[b] World Bank (2013). *World Development Indicators,* accessed on August 26, 2013, http://data.worldbank.org/data-catalog/world-development-indicators.

The general environment and socioeconomic situation in the four study countries are presented in Table 1.2. The latest available data indicate improved living conditions in all four countries, and improved health in Fiji, Solomon Islands, and Vanuatu, with less than 12% of children (age 5 and younger) underweight. Education of adults older than 15 years is higher than 80% in Fiji and Vanuatu. In all the four countries, access to improved sanitation facilities in urban areas is above 60%, while access to improved water sources in urban areas is above 90%.

Table 1.2
Environment and Socioeconomic Conditions in Fiji, Solomon Islands, Timor-Leste, and Vanuatu

Comparable Conditions	Fiji	Solomon Islands	Timor-Leste	Vanuatu
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, including 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 land mass is suitable for farming.	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.	Small island country; land area mostly in eastern side, while the whole island is divided with Indonesia; coastlines face Timor Sea in the south, Banda Sea in the north; pronounced variation in coastlines results in a wide range of oceanography and coastal geography and diverse marine habitats; largest extent of coral reefs, seagrass, mangroves found in Banda Sea; wider coastal plains, shallower support retention of sediments and nutrients promotes pelagic and benthic growth in Timor Sea and presence of oil and gas.	Islands range from atolls to mountainous/volcanic, with highest peak in Santo Island of about 1,800 meters above sea level; rapid changes in coastal geography, particularly areas with high population density due to reclamation and coastal construction; limited to narrow fringing reefs; very small area of mangroves.
General Climate Conditions[a]	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; El Niño Southern Oscillation (ENSO) events can be expected from June to August, and tropical cyclones during the wet season.	Humid and warm climate, with high and rather uniform temperature; rainfall at 3,000–5,000 millimeters (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 ENSO.	Lowest average temperatures in mountainous areas, rising temperature to lowland coastal areas; dry season (June to September) with southwest monsoon from Australia continent, wet season (December to March) corresponds to northeast monsoon affected by Pacific Ocean and Asian continent; heterogeneous rainfall, with wet areas in central to western parts, drier areas in north coast; average monthly rainfall above 100 mm, dry season less than 30 mm; scarce tropical cyclones since 1970, but coral reefs in southern part exposed to frequent cyclones in Indian Ocean and Timor Gap.	Wet season (November to April) known as cyclone season, influenced by South Pacific Convergence Zone and varies annually due to ENSO; average rainfall from >4,000 mm in north to <1,500 mm in south; warm temperature (January–February) about 4ºC higher than cool period (July–August); Port Vila had 23 tropical cyclones/decade, occurring mostly in January–February.
Population and Human Development				
Population				

Comparable Conditions	Fiji	Solomon Islands	Timor-Leste	Vanuatu
- 2012[b]	875,800	566,500	1,187,200	251,700
- mid-2035 (estimated)[c]	977,600	969,900	nd	400,033
- mid-2050 (estimated)[c]	1,060,000	1,246,000	3,217,000	539,000
- rural (2012 estimated, %)[b]	47	79	71	75
Health (proportion of children under 5 years old who are underweight)[d]	11 (2004 national survey)	11.8 (2006–2007 survey)	48.6 (2007)	11.7 (2007)
Education (literacy rate of adults above 15 years old; %)[e]	99 (2000–2004)	11.8 (2006–2007 survey)	58 (2011)	83 (2011)
Living standards (2011)[f]				
- communities' access to improved sanitation facilities (%)	92 (urban); 82 (rural)	81 (urban); 15 (rural)	68 (urban); 27 (rural)	65 (urban); 55 (rural)
- communities' access to improved water source (%)	100 (urban); 92 (rural)	93 (urban); 76 (rural)	93 (urban); 60 (rural)	98 (urban); 88 (rural)
Proportion (%) of population below the national poverty line[g]	34.3 (2007)	22.7 (2007)	41.9 (2001)	15.9 (2008)
2012 human development index (HDI) ranking among 186 countries[b]	96th (medium human development)	143rd (low human development)	134th (Medium human development)	124th (Medium human development)

nd – no data

Sources:

[a] **Fiji and Solomon Islands**: Rosegrant, M.W., R. Valmonte-Santos, T. Thomas, L. You, and C. Chiang (2015). *Climate Change, Food Security and Sound Economic Livelihood in Pacific Islands,* Table 2.2 Asian Development Bank and International Food Policy Research Institute. http://www.adb.org/sites/default/files/publication/175046/climate-change-food-security-pacific.pdf). **Timor-Leste:** National Coral Triangle Initiative Coordinating Committee of Timor-Leste (2012). *State of the Coral Reefs of Timor-Leste Coral Triangle Marine Resources: Their Status, Economies, and Management,* accessed on January 24, 2013; Coral Triangle Learning Resource Network, http://www.coraltriangleinitiative.net/SCTRlaunch; Australian Bureau of Meteorology

and CSIRO (2011a). *Climate Change in the Pacific: Scientific Assessment and New Research. Volume 2: Country Reports,* accessed on August 29, 2013. http://www.pacificclimatechangescience.org/wp-content/uploads/2013/06/PCCSP_Vol2_Ch3_Easttimor.pdf; **Vanuatu:** Reti, M.J. (2007). *An Assessment of the Impact of Climate Change on Agriculture and Food Security in the Pacific A Case Study in Vanuatu*. FAO SAPA Apia, Samoa**;** Government of Vanuatu. *Climate of Vanuatu*, accessed on August 29, 2013, http://www.meteo.gov.vu/VanuatuClimate/tabid/196/Default.aspx; Krüger, J., and A. Sharma. 2008. Vanuatu *Technical Report. High-Resolution Bathymetric Survey of Efate Fieldwork Undertaken from 2 to 27 August 2003*, accessed on August 29, 2013, http://ict.sopac.org/VirLib/ER0110.pdf; Pacific Islands Applied GeoScience Commission, SOPAC, Suva, Fiji; Australian Bureau of Meteorology and CSIRO. 2011b. *Climate Change in the Pacific: Scientific Assessment and New Research*. Volume 2: Country Reports, accessed on August 29, 2013, http://www.pacificclimatechangescience.org/wp-content/uploads/2013/08/Ch.-16.-Vanuatu.pdf.

[b] United Nations Development Programme. 2012c. *Human Development Report: International Human Development Indicators.* Country profiles, accessed on February 25, 2013, http://hdrstats.undp.org/en/countries/profiles.html.

[c] Bell, J., T., J.H. Adams, J.E. Johnson, A.J. Hobday, and A. Sen Gupta. 2011b. Pacific communities, fisheries, aquaculture and climate change: An introduction, Chapter 1, Table 1.2. *In* J.D. Bell, J.E. Johnson, and A.J. Hobday (eds.). 2011a. *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*. Noumea, New Caledonia: Secretariat of the Pacific Community.

[d] Fiji and Solomon Islands: Rosegrant, M., R. Valmonte-Santos, T. Thomas, L. You, and C. Chiang. 2015. *Climate Change, Food Security and Sound Economic Livelihood in Pacific Islands*, Table 2.2; Timor-Leste and Vanuatu: World Bank 2013. *World Development Indicators*, accessed on August 26, 2013, http://data.worldbank.org/data-catalog/world-development-indicators

[e] Fiji: National Food and Nutrition Center. 2007. *2004 Fiji National Nutrition Survey. Main Report*. Suva, Fiji; Solomon Islands: Solomon Islands Government. 2010. *National Food Security, Food Safety and Nutrition Policy, 2010–2015*; Timor-Leste and Vanuatu: UNESCO Institute for Statistics .2012. Data Centre *In* United Nations Development Programme. 2012. Human Development Report: International Human Development Indicators. Country profiles. http://hdrstats.undp.org/en/countries/profiles.html, accessed on February 25, 2013.

[f] World Bank 2013. *World Development Indicators,* accessed on August 26, 2013, http://data.worldbank.org/data-catalog/world-development-indicators

[g] Ahmed, M., J. Maclean, R.V. Gerpacio, and M. Sombilla. 2011. *Food Security and Climate Change: Rethinking the Options,* Table 7, page 13. Pacific Studies Series. Manila. http://www.adb.org/publications/food-security-and-climate-change-pacific-rethinking-options. Refers to percentage of the population below the basic needs poverty line. This reference includes not only food, but also myriad other essential nonfood items (goods and services) that each household or individual needs to maintain a basic standard of living.

The overall indicators, particularly on the socioeconomic aspects, confront the national governments of these countries on achieving the Millennium Development Goals, including poverty alleviation and food and nutrition security. Based on the United Nations human development index (HDI), Solomon Islands is under the low human development category, indicating poor progress in achieving access to three basic dimensions—namely, health, education, and living standards at the national level. Indicators of living standards consist of access to clean water, electricity, toilet, cooking fuel, housing, and other parameters, such as freedom, dignity, and self-respect. Fiji, Timor-Leste, and Vanuatu are performing better under the HDI, falling into the medium human development category.

The ability of these countries to improve their food security and nutritional status depends on their potential to produce their own food. The agriculture and fisheries sectors are both affected by weather conditions. All four Pacific CT study countries are subjected to harsh weather conditions, including El Niño events and tropical cyclones. Rosegrant et al. (2015) note that Fiji experiences about 10–12 cyclones every 10 years, while Solomon Islands experiences 1–2 cyclones per year. These severe weather disturbances destroy crops and farmlands, and fishing activities cease during cyclones. Even without serious weather conditions, the limited land available and accessible for agriculture as well as rights to fish in coastal areas in these countries hamper the capacity to produce food from the agriculture and fisheries sectors.

D. Brief Description of Key Adaptation Strategies and Implementation Arrangements

This research project and report complement and inform the broad climate change adaptation strategies by investigating future prospects for fisheries in the four PICT project countries and assessing the effectiveness of three main adaptation strategies affecting coastal communities—marine protected areas (MPAs), low-cost inshore fish aggregating devices (FAD), and aquaculture—to alleviate the impacts of climate change in the four countries. These adaptation strategies target food security, enhanced livelihoods, and environmental preservation, including coastal management. Information about these strategies and implementation arrangements in the PCT countries are discussed below.

Box 1.1. Terms Commonly Used in Community Marine Managed Areas in the Pacific Islands

- *Community conserved areas* (CCAs, also called indigenous CCAs)—natural and/or modified ecosystems containing significant biodiversity, ecological, and cultural values, and voluntarily conserved by indigenous, mobile, and local communities through customary laws or other effective means. CCAs can include ecosystems with minimum-to-substantial human influence, cases of continuation, revival or modification of traditional practices, or new initiatives taken up by communities in the face of new threats or opportunities.
- *Locally managed marine areas* (LMMAs)—areas of nearshore waters and coastal resources that are largely or wholly managed at a local level by the coastal communities, land-owning groups, partner organizations, and/or collaborative government representatives who reside or are based in the immediate area.
- *Marine managed areas* (MMAs)—estuarine and adjacent terrestrial areas designated using federal, state, territorial, tribal, or local laws or regulations intended to protect, conserve, or otherwise manage a variety of resources and uses.
- *Marine protected areas* (MPAs)—clearly defined geographical spaces that are recognized, dedicated, and managed through legal or other effective means, to achieve long-term conservation of nature with associated ecosystem services and cultural values.
- *No-take zones* (NTZs)—areas that restrict any form of exploitation or harvest, and thus prevent any human activities. NTZs can cover a whole MPA or designated areas within an MPA that are of high importance or vulnerability.

Source: Govan, et al. (2009).

1. Marine protected areas

In the context of marine resource conservation and protection, Govan et al. (2009) discussed community conserved areas (CCAs), locally managed marine areas (LMMAs), marine managed areas (MMAs), MPAs, and no-take zone (NTZs) (Box

1.1). CCAs, LMMAs, and MMAs all have the same objectives of natural resource conservation and protection, while MPAs and NTZs are management tools applied to these resource-conserving concepts. Other tools can be gear restrictions, seasonal closure, and species-specific restrictions.

Among the four PICT project countries, Fiji established its first LMMA (Ucunivanua) in 1997 (UNDP 2012a). Fiji also has the highest area coverage of total LMMA, at 10,186 square kilometers (km^2), followed by Solomon Islands with 941 km^2, Vanuatu with 58 km^2 (Govan et al. 2009), and Timor-Leste with 7 km^2 in 2010 (World Bank 2013). The ability of Fiji to expand its LMMA at a fast rate may be attributed to the support of the national network of nongovernment organizations (NGOs) and government organizations promoting Fiji's LMMAs.[2]. About 250 of 388 villages from 14 provinces of Fiji have created some form of community-based management set-up (Table 1.3) (Govan et al. 2009; LMMA AR 2009). Because neighboring villages realized the benefits of such arrangements, interested community members have likewise organized themselves and have requested support to learn the skills from LMMA Network members.

Table 1.3
Inventory of LMMAs in Pacific Coral Triangle Project Countries in 2008

Country	Total (number)		LMMA Area	Management	Legally Gazetted
	LMMA	Villages	(km^2)	Plans (no.)	
Fiji	250	388	10,745	208	1
Solomon Islands	74	148	249	60	0
Vanuatu	26	27	290	5	1

Source: Reprinted table from LMMA AR (2009).

Solomon Islands joined the LMMA Network in 2003, with around 74 LMMAs (Table 1.3) (LMMA AR 2009). Similar to Fiji, LMMA in Solomon Islands has the spillover effects; thus, Govan et al. (2009) reported a higher number at 127 MMAs, of which 113 are active. Other communities have indicated interest in establishing LMMAs. As a result, NGOs and government agencies (e.g., Ministry of Fisheries and Marine Resources) have supported and increased awareness of conservation and management efforts. Hence, Kauhiona and Vevekaramui (2013) reported 162 LMMA sites in 2012 for Solomon Islands, which are currently being confirmed by members of the Solomon Islands LLMA Network.

Marine conservation activities implemented by communities in Vanuatu have been ongoing for several years, starting with the assistance of the Vanuatu Department of Fisheries (VDOF) in the 1990s (UNDP 2012b). VDOF persuaded the North Efate communities to close certain marine areas for Trochus recovery. This was followed by turtle monitoring spearheaded by the Vanuatu Wan Smolbag to conserve turtles in Nguna-Pele Islands. In 2003, the Nguna-Pele MPA established its network, comprised of local and indigenous NGOs of 16 communities from the two islands, with the main objective of sustainable use and long-term existence of marine and terrestrial resources. In 2007, Nguna-Pele joined the LMMA Network, and is currently in the initial phase of establishing a countrywide LMMA.[3]

[2] Fiji LMMA formally joined the Locally Managed Marine Area Network in late 2000, and is thus called an FLMMA. LMMA Network members consist of those with conservation and resource management projects that are using (or planning on using) an LMMA approach. Member include community members, land-owning groups, traditional leaders, elected decision makers, conservation staff, university scientists and researchers, and donors (LMMA Network accessed on October 3, 2013. http://lmmanetwork.dreamhosters.com/home).
[3] LMMA Network accessed on October 3, 2013, http://lmmanetwork.dreamhosters.com/home.

The Coral Triangle Support Partnership requested the international LMMA Network to visit Timor-Leste to encourage coastal and small island management. During this visit, three sites—Tutuala, Batugade, and Atauro Island—were invited to develop LMMA activities in 2010.[4]

The benefits of establishing and maintaining MPAs that led to the rising number of LMMAs in these PICT countries include biodiversity protection, enhanced fisheries populations and productivity, improved livelihoods, and enhanced tourism (Lutchman et al. 2005). Pascal, Seidl, and Tiwok (2012) further described the benefits of MPAs by evaluating the ecosystem services of coral reefs that extend to subsistence fisheries, commercial fisheries, tourism, protection against coastal flooding, and bequest value.[5] Economic benefit analyses of nine MPA case studies in Vanuatu demonstrated the positive effects of MPAs to marine resource productivity, coastal environment, and income growth through tourism revenue (Table 1.4). In addition, the benefits from five MPA case studies in Fiji are presented in Table 1.5, while the overall benefits of MPAs per ecosystem service in these case studies are presented in Table 1.6.

Table 1.4
Impacts of MPAs on Coral Reef Ecosystem Services in Nine Case Studies in Vanuatu

Ecosystem Service	MPA Contributing Factor	MPA Impacts
Subsistence fishing Commercial fishing	Impact on fishing productivity	• Net fishing = 15%–33% increase in yields • Spearfishing = 6%–22% increase in yields • Line fishing = 6%–33% increase in yields
Tourism and associated expenses	Role on tourist visit motivation and habitat	Between 5% and 20% of reef tourism revenues
Bequest value	Impact on ecosystem health	Contributing factor between 10% and 30% of bequest value
Coastal protection	Impacts on habitat	Contributing factor between 10% and 30% of the coastal habitat protection

Source: Reprinted from Pascal, Seidl, and Tiwok (2012).

Table 1.5
MPA Benefits in Two Case Studies of Viti Levu Island, Fiji, 2011

Benefit	Korolevu-i-Wai MPA	Navakavu MPA
Total annual benefits (FJ$)	3.5 million	1.15 million
Spillover effect outside of village boundaries (%)	>35	>70
Households benefitting (food/nutrition security [protein]; cash) (number)	400	180
Tourism business (number)	>25	-
Job creation (number)	300	-
Visitors (number)	>42,000	-
Coastal flood protection		
• Area (square meters [m^2])	80,000	17,000
• Houses (number)	550	760

Source: Summarized from Pascal, Seidl, and Tiwok (2012).

4 Ibid.
5 Bequest value is the value of preserving the natural environment for future generations.

Table 1.6
MPA Benefits per Ecosystem Service in Two Case Studies of Viti Levu, Fiji, 2011

Ecosystem Service	Korolevu-i-Wai MPA	Navakavu MPA
	(%)	
Bequest value	2	4
Subsistence fishing	5	6
Commercial fishing	6	17
Coastal protection against flooding	29	72
Reef-associated tourism	58	1

Source: Summarized from Pascal, Seidl, and Tiwok (2012).

The total MPA cost in Fiji was calculated at FJ$60,000, with an average annual cost of FJ$13,000 in Korolevu-i-Wai MPA and FJ$7,500 in Navakavu MPA (Pascal, Seidl, and Tiwok 2012). As a public investment, the MPA cost-benefit ratio is more than 20 (at a 25-year life span with a 10% discount rate), while return on investment since the MPAs' establishment is 12 for Koreolevu-i-Wai and 1.7 in Navakavu (Pascal, Seidl, and Tiwok 2012). Annual costs of other LMMAs in the project countries are presented in Table 1.7.

Table 1.7
Annual Costs of Different LMMAs in Three Pacific Island Coral Triangle Countries

Country	Site/Project	Annual Cost (US$)			Notes
		Per Site	Per km^2	Per km^2 in NTZ	
Fiji	Daku	478	81	166	Site in operation over 7 years from start-up.
	Nasau	938	158	171	In operation over 4 years from start-up.
	Navakavu	725	39	247	In operation over 5 years from start-up.
	170 IAS Fiji LMMA sites	800	14.6	265.8	Establishment and ongoing support of ultimately 170 sites over 5 years.
	Waitabu	3,000		12,000	Project costs averaged over 10 years. Single site and staff costs estimated using consultancy rate equivalent.
Solomon Islands	Western Province/WorldFish, Isabel	3,000	~100	3,500	Project average costs from startup to ongoing support over 3 years. 2 large managed areas containing 26 NTZs.
	Western Province/WWF	16,000/MPA; 5,000/NTZ		2,900	Project average cost from startup to ongoing support over 3 years. 4 sites/cluster of NTZs.
	Malaita, Gela, Guadalcanal/FSPI	1,851–2,569		4,634 – 6,432	Includes in-kind and other indirect costs. Averages start-up and ongoing costs. Higher figures include government, network,

Country	Site/Project	Annual Cost (US$)			Notes
		Per Site	Per km^2	Per km^2 in NTZ	
					and technical support.
	Arnavon Islands/TNC	20,000	125	125	Ongoing support; 1 large MPA.
Vanuatu	FSPV	5,537		2,187	Includes in-kind and other indirect costs. Costing averages include start-up and ongoing costs. 9 sites.

Notes: Costs exclude community in-kind contributions, unless otherwise stated.
FSPV = Foundation of the Peoples of South Pacific Vanuatu; FSPI = Foundation of the Peoples of the South Pacific International; IAS = Institute of Applied Science (University of South Pacific); LMMA = locally managed marine area; MPA = marine protected area; NTZ = no-take zone; TNC = The Nature Conservancy; WWF = World Wildlife Foundation.
Source: Reprinted Table 19 from Govan et al. (2009).

Despite the achievements of MPAs and rising number of LMMAs (Table 1.3), the number of legally recognized MPAs is still relatively low. Management of MPAs and LMMAs is based on traditional systems, where a coastal fishing area is part of the community's customary property rights and is respected by the local system. Govan et al. (2009) pointed out that LMMAs are implemented primarily for livelihood and food security reasons. For example, in the 170 Fiji LMMAs, 44% are for fisheries management, 14% are for conservation, and 42% have mixed objectives. More important, 78% of the respondents from Navakavu MPA in Fiji highlighted that assurance of fish supply for future generations is the primary motivating factor that led them to the establish their MPA. This goal can be achieved through working in partnerships with the Government of Fiji and NGOs.

The primary responsibility of MPA management lies with the community, but government support is needed in terms of advice and guidance. Also, in many cases, funding is needed as well, to support alternative sources of livelihood for communities during the time the MPA is being established. Sustainable multi-year funding is required for the transition to effective fisheries management at the grassroots level, but community awareness about the level and duration of funding is essential (Gibbs 2013). However, this funding should not be open-ended. Instead, financial support to MPAs should be performance-based, requiring an existing management plan that outlines the locally established regulations, policies, and other actions, as well as the provision of regular reporting. Finally, legislation is a requirement to establish a system for funding and reporting to gain the confidence of the people that money can be tracked and performance can be measured.

2. Fish aggregating devices

Fish aggregating devices (FADs) have captured the interest of Pacific Island countries because of their anticipated benefits. Fiji's Department of Fisheries (DOF) has deployed FADs during the last 5 years (Davetanivalu 2013), while the Ministry of Fisheries and Marine Resources (MFMR) in Solomon Islands deployed them in 2010 (Kauhiona and Vevekaramui 2013), DOF in Vanuatu deployed them in the early 2000s, and Timor-Leste deployed them in July 2013. Table 1.8 summarizes the benefits and adverse impacts of FADs in the Pacific Islands.

Table 1.8

Benefits and Adverse Impacts of FADs in Pacific Islands

Benefits	Adverse Impacts
• *Biological* - Higher fish production leading to increased catch per unit of effort - Reduced fishing pressure on reef resources	Overexploitation of a resource
• *Socioeconomic* - Import substitution reduces reliance on fish imports for food - Export creation where higher fish catch enhances marketing of fish products - Commercial development that promotes market channel development - Creation of jobs for fabrication, deployment, monitoring, and maintenance; post-harvest processing of tuna products - Improved fishing practices—reduction in fuel consumption; safety at sea, since a FAD becomes a marker of a defined fishing ground	Market saturation Vandalism
	Natural disasters

Source: Summarized from Sharp (2011).

WorldFish Center (WFC), University of Queensland (UQ), SPC, and MFMR are working together to carry out alternative livelihood options to divert fishers in Gizo (Solomon Islands) away from the MPA. These agencies have deployed several inshore FADs in 2008 and 2009. Different designs of FADs are being tested (Table 1.9) in several villages of Gizo (Sokimi 2011). Investment costs per FAD design are also provided in Table 1.9.

Table 1.9
Fish Aggregating Device Designs Deployed by SPC, UQ, and WFC in Gizo, Solomon Islands, 2011

	SPC	UQ	WFC
Floating elements:			
Pressure floats (no.)	5	4	5
Purse-seine floats (no.)	4	13	14
Nylon rope (m)	5 of 20-mm rope		
Buoyancy (kg)	116	145	180
Max depth (m)	200	200	200
Connecting parts	Stainless steel (SS) thimble 16-mm SS swivel (no shackles used) SS thimble and 3- x 5-mm copper swages	One length of rope; no connecting parts	One length of rope; no connecting parts
Upper mooring	100 m of SS 5-mm wire	100-m x 200-mm nylon rope	
Connecting parts	SS thimble and 3- x 5-mm copper swages 16 mm SS swivel (no shackles used)	Splice; no connecting parts	Only one rope used in the whole system; 600 m of polypropylene rope
Lower mooring	500 m of 12-mm polypropylene rope 2- x 1.8-L pressure floats	500 m of 12-mm polypropylene rope 2 x 1.8 L pressure floats	
Connecting parts	12-mm galvanized swivels 13-mm hi-load safety	#3 Nylite connector 22 mm hi-load shackle	Bottom end of propylene rope spliced directly to

	SPC	UQ	WFC
	shackle	22-mm short-bow swivel	anchor girdles with protective plastic hose over spliced eye
Anchoring elements	20 m of 13-mm galvanized chain 1 grapnel made with 76-mm galvanized pipe and 25-mm rebar	10 m of 20-mm regular-link chain Discarded heavy machinery or cement block	3 m of 13-mm chain 2 half-drum cement anchors + 1 grapnel
APPROXIMATE TOTAL COST (AUS$)	1,200	1,500	750

Source: Reprinted Table. Sokimi (2011).

Table 1.10 presents annual catch and revenues with and without FADs in inshore waters of Niue, another Pacific Island country (Sharp 2011).

Table 1.10
Annual Catch (kg) and Revenue (NZ$) with and without Inshore FADs in Niue, 2001–2008

	CPUE	Effort	Catch	Price	Revenue
	(kg/hr)	(hrs)	(kg)	(NZ$)	
With FADs	8.69	399	3,463	7.50	25,972.89
Without FADs	6.29	399	2,507	7.50	18,799.71
Net gain			956		7,173.18

Source: Reprinted Table 3 from Sharp (2011).

Although the study was conducted in Niue, the ultimate outcomes are comparable to the current study on FADs as an adaptation strategy primarily targeting food security and livelihoods for the fishers residing in the coastal communities of the PICT project countries. Inshore FADs improve fish productivity by attracting targeted tuna species and thereby improving the catch of inshore waters that are otherwise available only in offshore commercial fisheries (Table 1.10). This finding supports the modeling results of our current study, which showed that adoption of inshore FADs will decrease prices of tuna, coastal finfish, coastal invertebrates, and freshwater finfish in 2035 as a result of improvement in catch in Vanuatu. Coastal finfish and tuna, the two most important sources of fish and seafood in Vanuatu, supply about 77% of current consumption. Coastal finfish are widely consumed by poorer households in the country. Furthermore, because of the identified fishing ground, consumption of fuel by coastal fishers is reduced, while at the same time, inshore FADs keep fishers safe while they are at sea, especially during extreme weather conditions. As shown in Table 1.10, deployment of inshore FADs led to higher revenue and profit compared with fishing without FADs.

In 2005, SPC (cited in Sharp 2011) further investigated the cash flow of the FAD program in offshore and inshore waters of Niue (Table 1.11). The findings of the SPC research, plus the modeling results of our study on prices, fish production, and income, are indicators that can guide the private sector and the government in terms of investments in FADs. The SPC study also calls for government support on FAD development and management plans.

Table 1.11

Cash Flow and Net Present Value of FADs in Niue

Description	Year 1	Year 2
	(NZ$)	
Financial gain (cash inflow)		
Offshore FAD	64,027	64,027
Inshore FAD	7,712	7,712
TOTAL GAIN	71,740	71,740
Cost of FAD (cash outflow)		
5 Offshore FADs	23,839	
3 Inshore FADs	10,215	
TOTAL INVESTMENT	34,054	
Maintenance of FAD (cash outflow)		
5 Offshore FADs		3,706
4 Inshore FADs		1,969
TOTAL MAINTENANCE		5,675
Cash flow		
Offshore FAD	40,188	60,321
Inshore FAD	-2,503	5,743
NET CASH FLOW	37,686	66,065
Cumulative cash flow	37,686	103,750
Net present value or NPV (5% discount rate)		
Offshore FAD NPV	92,987.55	
Inshore FAD NPV	2,825.94	
TOTAL NPV	95,813.49	

Source: Reprinted Table 5 from Sharp (2011).

The favorable results of the benefit-cost analysis and total benefits of the Niue FAD program support the findings of the modeling regarding the benefits of significant expansion of investment in FADs. The increase in catch rate and reduction of fuel consumption are significant benefits, particularly for small-scale fishers. Given the public goods nature of FADs, with broad access to many fishers, government investment policy on the development, deployment, maintenance, monitoring, and replacement of FADs is justified. However, it would also be appropriate to involve the private sector and communities in developing and managing FADs. Sharp (2011) recommends (1) encouraging the private fishing sector to fabricate, deploy, and maintain FADs; (2) assigning the government responsibility for maintaining investment in FAD replacement, fabrication, deployment, maintenance, and monitoring, and for regulating placement of FADs to avoid overcrowding and diminishing returns; (3) promoting and supporting data collection; (4) extending training to fishers on FAD fabrication and deployment and fishing techniques; and (5) promoting the benefits of FADs to the private sector.

3. Aquaculture

Aquaculture was introduced to Pacific Island countries as early as the 1920s, specifically in Vanuatu with the introduction of Pacific oysters (Adams, Bell, and Labrosse 2001). This was followed by the short-lived culture of Macrobrachium in Santo Island from 1978 to 1983, tilapia from New Caledonia in Efate Island in the early 1980s, Trochus in the late 1980s, and the ongoing Teouma prawn hatchery in Efate at commercial scale. In Solomon Islands, aquaculture was introduced through the then ICLARM Coastal Aquaculture Centre (CAC) in Guadalcanal province. About 50 village-based giant clam farms and 2 shrimp farms were maintained in the ICLARM-CAC. However, ethnic tensions in the early 2000s destroyed all aquaculture and office facilities of ICLARM (now WorldFish).

Aquaculture in Fiji has had varying outcomes. The first aquaculture was tilapia in 1953, followed by Eucheuma, oyster, mussel, Macrobrachium, and carp of varying successes (Adams, Bell, and Labrosse 2001). The Government of Fiji has supported considerable investments in aquaculture; however, because of biodiversity issues, aquaculture activities are progressing at a cautious pace. The advantages and disadvantages of carrying out aquaculture activities in the Pacific Islands are presented in Table 1.12.

Table 1.12
Advantages and Disadvantages of Aquaculture in Pacific Islands

Advantages	Disadvantages
• High demand of species associated with coral reefs: a) aquaculture and seafood markets in Asia (e.g., napoleon wrasse, grouper, sea cucumber, spiny lobster, Trochus, pearl oyster, giant clam, green snail) b) marine aquarium trade (e.g., clownfish, angelfish, hard coral, soft coral, giant clam) c) pharmaceutical trade (e.g., algae, sponge, soft coral, seahorse) • Availability of suitable grow-out sites in pristine habitats—presence of favorable environmental and coral reef conditions • Favorable geography for restocking and stock enhancement—cultured juveniles released in inshore waters cannot emigrate and are easy to recapture • Relatively inexpensive labor force	• Traditions and familiarity of coastal communities working with marine resources • Limited domestic markets • High-added-value export markets targeted • Transport problems • Socioeconomic factors—lack the infrastructure, capital, and skilled labor • Fragile habitats • Freshwater is limited, except for the large islands of Melanesia, which have extensive river systems • Cyclones

Note: Reprinted from “Fisheries sector under climate change in the coral triangle countries of Pacific Islands: Current status and policy issues,” by Valmonte-Santos, R., M.W. Rosegrant, and M.M. Dey, 2016. *Marine Policy*. Copyright (2016) by Elsevier.
Sources: Compiled from Adams, Bell, and Labrosse (2001); and Nandlal (2011)

In 2011, WorldFish, in partnership with MFMR and SPC, carried out the study *Aquaculture and Food Security in the Solomon Islands* to help the Solomon Islands Government better respond to the increasing demand for fish and fully realize the potential of aquaculture for enhancing food security and livelihoods in response to rising population and climate change (WFC 2011). Initial results of the study indicated the feasibility of private investment in tilapia or milkfish pond culture; however, production costs should be kept low and competitive through locally sourced or produced feeds, fertilizers, and seed production. Preliminary results also showed that backyard or household pond culture is not enough to meet fish demand. Hence, a combination of “enterprise type” is needed to produce an estimated production of 2,500 metric tons (t)/year (Table 1.13). This implies the need for a medium-scale type of aquaculture enterprise or business in order to meet fish demand of around 2,500 t/year (WFC 2011). Producing this volume of fish will ensure food security and encourage income from aquaculture activities.

Table 1.13
Combination of Enterprise/Production to Achieve an Estimate of 2,500 t/yr for Aquaculture, Solomon Islands

Enterprise Type	Annual Fish Production (kg/unit)	Farm Units (number)	Infrastructure Costs (US$)	Annual Operating Costs (US$)	Estimated Annual Fish Output (tons)
Households	120	500	30,000	60,000	60
Household "cluster"	6,000	20	120,000	100,000	120
Schools	25,000	6	155,000	130,000	150
Palm oil	50,000	2	56,000	110,000	100
Medium enterprise	300,000	7	860,000	2,300,000	2,100
Total			~1.2 million	~2.6 million	~2,500

Source: Reprinted as Box 2 from WFC (2011)

Aquaculture, particularly inland aquaculture, is more resilient to climate change compared with wild reef fisheries, especially in the Pacific Islands (Ponia 2010). One of the key challenges of aquaculture in the small economies of PICT countries is to attract the interest of the private sector to invest in aquaculture. Ponia (2010) reported that the French territories (French Polynesia, New Caledonia, and Wallis and Futuna) are the primary contributors to increasing aquaculture production and value in the Pacific region. This is largely the result of long-term approaches and a strong level of government policy support that attracts investors and stabilizes aquaculture production (Ponia 2010). Unfortunately, a similar level of support is difficult for the PICT countries as well as countries with small economies.

At the national level, proposed approaches for aquaculture development include setting a feasible point for government-led aquaculture activities to attract and motivate private investors, and determining a realistic and practical scale of operations. The Asia model of aquaculture is based on economies of scale, where the level of production and marketing is achieved through numerous small-scale producers that change their production based on market demands (Ponia 2010). For the Pacific Islands region, the reasonable approach would be to maintain regulatory oversight of the national governments and create an investment climate focusing on small- to medium-scale enterprises as a way to meet domestic demand and to compete in selected international markets (Ponia 2010).

Aquaculture development would be enhanced by (1) reinforcing inter-regional coordination and cooperation based on research, training, and information exchanges; (2) ensuring the security of tenure for aquaculture operators, where long-term leases to aquaculture operations will be provided; (3) ensuring affordable and reliable supply of feed, experimenting with local ingredients versus imported fish meal, and reducing tariffs on imported feeds; (4) ensuring seed (fry) availability and quality through (a) funding of public fish hatcheries for freshwater species, (b) provision of broodstock to hatcheries and conduct of research on marine seed, and (c) diagnostic services, research into new strains, certification, production standards, and seed inspection to ensure seed quality; and (5) creating incentives for investment in aquaculture through loans with preferential rates and access to loans made easier (Hishamunda et al. 2010).

Rosegrant et al. (2015) identified the following recommendations for aquaculture operations in the PICT countries: (1) undertake rigorous economic evaluations of aquaculture programs during the design and evaluation phases to determine their viability; (2) establish an effective and cost-efficient quarantine facility; (3) and encourage active participation by and strengthen the role of the private sector, particularly on 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.

2. MODELING METHODOLOGY AND DESCRIPTION[6]

A. Introduction

The two broad approaches used to analyze the impact of climate change in fisheries and aquaculture are bioeconomic modeling and market supply and demand (Briones, Garces, and Ahmed 2006). One benefit of bioeconomic modeling is that it can incorporate climate change scenarios by altering an appropriate set of ecosystem or population parameters. However, much of the required information on resource and ecosystem interactions is not available for Pacific Island countries. The market supply–demand approach represents climate change in terms of supply shocks, and works out its economic consequences using the microeconomic tools of supply and demand. Delgado et al. (2003) have effectively used this approach to analyze the "fisheries collapse" scenario. Given the scarcity of data regarding the biological and physical responses to climate change in the Pacific Islands, this study has developed and used a market fish supply–demand model.

B. Conceptual Framework

The study has followed a three-step procedure to measure the potential impacts of various climate change adaptation strategies: (1) development of a baseline model of the fisheries sector for each country; (2) collection and construction of data sets for model parameters, exogenous variables, and *ex ante* impact indicators of various climate change adaptation strategies; and (3) analysis of the overall impact of climate change adaptation strategies by incorporating the *ex ante* impact indicators into the fisheries sector model.

Figures 2.1 and 2.2 represent the economic framework used in each of the four Pacific project countries for assessing the impact of climate change adaptation strategies. As shown in Figure 2.1, the framework considers three supply scenarios: scenario I (S_1)—before climate change; scenario II (S_2)—with climate change effects, but no adaptation strategy; and scenario III (S_3)—after adopting climate change adaptation strategies. The supply curve for capture fisheries and aquaculture under scenario 1 (no climate change effect) is depicted by $S_{1.}$ The actual (or perceived) supply curve of farmers/fishers may shift to the left from the S_1 to the S_2 position as a result of the realized (or potential) negative impacts of climate change (scenario II). These impacts may be a reduction of catch per unit of effort, lower productivity, and higher cost per unit of fish produced or caught, among others. It is, however, important to note that impact of climate change on seafood supply is indeterminate and climate change may also have positive effects on some sub-sectors o aquaculture/fisheries; in that case, the supply curve may shift to the right (i.e., the position of S_2 will be at the right side of S_1).

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change indicates that the impact of climate change on fisheries is uneven (Pörtner et al. 2014); and as such, one can expect that natural productivity and fish stocks to increase for some species and decline for others.

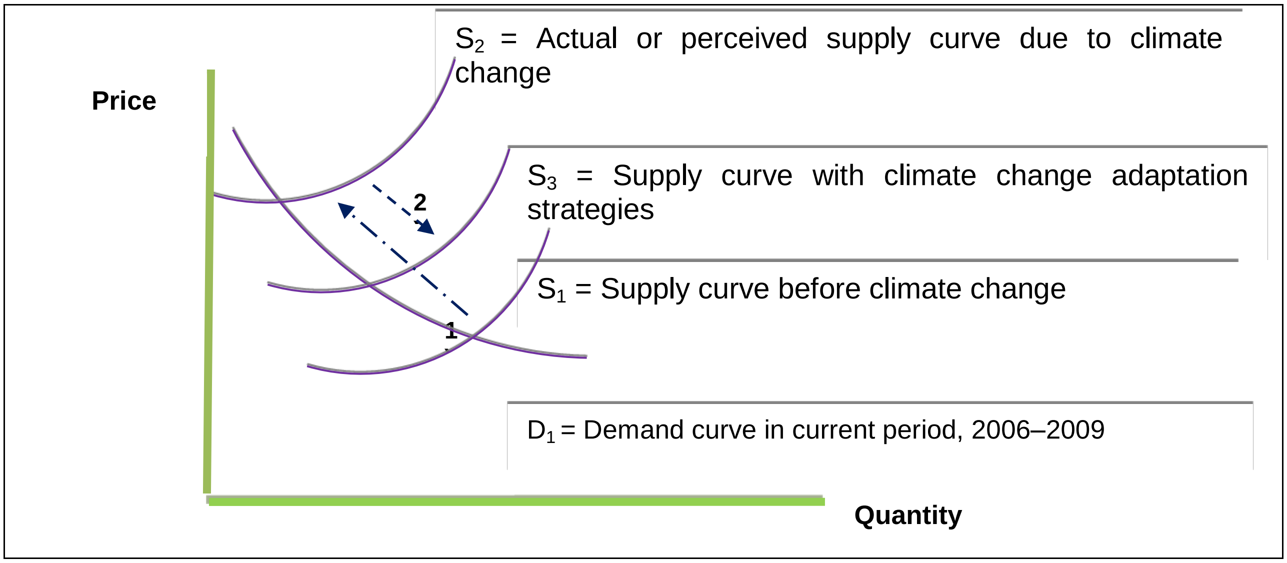
The nature of supply curve differs between aquaculture and capture fisheries sub-sectors. Output, or total catch, of capture fisheries can increase or decrease due to changes in stock abundance and effort. Higher level of stock abundance (biomass) yields higher catch per effort, given all other factors held constant. Supply curve of a particularly capture fishery under a specific scenario (S_1 or S_2) assumes a particular stock size (biomass), and underlying the

[6] This Chapter draws extensively from Dey, et al. 2016a.

changes in the supply curve of capture fisheries (from S_1 to S_2) there will be changes in biomass.

The adoption of various climate change adaptation strategies is expected to reduce the negative effects of climate change. As a result, the supply curve from capture fisheries and aquaculture (scenario III) may shift from the S_2 position to S_3. Comparison of S_1 and S_2 shows the impact of climate change, while comparison of S_2 and S_3 shows the effect of climate change adaptation strategies. The main focus of this study has been to estimate the gap between the S_3 and S_2 supply curves and to assess the impact of climate change adaptation strategies.

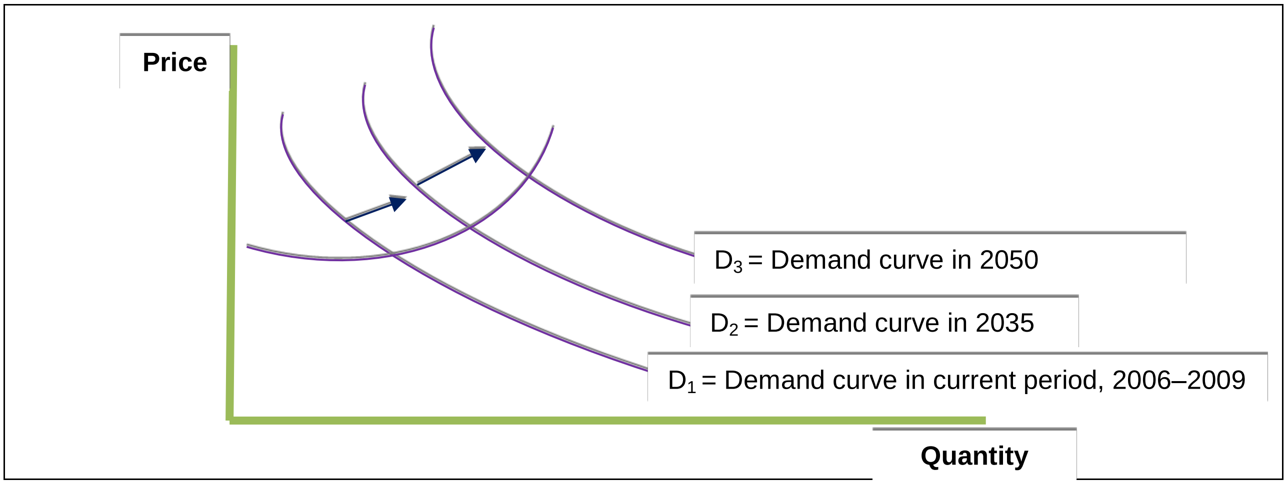
Figure 2.1
Shifts of Supply Curve due to Climate Change and Adaptation Strategies



Note: Arrows with 1 and 2 indicate directions of shifts in supply curves due to changes in productivity and/or cost per unit of production.
Adapted from "Analysis of the economic impact of climate change and climate change adaptation strategies for fisheries sector in Pacific coral triangle countries: Model, estimation strategy, and baseline results" by Dey, M.M., M.W. Rosegrant, K. Gosh, O.L Chen, and R.A. Valmonte-Santos. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Dey et al. 2016a.

This study has considered three time periods: current (represented by the average data of the three most recent available years 2006–2009), mid term (2035), and long term (2050). Each of these periods is represented by a specific demand curve. As shown in Figures 2.1 and 2.2, D_1 denotes the demand situation in the immediate past (2006–2009). The demand is likely to shift upward with the increase in population and income from D_1 to D_2 in 2035 and D_3 in 2050.

Figure 2.2
Shifts of Demand Curve due to Income and Population Changes



C. Algebraic Representation of the Fisheries Sector Model

The fisheries sector model developed to evaluate the impact of climate change adaptation strategies is based on the modified balance-of-trade function approach suggested by Martin and Alston (1994) and used by Dey et al. (2000). The basic form of the model formulated for this project for a national economy can be expressed as:

$$\mathrm{H}^1 = \mathbf{e}(\mathbf{P}, \mathrm{u}^{\mathrm{i}}) - \mathbf{g}(\mathbf{P}, \mathbf{V}, \boldsymbol{\lambda}) - \mathrm{f} \ldots\ldots\ldots\ldots\ldots..(1)$$

where
e = expenditure function of a national economy,
P = vector of domestic prices of different fish groups,
u^i = level of utility exogenously specified to define Hicksian money-metric measures of welfare change,
g = function that defines maximum profit generated from capture fisheries and aquaculture in the national economy,
V = vector of fixed factors,
λ = vector of technology and fisheries management variables representing the state of climate change adaptation strategy, and
f = financial inflow (outflow) to (from) the non-fisheries/aquaculture sector.

The impact of the climate change adaptation strategy (new management practices/technologies) on welfare is obtained from equation (1) by comparing the net expenditures required to achieve a given level of utility (U^i) under "no climate change adaptation strategy" ($\boldsymbol{\lambda}_0$) (scenario II), and under the "climate change adaptation strategy" ($\boldsymbol{\lambda}_1$) (scenario III). An equivalent variation version of the measure is defined with the utility level in the expenditure function held constant at the level achieved after implementing the climate change adaptation strategy (u^1):

$$\mathrm{H}_1^1 - \mathrm{H}_0^1 = \mathrm{H}(\mathbf{P}_1, \mathbf{V}_1, \boldsymbol{\lambda}_1, \mathrm{u}^1) - \mathrm{H}(\mathbf{P}_0, \mathbf{V}_0, \boldsymbol{\lambda}_0, \mathrm{u}^1) \ldots\ldots\ldots\ldots\ldots..(2)$$

The modified balance-of-trade function defined in equation (1) shares the fundamental parameters of the behavioral system; it includes the parameters of the consumer expenditure system and the profit function. Three subsectors (oceanic commercial fisheries, coastal subsistence fisheries, and aquaculture) have been studied for each country.

It is assumed that fish production can be represented by a normalized quadratic profit function. The profit function subsumes the effects of fixed factors and intermediate inputs into the constant terms, and the quadratic profit function can be expressed in this multiple product case as:

$$\pi = a_n p_n^{'} + \sum_{i=1}^{n-1} a_i \, p_i^{'} + 0.5 \sum_{i=1}^{n-1} \sum_{j=1}^{n-1} b_{ij} \, [(p_i^{'} p_j^{'})/(p_n^{'})^{\,2} \quad] \ldots \ldots \ldots \ldots \ldots . (3)$$

where
π = profit (not normalized),
$p_i^{'}$= effective nominal price of the i[th] fish group,
$p_n^{'}$ = effective nominal price of the *numéraire* fish group, and
Z = a set of conditioning variables, including various environmental factors.

The effective price of fish group i is defined as:

$$p_i^{'} = \ \mathrm{p_i} \, \lambda_\mathrm{i} \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

where
λ_i = an index of climate change adaptation strategies (new management practices/technologies) in farming/fishing of fish group i, set to unity in the base period.

For a specific scenario (I, II or III discussed earlier), the profit function represented in Eq. (3) assumes a given level of exogenous factors (Z) such as technology, stock size (for capture fisheries) and other biological and environmental factors. These exogenous factors are expected to change over time. Biological conditions (like stock abundance) and technology have been modeled as exogenous components that shift the level of production. It is considered that profits are an increasing function of the exogenous factors (Z); for capture fisheries, higher stock abundance will give higher profits.

The new management practices/technologies are assumed to be a disembodied, output-augmenting technical change. The technical change increases the "effective" quantity of fish associated with a given physical quantity, and there is a corresponding change in the effective price of the fish. This specification of technical change in the profit function leads to proportional shifts in the resulting supply curves and a shift in the intercept on the price axis.

This climate change adaptation index (λ) represents a proportional shift down of the supply function involving two proportional shifts: a λ percentage proportional shift in the price direction, and a λ percentage proportional shift in the quantity direction.[7] The proportional shift in the price direction results from increases in the output of one product or species (say, i) without any reduction in the output of other products or species, referred to in the literature as a pure

[7] The effect of a technological change in shifting the output supply curve has been the subject of a great deal of agricultural economics literature. See, for example, Lindner and Jarrett (1978), Norton and Davis (1981), and Alston, Norton, and Pardey (1995) for details and evidence. Alston, Norton, and Pardey (1995) assumed vertically parallel shifts in supply curves due to research. A combination of the type of supply shift assumed in this project and a parallel shift of the type followed in Alston, Norton, and Pardey (1995) could be used to generate a pivotal shift (i.e., a proportional supply shift in the quantity direction) (Martin and Alston 1997).

productivity effect[8] (Martin and Alston 1994, 1997). The proportional shift in the quantity direction results from an increase in the output of product or species i achieved by reducing the output of other products or species, known as the competitiveness effect (Martin and Alston 1994, 1997). A λ percent output augmented by technical change, as assumed in this project, will yield an increase in output that is larger than λ percent. Following the envelope theorem, the supply functions for different fish groups are obtained by differentiating the profit function (equation 3) with respect to effective prices. For each non-*numéraire* fish group, the equations take the form:

$$q_i^{'} = a_i^{'} + \sum_{j=1}^{n-1} b_{ij} \left(\frac{p_j^{'}}{p_n^{'}}\right) \ldots\ldots\ldots\ldots\ldots (5)$$

While for the *numéraire* group, the supply function is:

$$q_n^{'} = a_i^{'} - 0.5 \sum_{i=1}^{n-1} \sum_{j=1}^{n-1} b_{ij} \left[(p_i^{'} p_j^{'}) / (p_n^{'})^{2} \right] \ldots\ldots\ldots\ldots\ldots (6)$$

An Almost Ideal Demand System (AIDS) representation (Deaton and Muellbauer 1980) will be used on the consumption side. The AIDS share equation can be written as:

$$w_i = \propto_i + \sum_{j=1}^{n} \varphi_{ij} \ln p_j + \beta_i \ln \left(\frac{e}{P}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where
e = total expenditure on fish,
Pj = price of the jth group of fish,
w_i = share of total fish expenditure allocated to the ith fish group.

The price index (P) is defined as:

$$\ln P = \propto_0 + \sum_{j=1}^{n} \varphi_j \ln p_j + \frac{1}{2} \sum_{j=1}^{n} \sum_{j=1}^{n} \varphi_j \quad \ln p_i \ln p_j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

The AIDS expenditure function is:

$$\ln e = \ln P + u\beta_o \sum_{j=1}^{n} \ln p_k^{\beta k} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

The final equation needed to complete the model is the income-expenditure equation for equating production income with expenditure and any inflow (outflow) to (from) non-fishery/aquaculture activities:

$$e - \pi - f = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

[8] The pure productivity effect is equal to the benefits from an equivalent parallel shift of the supply curve assumed by Alston, Norton, and Pardey (1995).

D. Model Parameters and Data

The country models require (1) baseline data on demand, supply, and prices for each fish type; (2) parameters for the fish supply and demand equations (equations 5, 6, 7, 8, and 9); and (3) data on exogenous variables, including climate change trend and climate change adaptation strategies. Baseline data on demand, supply, and prices for various fish types were collected from various secondary sources and surveys of local markets in each country. Secondary sources are cited in detail in the sections of each country's case study. As no published estimates of demand and supply elasticities for the fisheries sector are available, and the resources and time needed to estimate these elasticities were lacking, a subjective elicitation process and secondary data were used to make benchmark estimates. This process, using expert opinion surveys (EOSs) and focus group discussions (FGDs), is described in more detail in this section. Expertise of respondents range from capture fisheries and aquaculture, climate change mitigation/disaster management, meteorology, economics and statistics. The preliminary benchmark estimates were presented to various experts for validation in intensive validation meetings.

The slopes of the supply functions (equations 5 and 6) were inferred from the local price elasticities of supply, the relevant base period price, and quantity variables. The intercepts were then obtained by subtraction, and were used to calibrate the production system to the base data set. Following Martin and Alston (1994), the demand system (equations 7, 8, and 9) was parameterized based on market price and income elasticities of demand for various groups of fish; base period data on price, quantity, and expenditure shares of different groups of fish; and using the symmetry and homogeneity, and adding up restrictions of the demand system. The intercepts of the demand equations were also obtained by subtraction to calibrate the demand system to the base data set. The value of "u" is set at 0.5, consistent with other analyses.

The International Food Policy Research Institute (IFPRI) project team constructed *ex ante* indicators of the direct impact of climate change adaptation strategies using data collected through FGDs and EOSs. The values of these indicators (λ_i) were computed by comparing the cost per unit of fish produced (cost per unit of catch for capture fisheries) and/or volume of fish produced/captured between scenarios II and III, as discussed earlier.

E. Overall Impact Assessment

We used the *ex ante* indicators of the direct impact of climate change adaptation strategies in the fisheries sector model to estimate the effects of various adaptation strategies on fish supply, demand, price, and trade. The specified climate change adaptation strategies were used in the fish sector model to estimate the economic (welfare) gain to society. The fish sector model (equations 3 to 10, which include behavioral models of supply relations, Marshallian demand equations, market-clearing conditions, and income-expenditure conditions) was solved using linear program solver in Excel 4.0.

We computed an equivalent version of welfare measure using equation 2, which can be written as follows:

$$H_1 - H_o = [e(\mathbf{P}_1, u^1) - e(\mathbf{P}_o, u^1)] - [g(\mathbf{P}_1, \mathbf{V}_1, \lambda_1) - \mathbf{g}(\mathbf{P}_o, \mathbf{V}_o, \lambda_o)] - [f_1 - f_0] \qquad (11)$$

In equation (11), the total welfare change is equal to (1) the equivalent variation for the change in consumer welfare due to price change induced by the adoption of adaptation strategies (the first term in brackets) minus (2) the increase in producer profit due to the adoption of adaptation strategies (the second term in brackets), minus (3) changes in inflow (outflow) to (from) non-fishery/aquaculture activities (the last term in brackets).

We solved the model (equations 3 through 10) for three different time periods: current (2006–2009), medium term (2035) and long term (2050). We shifted the supply equations (equations 3 through 6) with various time period-specific values of λ_i, and the demand equations (equations 7 through 9) with time period-specific income and population. We estimated the values of fish supply, demand, net trade, and domestic fish prices for various fish species groups in two time periods (2035 and 2050). We followed comparative static analysis. Our focus in this study was not to generate projections for key variables in the fisheries sector, but to examine how projections respond to various developments or events within and outside of the fisheries sector. We accomplished this by implementing various country-specific climate change adaptation strategies.

As indicated earlier, our models are country-specific fish sector models designed to analyze the effects of climate change and related adaptation strategies in individual countries. We used global prices of different fish groups as exogenous variables in our modeling exercise. Most recent global projections of fish prices generated by IFPRI and research partners (see Msangi et al. 2013) are used in the models. Given global fish prices and other exogenous variables, our models endogenously determine domestic fish prices, supply, demand, export, and import of various fish categories for each of the study countries.

For each time period, we ran the model for a baseline scenario and for various adaptation strategies. The baseline scenario denotes the most likely case that we identified with respect to trends in the exogenous variables (including population, income growth, technological change in aquaculture/fisheries, climate change, etc.). For climate change trajectories under baseline scenarios (λ_0), we have followed low (B1) and high (A2) emission scenarios originally reported in the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (Nakićenović et al. 2000) and subsequently used by Bell et al. (2011b). However, countries differ in assumptions regarding the baseline scenario and adaptation strategies. As in any other modeling effort, the outcomes are likely to be influenced by the assumptions that are adopted. For this reason, we implemented a baseline scenario, and each of the adaptation scenarios, for two growth rates of per capita real income.

The supply and supply systems of each of the country-specific models consider six groups: tuna, other oceanic finfish, coastal finfish, coastal invertebrates, freshwater finfish, and freshwater invertebrates. These fish groups are found in oceanic, coastal, and freshwater areas, as well as those produced in aquaculture.

1. *Tuna Supply: Catch by national and foreign fleets*

Broadly speaking, there are three types of tuna and oceanic catches: catch by domestic/national fleets in national waters, catch by domestic fleets in international waters, and catch by foreign fleets in national waters. Because of the focus of this report on national food security, the supply volumes used in our analysis include catch by national fleets in both national and international waters, but do not include catch by foreign fleets in national waters. Our models project the behavior of fish production, consumption and trade sectors of four pacific countries under alternative scenarios. Tuna catch by foreign vessels is not determined by the economic factors of supply and demand that are analyzed in this report. Rather, foreign catch is determined by international and regional agreements, including regional agreements like the Pacific Islands

Forum Fisheries Agency (FFA) and the Parties to the Nauru Agreement (PNA). Relative contributions of tuna catch by foreign fleets and that of national fleets in most of our case-study countries vary substantially over period, partly due to changes in bilateral/regional/international agreements. Therefore, we have treated catch by foreign fleets as a residual sector, influenced by domestic demand and supply (which includes catches by national fleets outside national water). The available data on tuna catch by foreign vessels supports this interpretation.

Among the four case study countries, foreign vessel catch water is not very substantial in Fiji and Vanuatu. In fact, the total tuna catch by national fleets of Fiji and Vanuatu are higher than the total tuna catch in their respective national waters. For example, in 2008 total tuna catch by Fijian national fleets was 11,656 t whereas total tuna catch in Fijian national water was only 8,536 t. Similarly, in 2008 total catch by Vanuatu national fleets was 47,234 t, but the total tuna catch in Vanuatu national water was only 6,021 t (FFA database). Among the four case-study countries, tuna catch by foreign fleets is a significant source of government revenue only in Solomon Islands.

We used the projection of the Spatial Ecosystem and Population Dynamics Model (SEAPODYM)[9] as a reference for the likely effects of climate change on tuna catch under a relatively low emission (B1 scenario) and a relatively high emission scenarios (A2 scenario). The preliminary simulations of the potential impact of global warming on tuna populations using SEAPODYM are presently available only for skipjack and bigeye tuna, and are reported in Lehodey et al. 2011 (Bell et al. 2011b). Among the four main species of tuna (albacore, bigeye, skipjack and yellowfin), skipjack tuna is the highest contributor (more than 70%) of total tuna catch in the Pacific region.

The results of SEAPODYM model show that the concentrations of skipjack and bigeye tuna are likely to be located further east than in the past due to climate change. As reported in Lehodey et al. 2011, catch of skipjack tuna in Fiji is likely to increase by 25.8%, relative to 1980-2000 (20 years) average, in 2035. The corresponding increase in Vanuatu is 18.4%. Tuna catch is expected to increase by 3.2% in Solomon Islands in 2035 (Bell 2010). We have used more conservative estimates of the likely effect of climate change on tuna catch (please see Appendix Tables A4, A8, A12 and A16).

For Fiji and Vanuatu, where tuna catch by their national fleets are higher than the tuna catch in their respective national waters, our projections of tuna catch are within the sustainable limits of tuna population, particularly given the significant increase in tuna population projected under climate change. Solomon Islands and Timor-Leste are keen to develop their domestic tuna industry, and their aim is to access some of the tuna resources currently utilized by foreign vessels. Our models for Solomon Islands and Timor-Leste reflect that reality, as will be seen in the individual country chapters below. The projected tuna catches for Solomon Islands and Timor-Leste in this report represent only a small share of total tuna resources available in their respective national waters.

We carefully considered the data availability situation in the project participating countries, and developed the modeling and impact assessment framework accordingly. We used three broad types of data: endogenous variables (i.e., the variables determined by the models, such as quantity of various types of fish produced, prices of different fish types); model parameters (e.g., elasticities); and exogenous variables (e.g., likely effects of climate change adaptation

[9] For details on SEAPODYM, *see* http://www.spc.int/OceanFish/en/ofpsection/ema/ecosystem-a-multispecies-modelling/seapodym/148-seapodym

strategies on the cost of fishing). We used available secondary data, primarily from the Asian Development Bank and the Food and Agriculture Organization of the United Nations, for endogenous variables. As parameters, we have information collected through (EOSs and FGDs, and imposed various economic restrictions (such as symmetry and homogeneity, and adding up restrictions of the demand system) to minimize data needs. For exogenous variables, we relied on secondary data (such as various reports of the Secretariat of the Pacific Community on fisheries and climate change) and primary data collected through EOSs and FGDs. We believe that our careful use of economic theory and available secondary data has ensured the quality of the project outputs.

2. Coastal, freshwater fisheries and aquaculture

This research project has used Pratchett et al. (2011), Gehrke et al. (2011), and Pickering et al. (2011) as the main references for projected direct effects of climate change in coastal fisheries, freshwater fisheries and aquaculture production, respectively. The reported values of ($\lambda 0$) were adjusted based on experts consultation. It is important to note that many studies on climate change impact have used expert consultation as a way to collect relevant information (see, for example Pratchett et al (2011) and Butler et al. (2014).

F. Limitations of the Model and Steps Taken to Address Them

A limitation of the model is that it is confined to the fisheries sector. The model we followed is a multisectoral general equilibrium model of the fisheries sector, but it is only a partial equilibrium model in a broader sense in that the rest of the economy is exogenous (i.e., determined outside the model). Because the model ignores the impacts of events or policy changes in the fisheries sector on the other sectors of the economy, it consequently fails to account for the feedback effects on the fisheries sector. The extent to which this limitation affects the results depends on the size of the fisheries sector relative to the economy as a whole and the strength of its linkages with other economic activities. We addressed this issue by considering the financial inflow (outflow) to (from) the non-fisheries/aquaculture sector (f in equation 10) as endogenous in analyzing the potential impact of adaptation strategies. We allowed “f” in equation 10 to vary in the solutions.

Another modeling challenge we faced was the presence of information gaps in constructing the model. Among the generic challenges faced in the Pacific region are the availability and accessibility of data. Reports, documents, and secondary data from the national governments and other organizations are not easily accessible. Parameters of fish supply and demand equations, as well as data to estimate the elasticities, are not readily available. To address these problems, the project followed an innovative approach consisting of three steps:

Step 1. Compilation of secondary data from the region

We compiled data on fish supply and demand parameters from similar developing countries, including some of the Asian countries where coastal fisheries is an important economic sector and fish is an important source of people’s diet comparable to the Pacific Island nations. The IFPRI team members have extensive experience in modeling fish supply and demand in developing countries, including the widely cited studies, such as *IMPACT-Fish to 2020* (Delgado et al. 2003), *IMPACT-Fish to 2030* (Msangi et al. 2013), and AsiaFish model (Dey et al. 2005, 2008). These estimates were then subjected to expert opinion and validation in each country, as described in steps 2 and 3.

Step 2. Collection of primary data through EOSs and FGDs

We collected primary data via EOSs of economists, environmentalists, fisheries, climate change experts, and policy planners to elicit information on fish supply and demand responsiveness, existing and pipeline climate change adaptation strategies, and related policies. The EOS of fisheries experts was a key source of information and data, and constituted the main process under the modeling scenario, together with FGDs. The EOS was not implemented in Timor-Leste because of a lack of fisheries experts with enough knowledge and experience related to the economics of fisheries, as well as that of climate change. The IFPRI team interacted with experts from these Pacific countries who willingly shared reports, references, and other possible sources of information and data that were useful in the modeling exercise.

Step 3. Validation of the data and preliminary results by experts

Based on the secondary and primary data mentioned above, we developed the “tentative” models and presented the preliminary results and the data used to regional experts through a series of “data validation” workshops organized in June 2013. We also presented the model and the preliminary results in a May 2013 workshop of the North American Association of Fisheries Economists, which was attended by global experts on fisheries and aquaculture economics and modeling. Subsequently, we adjusted the model based on comments received from global and regional experts. We believe that the model developed and the analyses presented in the report are robust. Sensitivity analyses of a range of demand and supply elasticities around the best estimates show that the orders of magnitude in the results presented in this report are stable with respect to the elasticity estimates.

3. CASE STUDY: FIJI[10]

A. Overview of Fisheries Sector

Fiji has a total water area and exclusive economic zone of 1,290,000 square kilometers (km^2) (Table 1.1). The Food and Agriculture Organization of the United Nations (FAO) broadly categorized the fisheries sector into six main areas: coastal subsistence fishing, coastal commercial fishing, offshore locally based fishing, offshore foreign-based fishing, freshwater fishing, and aquaculture. The sector augments food and nutrition security, particularly in the rural coastal areas, livelihood and income generation, rural development, environmental preservation, and contribution to the country's gross domestic product (GDP). An estimated 3.8% of the economically active Fijian population was attributed to fisheries in 2007 (FAO 2010a). Hand, Davis, and Gillett (2005) further disaggregated the employment supported by the fisheries sector, as shown in Table 3.1. In addition, Ram-Bidesi, Lal and Connor (2011) reported that coastal subsistence fishers in Fiji comprise 65% of coastal fishing.

Table 3.1
Fisheries Employment by Category in Fiji, 2005

Fish Employment Category	Number of People Employed
Subsistence fishers	3,000
Inshore artisanal	2,137
Tuna cannery	800
Ornamental aquarium	650
Other fish processors	639
Aquaculture	550
Offshore fishery	510
Fish markets	340
Department of Fisheries	243
Input suppliers	185
Game and charter fishing	60
Slipways/ports	30
Total	9,144

Note: Reprinted from "Fisheries sector under climate change in the coral triangle countries of Pacific Islands: Current status and policy issues" by Valmonte-Santos, R., M.W. Rosegrant and M.M. Dey. *Marine Policy*. Copyright (2016) by Elsevier.
Source: T. Hand, D. Davis, and R. Gillett (2005). *Republic of the Fiji Islands: Fisheries Sector Review.* Mandaluyong, Philippines: Asian Development Bank.

In 2000–2008, about 1.7% of the total GDP was supported by the fisheries sector (Gillett 2009; Ahmed et al. 2011). Exports of fish accounted for 12.2% ($63.3 million) of the total exports ($518 million) in 2007 in Fiji; of this 12.2%, 60% was from the Fiji tuna industry in 2007 (FAO 2010a). Japan and the United States receive 51% of Fiji's tuna, while Australia, the People's Republic of China, New Zealand, and the European Union receive the remaining 49% (FAO 2010a; Rosegrant et al. 2015).

Of the six fish categories mentioned above, fish production and value were found to be highest in the coastal areas. Approximately 17,400 metric tons (t) of fish valued at $33.81 million were caught by coastal subsistence fishers (FAO 2010a). Artisanal or small-scale commercial fishers and subsistence fishers are heavily dependent on the coastal areas as sources of fish caught for food and nutrition and economic reasons (livelihood and income). Coastal areas encompass shorelines, lagoons, and reefs. In 2007, locally based offshore fisheries produced 13,740 t of

[10] This Chapter derives considerably from Dey et al. 2016b.

fish valued at $29.29 million, coastal commercial fisheries produced an estimated 9,500 t valued at $33.75 million, and freshwater fisheries produced at 4,150 t valued at $4.29 million (FAO 2010a). In 2007 in offshore fisheries, foreign-based vessels caught around 490 t of fish valued at $0.53 million. Aquaculture is still under development, with only 247 t produced at a value of $0.0017 million (FAO 2010a).

B. Common Fishing Practices and Gears

1. Offshore capture fisheries

Results from the focus group discussion (FGD) survey showed that long-line fishing and deep-sea drop-line trolling are the conventional fishing practices applied by Fijian fishers for oceanic fisheries. Similarly, the Department of Fisheries (DOF) (2005) and FAO (2010a) reported that offshore fisheries is mainly focused on tuna long-line both from domestic and foreign-based fishing vessels. DOF (2005) also identified hand-line fishing for snapper, pole and line as common fishing gears used by domestic vessels, and pole and line and purse seine fishing gears used by foreign boats. By issuing fishing licenses, DOF was able to keep track of fishing gears operated by domestic and foreign fisheries.

2. Coastal or inshore capture fisheries

Coastal fishers (artisanal/commercial and subsistence) have comparable fishing practices, dominated by hand-line, gillnet, and spear fishing (FAO 2010a; Singh 2005). The capture of aquarium fish for commercial purposes utilizes specialized fishing gears. In addition to these fishing gears, results from the FGD survey report the use of trolling, cast nets, and low-cost inshore fish aggregating devices (FADs). DOF has introduced FADs in Fiji during the last 5 years (Davetanivalu 2013). Flotation materials are available locally, such as bamboos and coconut leaves, which are easy to acquire and deploy once constructed.

Other fishing gears applied by Fijians include fish traps, seine nets, hand nets, line trawls, hook-and-line, reef gleaning, and skin diving; the last four fishing gears are predominantly used for subsistence fishing (FAO 2010a). Reef gleaning and skin diving are used for collecting shellfish and sea cucumber. Women and children exploit coastal fisheries through reef gleaning during low tide (Valmonte-Santos, Rosegrant and Dey 2016). Target species include shellfish, sea cucumber, octopus, sea urchins, eels, and small fish. Hand-line fishing, skin diving, and spearfishing are all dominated by men (Vuki, Naqasima, and Vave 2000).

3. Freshwater and estuarine fisheries

Based on discussions during the FGD, the following fishing gears and practices are applied in freshwater and estuarine areas of Fiji: wading gillnets, spearfishing, and free diving.

4. Aquaculture

Fish farming or aquaculture was first initiated in 1976 by DOF with the introduction of Nile tilapia (Davetanivalu 2013). Other culture species are freshwater prawn, grass carps, and silver carps. Culture of milkfish, seaweed, and pearls is under development based on the expert opinion survey (EOS) conducted in 2012.

Four types of aquaculture farming are practiced in Fiji: monoculture (one species in a pond); polyculture (two or more fish types stocked at the same time); integrated fish farming (culturing fish with the presence of a duck or chicken house built near or around the pond system); and backyard or small-holding farming, mostly for subsistence (Davetanivalu 2013). Riverine stocking of tilapia was also practiced in river systems, such as in Tailevu and Rewa Delta; however, DOF now discourages this practice because of biodiversity concerns (Davetanivalu 2013).

C. National Development Plans

The Government of the Republic of Fiji has created a number of development policies and plans that respond to Fiji's economic needs, safety assurance, environmental preservation, and other critical requirements. These policies and plans include the *Strategic Development Plan 2007–2011*, the *Sustainable Economic Empowerment Development Strategy (SEEDS) 2008–2010*, and the *20-Year Development Plan (2001–2020) for the Enhancement of Participation of Indigenous Fijians and Rotumans in the Socio-economic Development of Fiji*.

This section highlights three important areas related to the current study on climate change and development strategies of coastal communities.

1. Biodiversity and environment

Fiji has several existing climate change-related policies, legislation, plans, and programs under the umbrella of biodiversity and environmental preservation. In 1998, Fiji signed the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). Fiji's submission of the Initial National Communication under the UNFCCC in 2005 indicated its commitment to environmental conservation and preservation. This led to the development of the Environment Management Act (EMA) in 2005.

EMA 2005 and its associated regulations provide a mechanism for promoting and supporting the objectives of key national strategies and policies, including the *National Sustainable Development Strategy*, 1993 *National Environment Strategy*, 2002 Endangered and Protected Species Act, 2003 Endangered and Protected Species Regulations, 2007 *National Biodiversity Strategy and Action Plan* (NBSAP), 2010 *Clean Development Mechanism Policy Guideline*, and 2010–2014 *National Biodiversity Strategy and Action Plan Implementation Framework*. The EMA stipulates the development of a coastal management plan, which the Integrated Coastal Management (ICM) framework created by delineating the plan's scope and structure. The ICM framework provides a platform to (1) review current coastal conditions, (2) assess the current legal and institutional governing framework, and (3) recommend proposals for action and policy toward sustainable coastal resource management for Fiji.

With or without the effects of climate change, the Government of Fiji created the above legislation or acts primarily to ensure the sustainable use of the country's natural resources. For example, EMA 2005 was created "for the protection of the natural resources and for the control and management of developments, waste management and pollution control and for the establishment of a national environment council and for related matters" (GOF 2005). Its sanctions include the practice of sustainable use and development of natural resources, and identification of matters of national importance to Fiji. It also legalizes the creation of a national council that may develop a committee on coastal zone management (CZM) to prepare the CZM plan. Other units are also established to respond to disaster response planning and management, as well as administration of environmental impact assessments where proposals will need to be evaluated, particularly those that may lead to the erosion of coasts, coastline, or beach or the pollution of marine water, groundwater, freshwater, and any other water resources.

2. Marine and freshwater fisheries

Similar to the biodiversity and environment sector, the marine and fisheries sector also has legislation, acts, and programs that focus on influencing the coastal communities. These include the 1988 Fisheries Act, which was amended as the 1991 Fisheries Act (Amendment) Decree; the Marine Spaces Act; the 2002 Fiji Tuna Development and Management Plan; and the 2005–2010 Fiji Freshwater Aquaculture Sector Plan. Marine protected areas (MPAs) are covered under both the environment (NBSAP) and the Fisheries Act in Fiji (Valmonte-Santos, Rosegrant and Dey 2016).

Despite the benefits enjoyed by coastal communities, such as coral reef protection, leading to increases in fish populations, among others, Techera and Troniak (2009) identified crucial gaps in legislation and policies that hinder the replication of MPAs in other areas of the country. These gaps include (1) lack of any comprehensive protected area management legislation that deters carrying out best practices in integrated and networked areas; (2) fragmentation of legislation and policies where harmonization is needed, as well as administrative concerns; (3) the need for amendments to the Fisheries Act and regulations to encourage community participation in the identification, designation, and management of MPAs and enforcement of policies; and (4) recognition of locally managed marine areas (LMMAs) that contributes to integrated CZM.

3. Climate change

Fiji's 2007 NBSAP underwent review in 2011 to reflect current and emerging climate change issues at the local, national, and international levels. This review led to the development of the Fiji *National Climate Change Policy* (GOF 2012). Officially launched on March 1, 2012, the policy has the following goals:

- support the implementation of Fiji's roadmap for democracy and sustainable socioeconomic development in 2009–2014 under the *People's Charter for Change, Peace, and Progress* (GIF 2008);
- promote integration of climate change issues in national planning, budgeting, and implementation processes;
- provide guidance on the government's responses to climate change issues;
- guide sectors to develop appropriate climate change adaptation and mitigation strategies;
- support requests to regional and international agencies to provide resources and assistance in addressing national climate change issues; and
- contribute to Pacific regional actions and to meeting international commitments.

Similar to other Pacific and developing countries, the Government of the Republic of Fiji has begun preparing a National Adaptation Programme of Action (NAPA) and in 2011 published the *Government of the Republic of Fiji-National Climate Change Adaptation Strategy for Land-Based Resources* (GOF-NCCAS 2012). Based on Hay's (2011) comparison, the main focus of NAPA is on project-based urgent and immediate adaptation actions, and the absence of an action plan for implementation. In comparison, GOF-NCCAS is based on practical programs and strategies, and responds to immediate and long-term needs through the implementation of an action plan. Both documents recognize Fiji's vulnerability to climate change and offer disaster risk-reduction approaches to combat the impacts of extreme weather events.

In 2012, the Secretariat of the Pacific Community (SPC), in cooperation with the Fiji national team on climate change and other stakeholders, developed the *Republic of Fiji National Climate Change Policy* (SPC 2012). The following subsections focus on sectors affecting the coastal communities of Fiji.

3.1. Agriculture

The *National Climate Change Policy* identified some key mitigation activities that will increase sequestration, reduce greenhouse gas (GHG) emissions from agriculture, and thus support ways to tackle climate change by the coastal communities engaged in agriculture. These activities include using fuel-efficient farming equipment, adopting appropriate agro-forestry practices, applying minimal soil tillage and soil cover to minimize release of carbon in the soil, reducing the use of fertilizers that can be converted and released as GHGs, and capturing methane gas from manure (SPC 2012). Climate resilience activities for agriculture include planting diverse traditional crop species resistant to flood, drought, saltwater, and diseases and applying integrated farming practices.

3.2. Marine and fisheries resources

The *National Climate Change Policy* highlighted the urgency to mitigate these impacts by replanting and conserving mangroves and protecting coral reefs and coastal zones (SPC 2012). These resources act as physical barriers and buffers during the worst weather conditions. The presence of healthy coral reef systems strengthens the resistance of marine and fisheries resources to drastic changes in weather.

Other adaptation options for the marine and fisheries sector outlined by the *National Climate Change Policy* include preservation of mangrove areas, coral reefs, and other coastal zones; identification and application of alternatives to commercial fishing practices to diversify and increase stock sustainability; enhancement of watershed management to reduce river bed and bank instability; improvement of construction standards to minimize soil runoff and erosion during construction activities; the presence of more rigid development conditions to restrict development on dunes and foreshore areas; and application of better safety measures and codes of conduct to reduce risk of injury or death during fishing trips as a result of inclement weather.

3.3. Water resources

It will be considerably challenging if climate change damages potable water supply and water resources (saltwater intrusion, overflow of dams and rivers, contamination of water supply, blockage or excessive water flow, etc.). In the worst case, disruption of available potable water supply may lead to loss of human lives.

A potable water supply Infrastructure must be in place, even without climate change, as this is one of the basic services needed to meet the criteria for decent living conditions. There must also be other sources of water supply, such as aquifers and freshwater lenses.

3.4. Tourism

The *National Climate Change Policy* suggests the need to diversify tourist destinations and services to minimize disruption of this sector during extreme weather events.

3.5. Human health and welfare

Rural communities possess traditional knowledge of various medicines and cures from locally available sources. The strong safety nets within those communities are important attributes that spread climate resilience at the grassroots level.

3.6. Transport

Severe weather, such as cyclones, could disrupt land, sea, and air transportation. The inability to reach isolated victims during these events will hamper the provision of food, water, and medical treatment.

3.7. Communications

The advent of mobile phone services in most areas of the country must ensure a reliable telecommunications network that will provide channels for warnings and emergency calls specifically during disasters. This infrastructure must also allow ease of access of funds transferred from overseas aimed to assist with preparation for and responses to damage and natural disasters.

D. Modeling the Effects of Climate Change and Climate Change Adaptation Strategies

The data needed to run the model were collected from both primary and secondary sources. Primary data sources include the EOS and FGD. The EOS was conducted in Suva in July 2012. Experts from the Department of Environment, Department of Agriculture, Climate Change Unit, Ministry of Fisheries and Forestry, Ministry of Itaukei, National Project Management Unit-ANZDEC, and national research partners (NRPs) participated in the survey. A field visit to Vitawa village, Ra province, was made to implement the participatory rural appraisal (PRA) using FGD with fish farmers on 30–31 July 2012. Similarly, an FGD with capture fishers was implemented in Namauida village, Ra province, during the same month. The existing and pipeline aquaculture/capture fisheries technologies in Fiji were discussed in section B.

The climate change adaptation strategies in Fiji include various natural resource management (NRM) practices, including MPAs, LMMAs and the ridge-to-reef concept; alternative livelihood developments; enforcement of DOF regulations and compliance with the fisheries regulations and ordinances; inshore low-cost FADs; aquaculture; finance literacy; and post-harvest—improving the quality of products and reducing waste. Among these, NRM strategies and aquaculture are more prominent in the government and are reported as important climate change adaptation strategies.[11]

For each time period (2035 and 2050), we have implemented two baseline (most plausible) scenarios representing two annual growth rates of real per capita income: medium (1% per year) and high (2% per year) growth of real per capita income. Over the last 4 years (2008 to 2012), real per capita income in Fiji grew at a rate of –2.3% to +1.4% (World Bank 2013). We have assumed a population of 977,586 in 2035 and 1,060,706 in 2050.

The Fiji model, the data used in the model, and the preliminary results were presented to stakeholders at a “Model Validation” meeting held in Suva, Fiji, on 25 June 2013. Based on the comments received during the validation meeting, as well comments from other experts (e.g., participants of the North American Association of Fisheries Economists 2013 meeting), we have

[11] Data on the effects of various MPAs and LLMAs were collected from Clements et al. (2012), Goetze et al. (2011), Jupiter and Egli (2011), Jupiter et al. (2012), Rasher and Hay (2010), Rasher et al. (2011, 2012), Tawake et al. (2001), and Waqairagata et al. (2011).

made a minor revision to the model and implemented it for various scenarios. The validated baseline data (production, consumption, trade, and price), supply elasticities, and demand elasticities that were used in the model for Fiji are given in Appendix Tables A.1, A.2, and A.3, respectively. The supply quantities reported in Table A.1 do not include catch by foreign fleets. Broadly speaking, there are three types of tuna and oceanic catches: catch by domestic/national fleets in national waters, catch by domestic fleets in international waters, and catch by foreign fleets in national waters. The supply volumes reported in the Appendix tables and used in the analysis include catch by national fleets in both national and international waters, but do not include catch by foreign fleets in national waters. Foreign vessel catch in Fijian water is not substantial.

The fish demand elasticities used in the model reflect consumers' preference patterns in Fiji and substitutability of various fish products with other sources of animal protein in the country. We have also used alternative sets of elasticities to test the sensitivity of our modeling results. But all those detailed results have not been presented in this report for the sake of brevity. We find that minor variation of supply and demand elasticities (for example, using 0.5, instead of 0.6, as own price elasticity of tuna supply elasticities) does not change results. Even substantial variation of demand elasticities (almost doubling the value of income elasticity of tuna and other oceanic fish from 0.55 to 1.00, increasing income elasticities of coastal finfish, coastal invertebrates, freshwater finfish, and freshwater invertebrates from 0.60 to 0.80, from 0.85 to 1.00, from 0.50 to 0.90, and from 0.80 to 1.00, respectively) would increase the demand for tuna in 2035 under a baseline scenario from 10,953 t to 11,232 t (only a 2.5% increase).

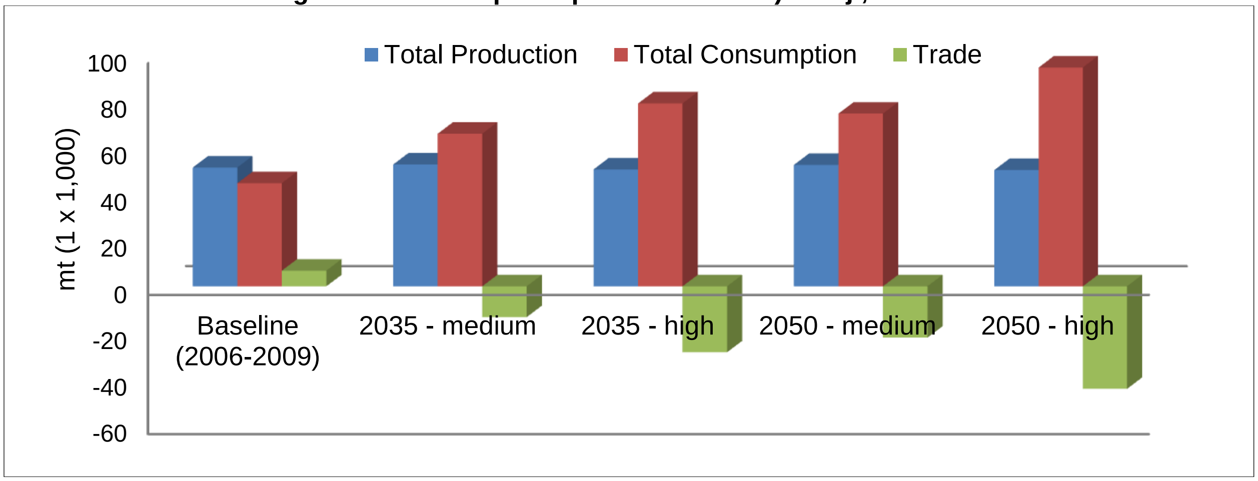
We have considered three climate change adaptation scenarios: aquaculture development (AQ), NRM (specifically MPAs, LMMAs, and FADs), and a combination of AQ+NRM. Scenario 1 (AQ) involves improvements in the productivity of freshwater (both finfish and invertebrate) aquaculture. Scenario 2 (NRM) addresses the changes in production and productivity in coastal and oceanic capture fisheries due to management regime shifts and adoption of resource enhancement practices, in particular MPAs and FADs. The overall shifts in the supply curve due to climate change (i.e., effect of climate change on fish production) in 2035 and 2050, as denoted by (λ_0) in equation 2, are reported in column 2 and column 6 of Appendix Table A.4. The data on climate change trends and their likely direct effects on fish production in 2035 were taken from Bell et al. (2011b), Gehrke et al. (2011), Lehodey et al. (2011), Pichering et al. (2011), and Prachett et al. (2011). Bell et al. (2011b) and other references cited above focus on 2035 and 2100, but do not have climate change scenarios for 2050. We generated the data for 2050 from the data ranges for 2035 and 2100, based on the opinions of the experts in Fiji and the Pacific region.

Climate change is likely to have positive effects on tuna and oceanic fish production (Lehodey et al. 2011) and negative effect on coastal fish production (Prachett et al. 2011) in Fiji. We used the projection of the Spatial Ecosystem and Population Dynamics Model (SEAPODYM) for the likely effects of climate change on tuna catch under relatively low and relatively high emission scenarios (Lehodey et al. 2008). The likely effects of various climate change adaptation strategies on fish production, as denoted by (λ_1) in equation (2), were collected through the EOS and FGD, and are reported in columns 3, 4, 5, 7, 8, and 9 of Appendix Table A.4. The positive (or negative) values of the shifts (λ) show increases (or decreases) from initial production level and/or reductions (or increases) in cost of fish production/catch. Various NRM strategies considered in the model for Fiji (such as MPA, LLMA, ridge-to-reef concept, and FAD) are likely to mitigate some of the negative effects of climate change on coastal fisheries, and would shift supply curves of both coastal and oceanic fisheries to the right (Figure 2.1) indicating increases in catch with the same cost of fishing and/or decrease in cost of fishing per unit of catch.

1. Effects of climate change on production, consumption, and trade (baseline scenario)

Figure 3.1 presents the projected production, consumption, and net trade of fish aggregate in Fiji for 2035 and 2050 under two baseline scenarios, with respective 1% and 2% annual growth rates of real per capita income. Results show that the aggregated fish consumption is expected to rise substantially in 2035 and 2050, and the demand for fish is likely to be higher than the production. These results imply that the country may need to import fish to fulfill this deficit in production under the baseline scenario (i.e., without any technological and policy interventions).

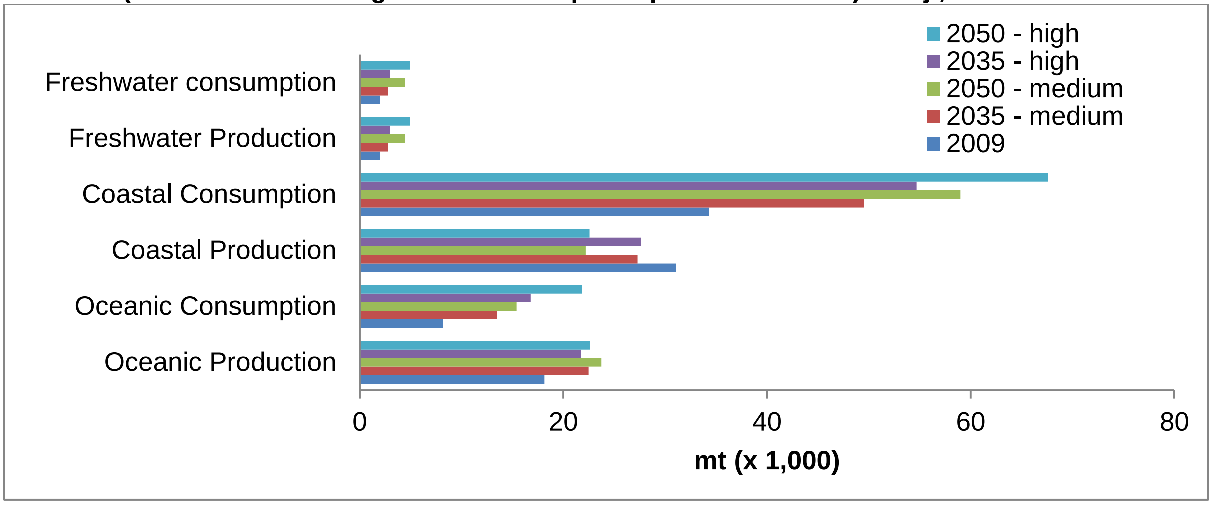
Figure 3.1
Projected Fish Production, Consumption, and Trade under Two Baseline Scenarios (1% and 2% annual growth rates of per capita real income) in Fiji, 2035 and 2050



medium = 1% annual growth rate of per capita real income; high = 2 % annual growth rate of per capita real income.
Source: Model projections.

There are four important points regarding the aggregate projections presented in Figure 3.1: (1) domestic production is projected to grow at a negligible rate; (2) domestic demand is projected to rise over the period; (3) as expected, higher income growth will be accompanied by higher rise in demand for fish; and (4) fish exports are expected to fall, fish imports are expected to increase, and, therefore, net trade (export minus import) is projected to decline over time. Figure 3.2 shows the projected quantities of production and consumption of different fish groups. It indicates that oceanic production is expected to grow to some extent, and that supply is likely to be higher than demand during the projected years. However, projections are quite different for coastal fisheries. The model projects that coastal production will decline over time, while demand for coastal fish will likely increase further.

Figure 3.2
Projected Production and Consumption of Different Types of Fish under Two Baseline Scenarios (1% and 2% annual growth rates of per capita real income) in Fiji, 2035 and 2050



medium = 1% annual growth rate of per capita real income; high = 2 % annual growth rate of per capita real income.
Reprinted from "Analysis of the economic impact of climate change and climate change adaptation strategies for fisheries sector in Pacific coral triangle countries: Model, estimation strategy, and baseline results" by Dey, M.M., M.W. Rosegrant, K. Gosh, O.L Chen, and R.A. Valmonte-Santos. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Dey et al. 2016a.

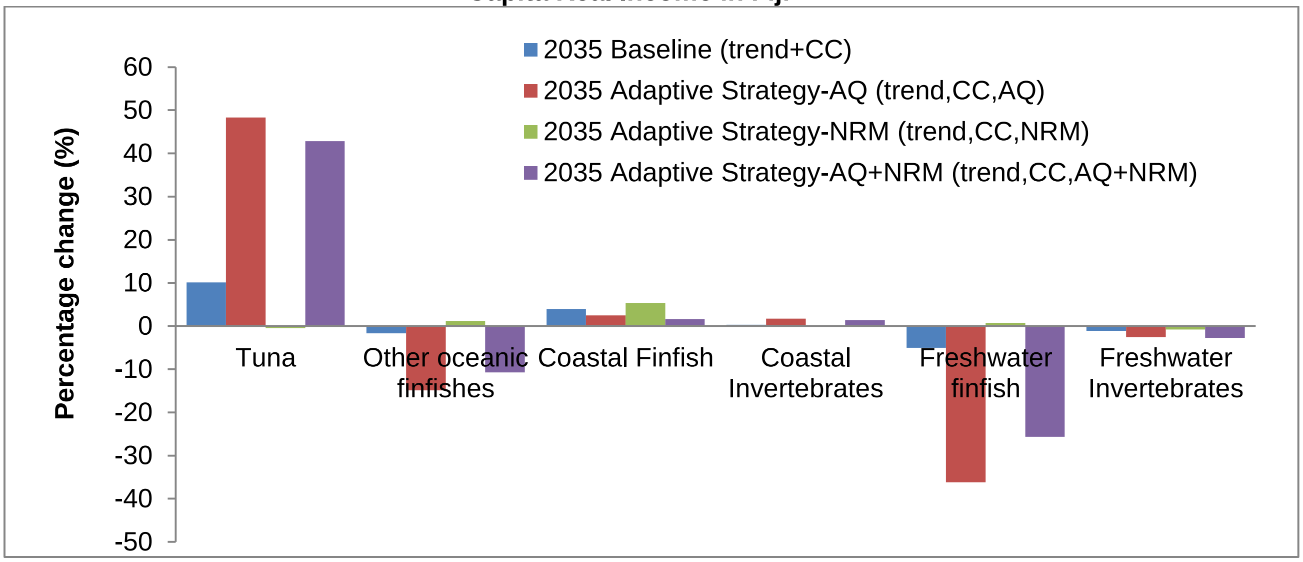
These results have serious food security implications, given that poor households mostly rely on coastal finfish for their fish consumption needs. Though the supply from freshwater areas is projected to expand substantially, its share is expected to remain small. The projected supplies of different fish types are plausible, given the past trends. The main reason for the decline in supply from coastal areas is the anticipated negative effects of climate change and other adverse environmental factors.

2. Effects of climate change adaptation strategies

2.1. Changes in fish prices

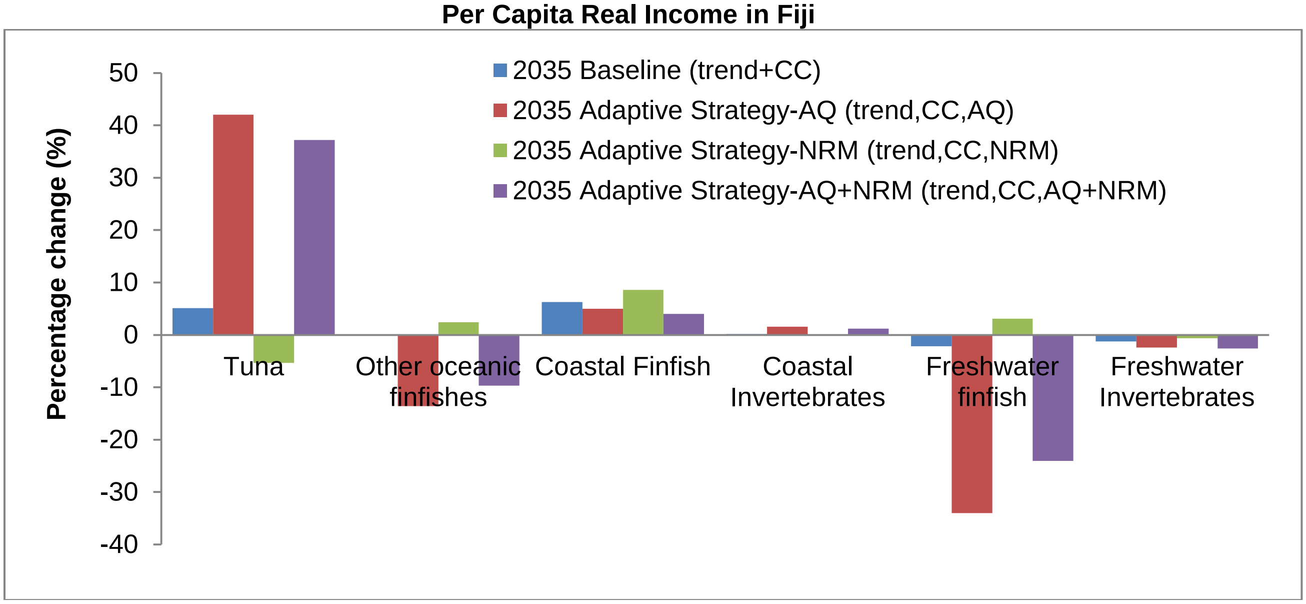
Figures 3.3 to 3.6 show the effects of different climate change adaptation strategies on fish prices in 2035 and 2050. Overall, the real prices of most fish categories are likely to remain unchanged under the baseline scenarios. This is mainly because increased demand for various fish types is expected to be met through increased importation of fish. However, the real price of tuna in Fiji is likely to rise, particularly in the long term (2050). Fiji is a net exporter of tuna. With rising income and population, tuna demand in Fiji will increase substantially, and net export of tuna will decrease. Our model shows that not all excess demand for tuna can be meet through trade adjustment. The decrease in tuna export is likely to be smaller than the increase in its domestic demand; as a result, the real price of tuna is expected to rise.

Figure 3.3
Percentage Change in Price from Baseline (2006–2009) to 2035 with 1% Annual Growth in Per Capita Real Income in Fiji



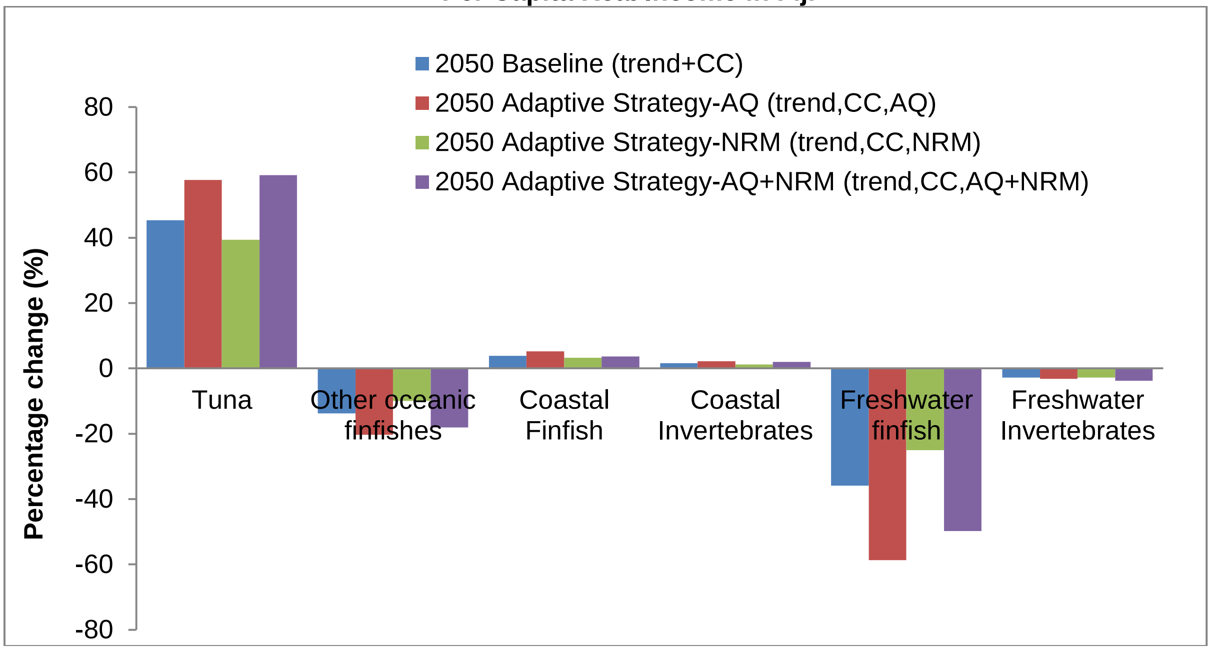
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Figure 3.4
Percentage Change in Price from Baseline (2006–2009) to 2035 with Average 2% Annual Growth in Per Capita Real Income in Fiji



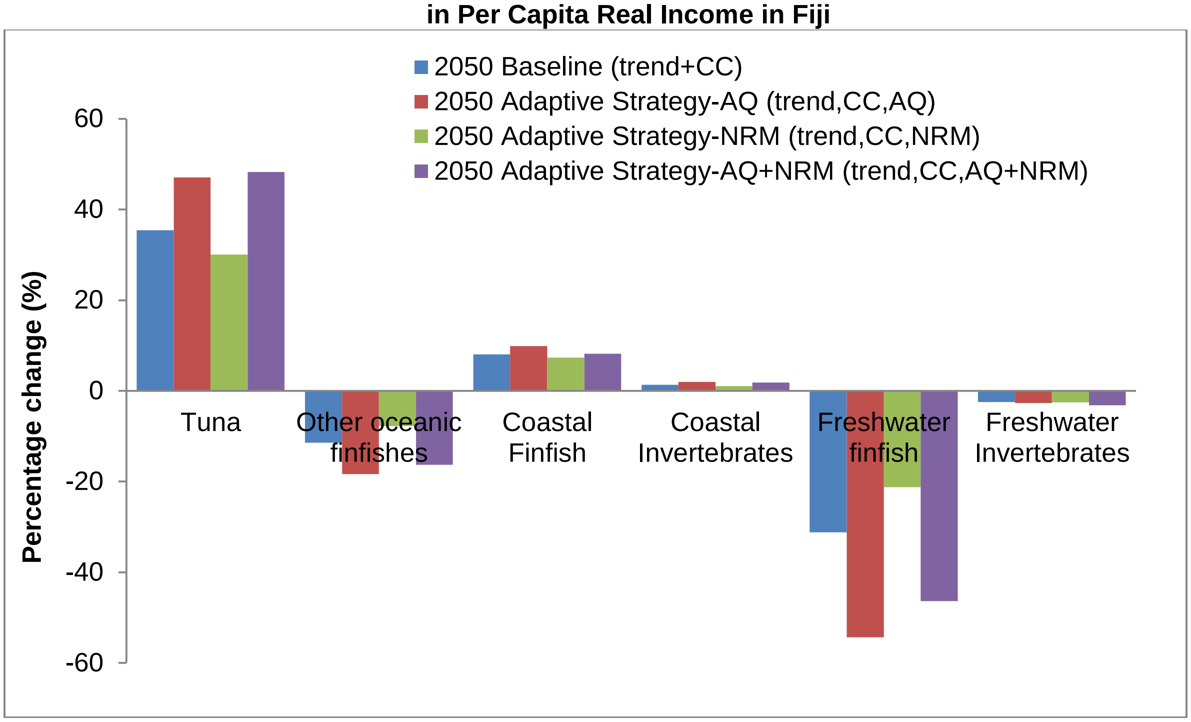
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Figure 3.5
Percentage Change in Price from Baseline (2006–2009) to 2050 with Average 1% Annual Growth in Per Capita Real Income in Fiji



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Figure 3.6
Percentage Change in Price from Baseline (2006–2009) to 2050 with Average 2% Annual Increase in Per Capita Real Income in Fiji



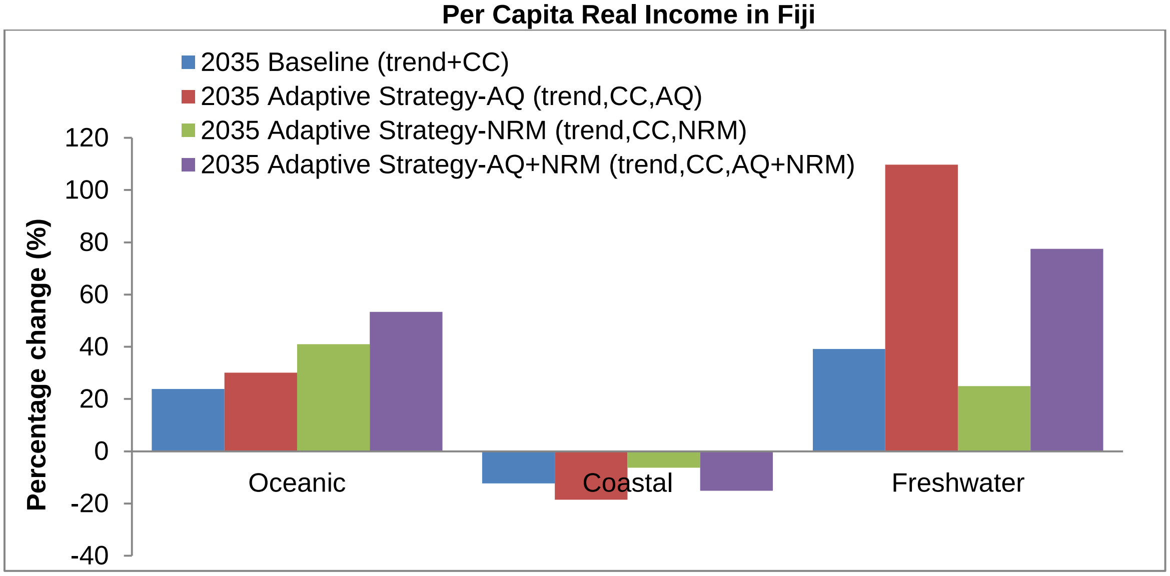
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Prices of both freshwater finfish and freshwater invertebrates are projected to decrease with the adoption of aquaculture technologies. Given that most of the freshwater production is for domestic consumption, this strategy is likely to improve Fiji's food security. Aquaculture development is expected to raise farmers' income and to increase their demand for tuna. This is likely to result in an increase of the real price of tuna over the period.

2.2. Changes in fish production

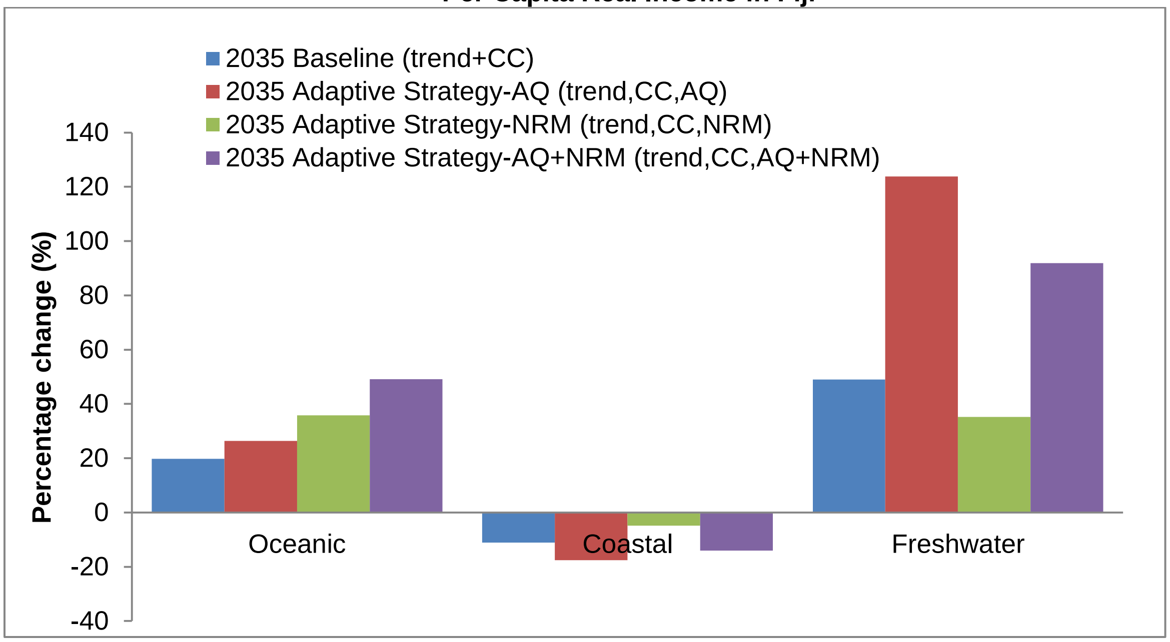
Figures 3.7 to 3.10 show the likely effects of different climate change adaptation strategies on fish production in 2035 and 2050. The baseline projection reflects the assumption that oceanic fisheries exhibit positive growth in catch, and coastal fisheries show decline in catch due to climate change (Lehodey et al. 2011; Prachett et al. (2011). Given that the coastal subsistence fisheries sector contributes the highest portion (42%) of total fisheries production in Fiji (Gillett 2009), a decline in fish harvest from coastal areas is a serious concern for the country's food security. Adaptation of various NRM strategies (such as MPAs) is expected to halt the decline in coastal fisheries, and to further expand production of oceanic fisheries. The results indicate that aquaculture development will directly increase production from freshwater aquaculture, and will indirectly increase tuna catch as a result of the increased income from aquaculture and the resulting higher price and market demand for tuna and other oceanic fish. As in the assessment for the other countries, that projected rate of increase in national tuna production due to increased investment in FADs is well within the sustainable tuna catch, as noted in Chapter 2 (and see Lehodey 2011; Bell 2010).

Figure 3.7
Percentage Change in Production from Baseline (2006–2009) to 2035 with 1% Annual Growth in Per Capita Real Income in Fiji



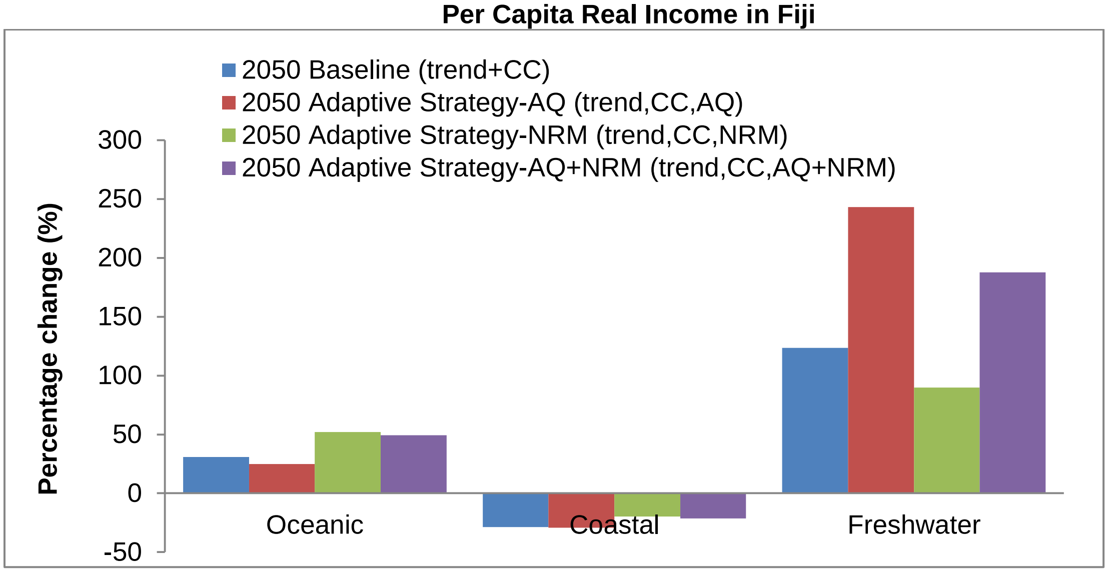
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Figure 3.8
Percentage Change in Production from Baseline (2006–2009) to 2035 with 2% Annual Growth in Per Capita Real Income in Fiji



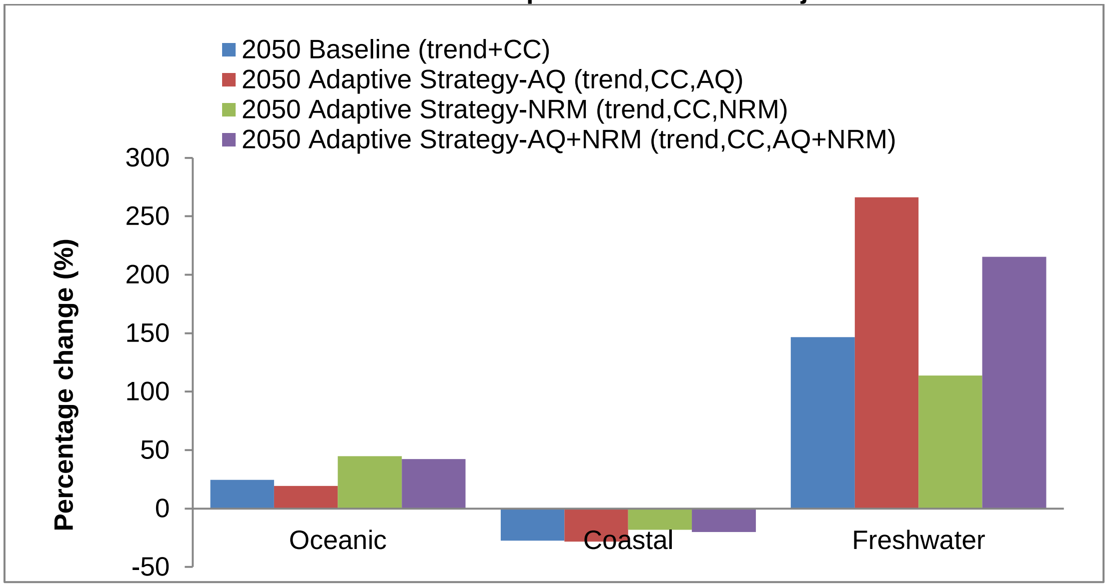
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Figure 3.9
Percentage Change in Production from Baseline (2006–2009) to 2050 with 1% Annual Growth in Per Capita Real Income in Fiji



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Figure 3.10
Percentage Change in Production from Baseline (2006–2009) to 2050 with 2% Annual Growth in Per Capita Real Income in Fiji

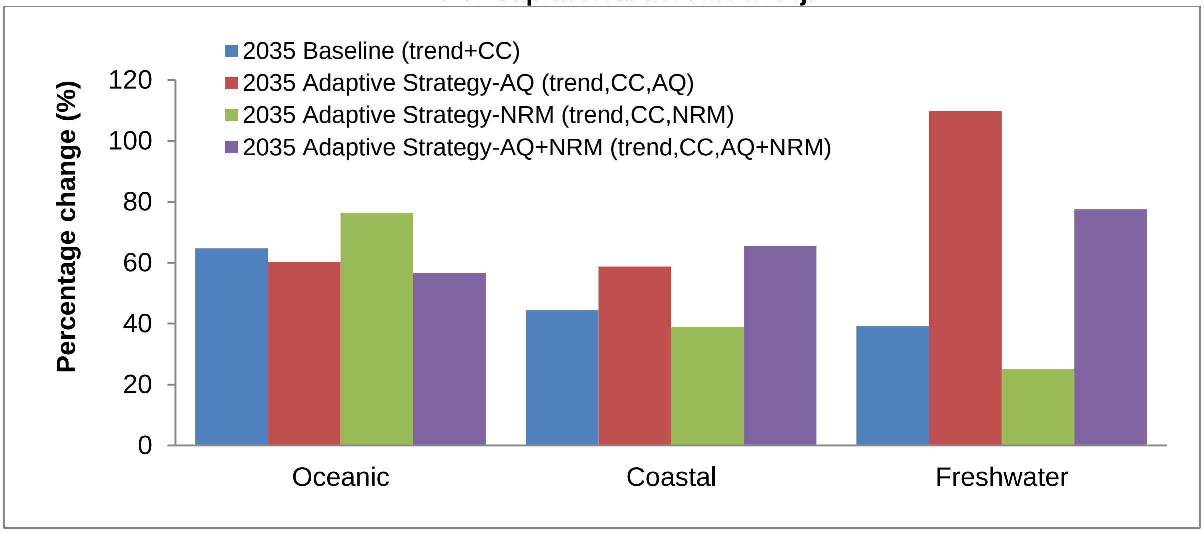


AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

2.3. Changes in fish consumption

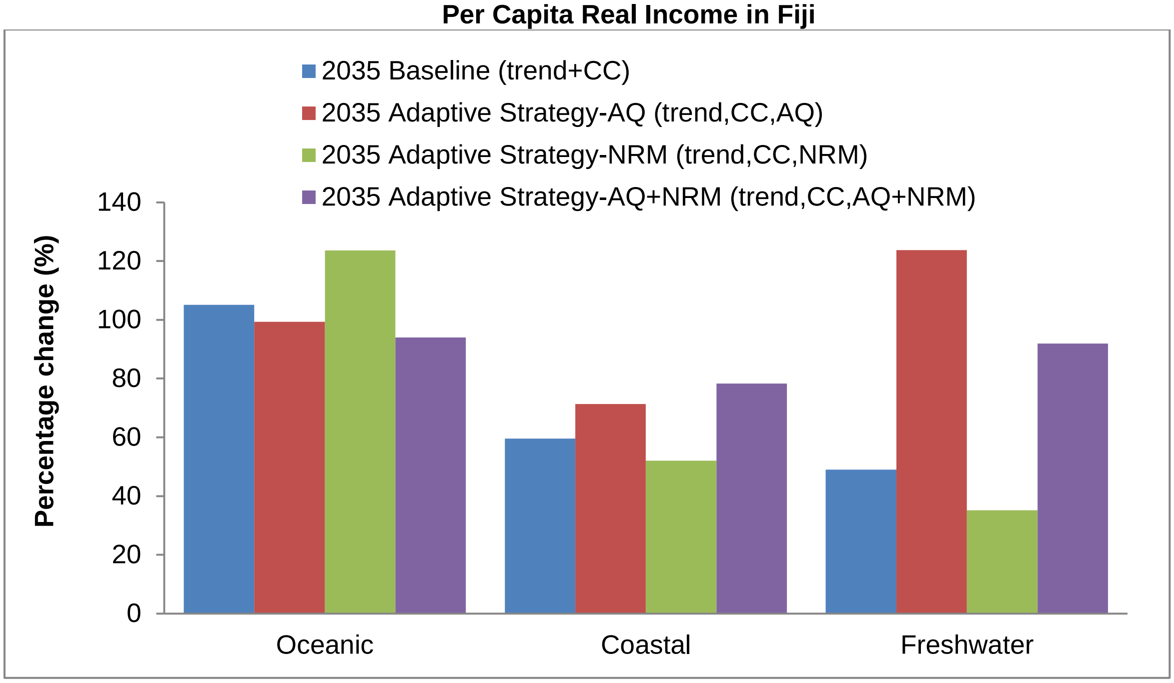
Figures 3.11 to 3.14 show projected fish consumption (i.e., fish demand) under baseline projections and other adaptation strategies in 2035 and 2050. Baseline projections indicate that demand for all types of fish will increase over time, and the level of increase will be higher, with faster growth in per capita real income. With positive income elasticities of fish demand, these results are logical. Among different types of fish, the rate of increase in demand is expected to be higher for tuna and other oceanic fish in the medium term (2035). Through continuation of aquaculture development in Fiji, the rate of increase in the consumption of freshwater species is expected to be faster in the long run (2050). Between the two real-income growth scenarios, the model predicts that the demand for tuna and other oceanic species will increase at a faster rate with higher income growth.

Figure 3.11
Percentage Change in Consumption from Baseline (2006–2009) to 2035 with 1% Annual Growth of Per Capita Real Income in Fiji



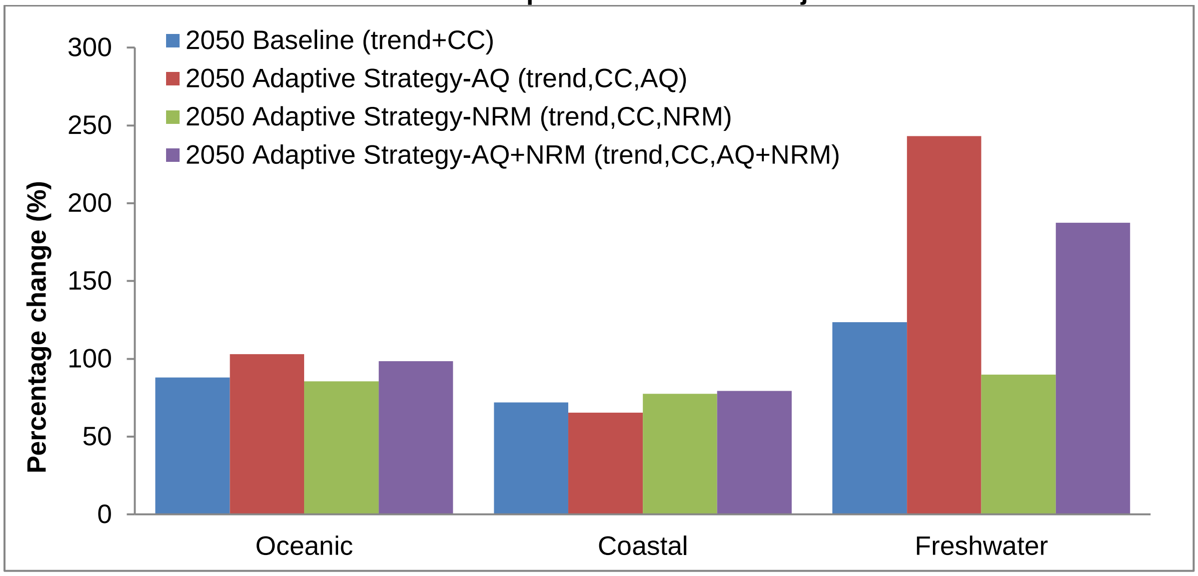
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Figure 3.12
Percentage Change in Consumption from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Fiji



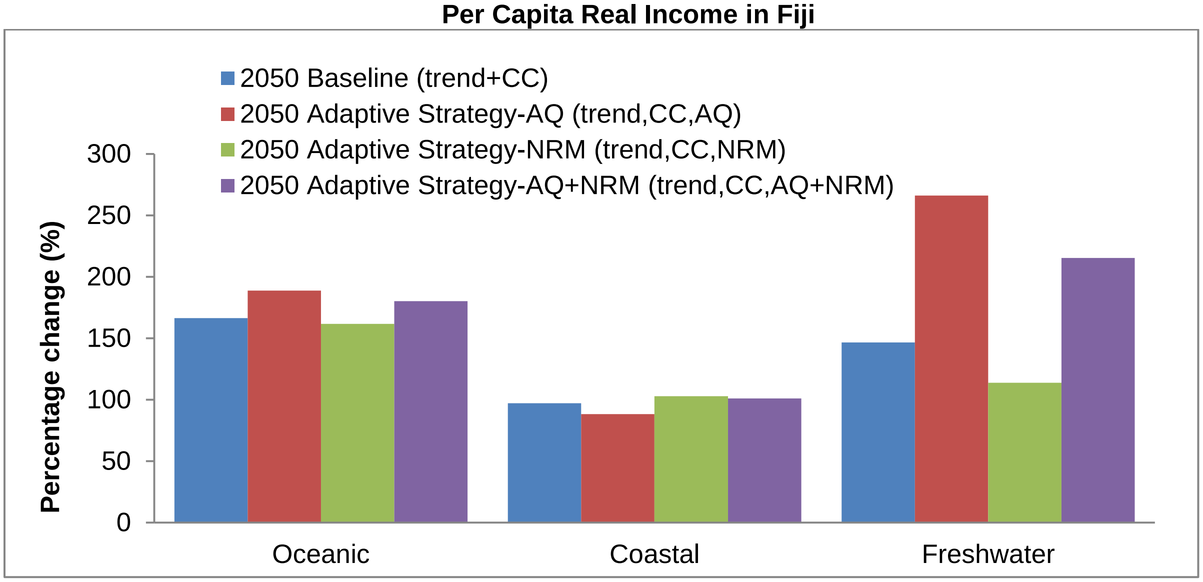
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Figure 3.13
Percentage Change in Consumption from Baseline (2006–2009) to 2050 with 1% Annual Growth of Per Capita Real Income in Fiji



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Figure 3.14
Percentage Change in Consumption from Baseline (2006–2009) to 2050 with 2% Annual Growth of Per Capita Real Income in Fiji



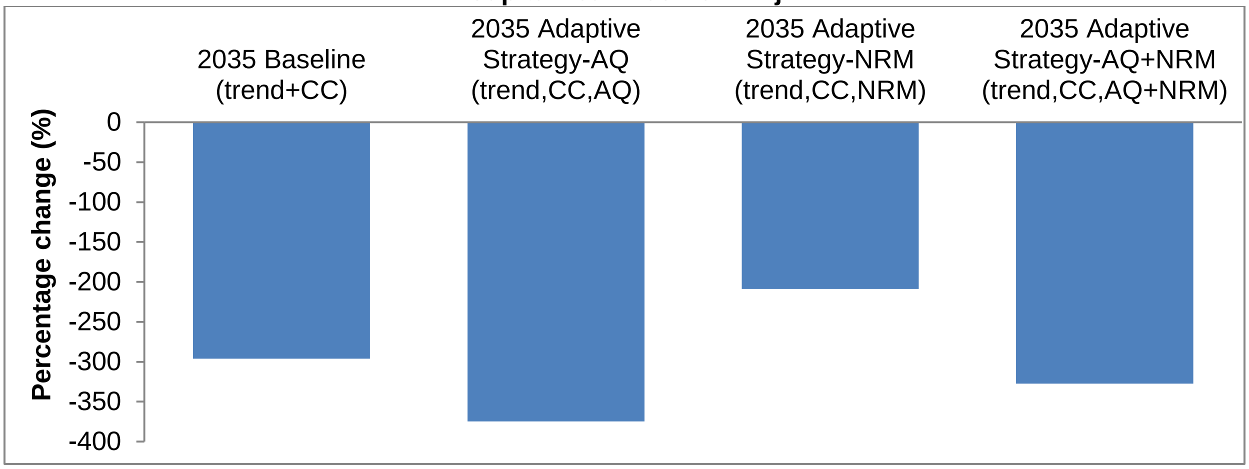
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

The model predicts that adaption of aquaculture development strategies will lead to increases in consumption of freshwater and coastal fish in the medium-term (2035) and increases in freshwater and oceanic fish in the long run (2050). As income rises over time, people may substitute coastal fish for oceanic species. Adaptation of various NRM strategies is expected to increase consumption of oceanic fish in the medium term, mainly because of increased domestic consumption. Given that Fiji is a net importer of coastal fish, adoption of NRM strategies is likely to substitute imported products for domestic production in the medium term without much increase in overall coastal fish consumption. However, adoption of NRM strategies is expected to increase coastal fish consumption in the long run (2050).

2.4. Changes in net trade (export minus import)

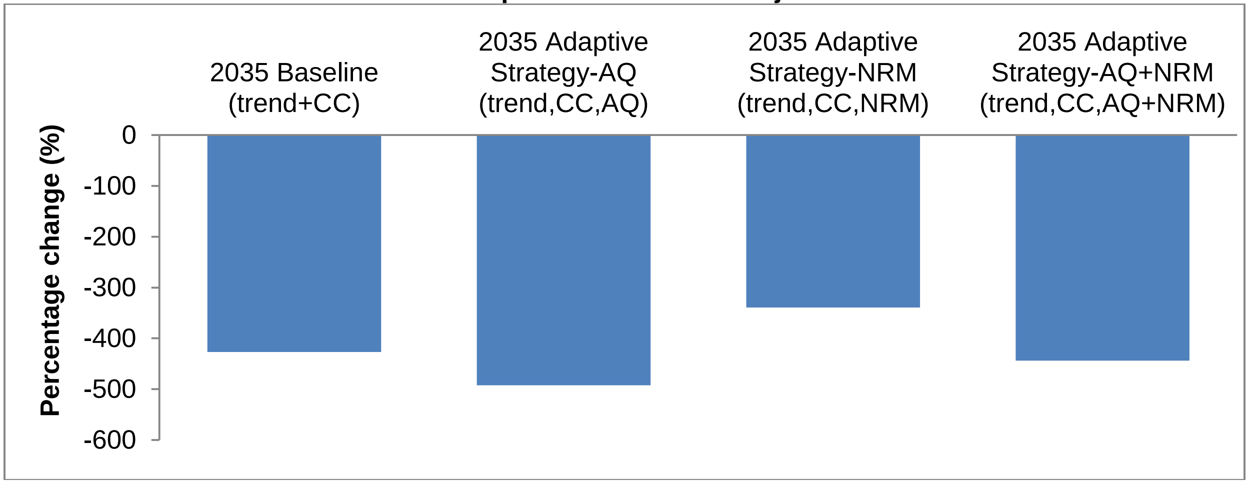
Figures 3.15 to 3.18 show the projected fish and seafood trade in Fiji under baseline scenarios and different climate change adaptation strategies in 2035 and 2050. Trade is represented in terms of net exports, with negative numbers representing net imports. The models predict that net imports of fish and seafood will increase under all the baseline scenarios, and the rate of increase in net imports is expected to increase over time and with higher income growth. The adoption of NRM strategies is expected to reduce Fiji's import of fish/seafood substantially, which will likely reduce the burden on foreign exchange.

Figure 3.15
Percentage Change in Net Trade from Baseline (2006–2009) to 2035 with 1% Annual Growth of Per Capita Real Income in Fiji



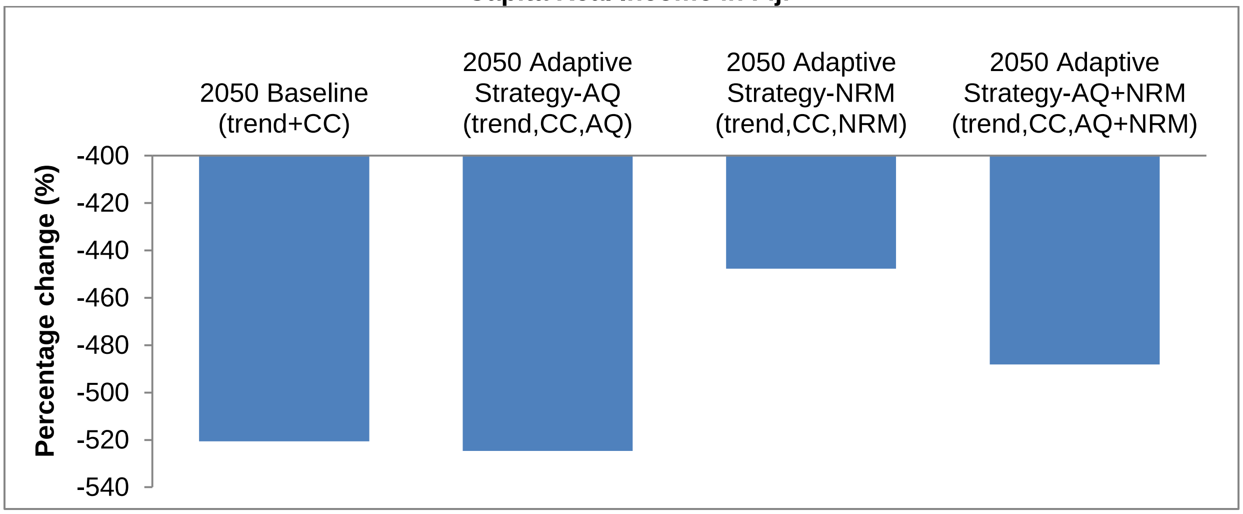
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Figure 3.16
Percentage Change in Net Trade from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Fiji



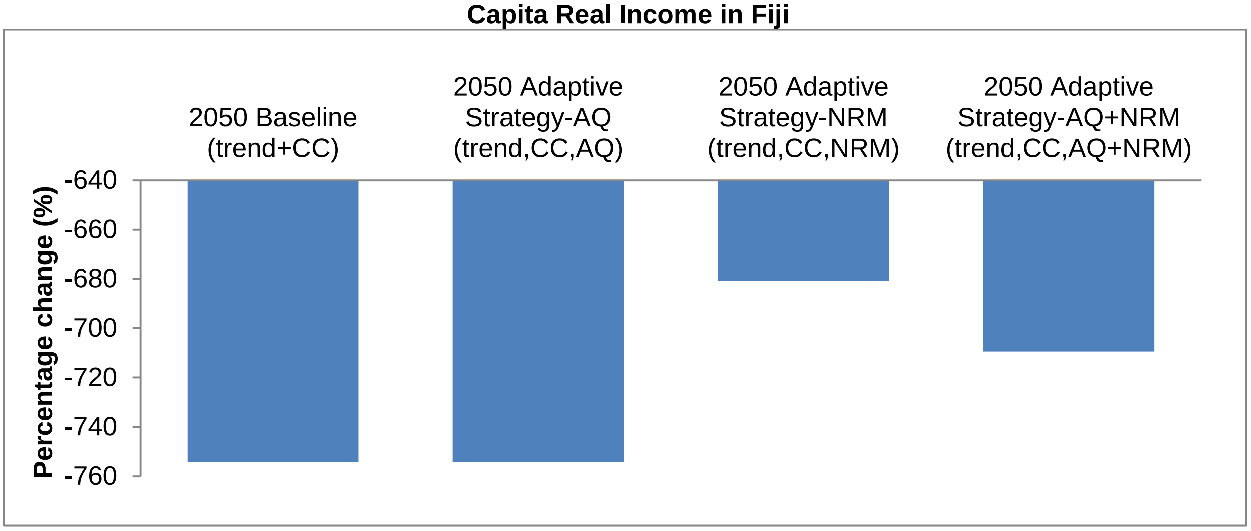
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b

Figure 3.17
Percentage Change in Net Trade from Baseline (2006–2009) to 2050 with 1% Annual Growth of Per Capita Real Income in Fiji



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

Figure 3.18
Percentage Change in Net Trade from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Fiji



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Dey et al. 2016b.

2.5. National-level economic gain from climate change adaptation strategies

The estimated national level net economic gains to both consumers and producers resulting from various climate change adaptation strategies in Fiji are reported in Table 3.2. These estimates show that net economic gain from adopting an NRM adaptation strategy is about $11.5 million (in 2009 constant price) per year in the medium term (2035) and about $14.5 million (in 2009 constant price) per year in the long term (2050). Aquaculture is likely to generate about $2.6 million (in 2009 constant price) in the long term (2050). These estimates are consistent with those from previous case studies reported in Section 7 of this report.

The estimated net economic gains resulting from NRM and aquaculture are significantly higher compared with their investment costs. For example, the production increase (supply curve shift) assumed in the Fiji modeling exercise will require about 20 fully functional MPAs/LLMAs with an annual investment cost of about $100,000 in 2035[12]. But the estimated yearly net economic gain from this investment in MPAs/LLMAs is about 100-fold of the investment cost. Similarly, our assumed aquaculture development strategy will require an annual investment of $50,000, with more than a 15-fold yearly gain in 2035.

Table 3.2
National-Level Economic Gain (equivalent variation) Resulting from Climate Change Adaptation Strategies, Fiji

Climate Change Adaptation Strategy	Economic Gain per Year (US$ in 2009 prices) 2035	2050
Aquaculture	802,701	2,638,290
Natural resource management (NRM)	11,560,219	14,496,463
Aquaculture + NRM	11,813,084	16,208,939

Reprinted from "Economic impact of climate change and climate change adaptation strategies for fisheries sector in Fiji" by Dey, M.M., K. Gosh, R.A. Valmonte-Santos, M.W. Rosegrant, and O.L. Chen. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Dey et al. 2016b

E. Summary

The review and analysis of available literature, the discussions at the national, provincial, and community levels through the EOS and FGD, and the modeling results and assessment carried out for this study generated key messages for Fiji with and without climate change adaptation strategies.

1. The baseline scenario showed the following likely situations:
    - Domestic production is projected to grow at a negligible rate; domestic demand is projected to rise over the medium term (2035) and long term (2050); as expected, higher income growth will be accompanied by higher rise in demand for fish; and fish exports are expected to fall, fish imports are expected to rise, and, therefore, net trade (export minus import) is projected to decline over time.
    - Coastal production is projected to decline over time, but the demand for coastal fish will likely increase. These projections have serious food security implications, given that poor households mostly rely on coastal finfish for their fish consumption needs. Though the supply from freshwater areas is projected to expand substantially, its share is expected to remain small. The main reason for the decline in supply from coastal areas is the anticipated negative effects of climate change and other adverse environmental factors.
    - Overall, the real price of fish groups is likely to remain unchanged, because increased demand for various fish types is expected to be met through increased imports of fish. However, the real price of tuna in Fiji is likely to rise, particularly in the long term (2050). Fiji is a net exporter of tuna. With rising income and population, tuna demand in the country will increase substantially, and the net export of tuna will decrease.

2. With climate change adaptation strategies, the likely scenarios are:
    - Prices of freshwater finfish and freshwater invertebrates are projected to decrease with the adoption of aquaculture technologies. Given that most of the freshwater production is for domestic consumption, this strategy is likely to improve food security in the country.

[12] For detail discussion on the cost of MPAs/LLMAs, the readers are referred to Pascal, Seidl and Tiwok (2012).

- Adoption of various natural resource management strategies (such as MPAs) is expected to halt production declines in coastal fisheries, and to further expand production of oceanic fisheries. The results indicate that aquaculture development will directly increase production from freshwater aquaculture, and will indirectly increase tuna catch as a result of the increased income from aquaculture, resulting in higher prices and market demand for tuna and other oceanic fish.
- Among different types of fish, the rate of increase in demand is expected to be higher for tuna and other oceanic fish in the medium term (2035). Through continuation of aquaculture development in Fiji, the rate of increase in the consumption of freshwater species is expected to be faster in the long run (2050). Between the two real-income growth scenarios, the model predicts that the demand for tuna and other oceanic species will increase at a faster rate with higher income growth.
- The adoption of NRM adaptation strategies is expected to reduce Fiji's import of fish/seafood substantially, which will likely reduce the burden on foreign exchange.

In addition, the annual national economic gains of these strategies were estimated to be $11.5 million for NRM in 2035 and $14.5 million for NRM and $800,000 for aquaculture in 2035 $2.6 million for aquaculture in 2050 using the 2009 constant price for all estimations. Annual investment costs were estimated at $100,000 for about 20 fully functional MPAs/LMMAs and $50,000 for aquaculture in Fiji in 2035.

With the above findings and analysis, the need is becoming more apparent to strategize and consider policy support by the government of the Republic of Fiji to fully implement, at a minimum, the following three main adaptation strategies for the coastal communities to combat climate change in Fiji: construction and deployment of low-cost inshore FADs, expansion and recognition of MPAs, and further development of aquaculture. Policy support should deal with the review and mobilization of the existing national development plans related to climate change and adaptation options to ensure the benefits will target the coastal communities and vulnerable groups, as well as facilitate the approval of any pending associated development plans.

4. CASE STUDY: SOLOMON ISLANDS[13]

A. Overview of Fisheries Sector

Solomon Islands ranks second (next to Papua New Guinea) in terms of total water area and exclusive economic zone of 1,340,000 square kilometers (km^2) among the Melanesian countries (Table 1.1). Given this expanse of sea area, the fisheries resources of the country contributed an average of 6.8% to the total gross domestic product in 2000–2008 (Gillett 2009; Ahmed et al. 2011). Total fish exports in 2007 were estimated at $22 million, dominated by the tuna industry at 65% (albacore, bigeye, skipjack, and yellowfin), while sea cucumber, items for the aquarium trade, seaweed, and shark fins constituted the nontuna fishery exports (Gillett 2009; Ahmed 2011; Rosegrant et al. 2015). Formal employment under the fisheries sector comprised 12% of the total labor force in 2004 (FAO 2010b).

Among the fisheries groups in Solomon Islands, offshore foreign-based fisheries contributed the highest value at $153.55 million, with production of 98,023 metric tons (t). This was followed by offshore locally based fish production valued at $32.66 million with 23,619 t harvest; the coastal subsistence fishery valued at $10.98 million with 15,000 t; the coastal commercial fishery valued at $3.31 million with 3,250 t; freshwater fisheries valued at $1.46 million with 2,000 t; and aquaculture valued at $0.04 million with 165 t and 8,200 pieces (e.g., pearls, corals) in 2007 (Gillett 2009; FAO 2010b).

B. Common Fishing Practices and Gears

1. Offshore capture fisheries

Based on the expert opinion survey (EOS) and focus group discussion (FGD) conducted in 2012, long-line, hand-line, and purse seine are the conventional fishing gears used to harvest capture fisheries in offshore areas. Kauhiona and Masolo (2011) and FAO (2010b) reported the same fishing gears plus pole-and-line gear as the common technologies used to catch tuna both by foreign-based and local fishing vessels in Solomon Islands.

2. Coastal or inshore capture fisheries

The EOS and FGD also reported that commercial and subsistence fisheries in the coastal areas utilize long-lines, hand-lines, gillnets, traps, and spears and masks. Reef gleaning, spears and masks, and skin diving are used to collect shells, other edible invertebrates, and small fish. Reef gleaning, particularly during low tide, is normally done by women and children (Valmonte-Santos, Rosegrant and Dey 2016).

Fish aggregating devices (FADs) have been in operation in various provinces of Solomon Islands since 2010, and additional FADs were deployed in 2011 (Kauhiona and Vevekaramui 2013).

3. Freshwater and estuarine fisheries

Traps, gillnets, hand-lines, and spears and masks for diving are the traditional methods practiced by fishers in freshwater and estuarine areas in Solomon Islands.

[13] This Chapter draws extensively from Dey et al. 2016c

4. Aquaculture

Aquaculture was introduced in Solomon Islands in 1984. However, the political conflicts in the late 1990s prevented the full realization of the industry. To date, this industry is still underdeveloped. Based on information from the EOS and FGD and from Kauhiona and Vevekaramui (2013), aquaculture is currently restricted to seaweed, corals, and clams. Culture species on the pipeline for aquaculture are milkfish, tilapia, black pearl, and oysters.

C. National Development Plans

The Solomon Islands Government (SIG) created a number of sectoral plans in conjunction with the country's economic development and environmental conservation. These plans respond to the needs and concerns of the local populace and regional and international agreements. The three main areas—namely, environment, fisheries, and climate change—and their national sectoral plans are directly related the current study on climate change and development strategies of coastal communities. Thus, they are presented in the following subsections.

In the international and regional arenas, Solomon Islands has likewise participated in and signed several treaties and conventions specifically on climate change, including the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, ratified in 1994; the Kyoto Protocol in 1998, ratified in 2003; submission of the Initial National Communication to the UNFCCC in 2004; participation in the Pacific Adaptation to Climate Change Project in 2000; endorsement of the *Pacific Island Framework for Action on Climate Change 2006–2015* in 2005 and disaster risk reduction and *National Disaster Risk Management Plan* in 2006; and completion of the Second National Communication to the UNFCCC (SIG 2012b).

1. Biodiversity and environment

Prior to any climate change legislation and policy, the SIG created the Environment Act 1998 for the "protection and conservation of the environment; establishment of Environment and Conservation Division; and the Environment Advisory Committee" (SIG-MECM 1998a). Environmental impact assessments of any development projects fall under the Environment Regulations 2008, while the main objective of the *Solomon Islands National Environmental Capacity Development Action Plan 2008–2012* is to manage the environment (SIG-MECM 2008a).

Simultaneous with the Environment Act 1998 was the establishment of the Wildlife Protection and Management Act 1998. This act focuses on the "protection, conservation and management of wildlife in Solomon Islands by regulating the export and import of certain animals and plants; to comply with the obligations imposed upon Solomon Islands under the convention on international trade of endangered species of wild fauna and flora and for other matters" (SIG-MECM 1998b).

Related to the commitment of the SIG to respond to climate change, the 2009 *National Biodiversity Strategic Action Plan* was developed to "build the capacity of stakeholders/resource owners (local/national level) to address climate change issues in biodiversity conservation" (SIG 2009a).

2. Marine and freshwater fisheries

The SIG has promulgated various aquaculture and fisheries policies to keep pace with development of the country's economic transformation, food security, and livelihood. For example, coastal and capture fisheries policies are embedded in the Fisheries Act 1998 (No. 6 of 1998), while the Solomon Islands Fisheries (Amendment) Act 2009 (No. 6 of 2009) has placed special emphasis on the non-exploitation of tuna resources to maximize the economic and social benefits to the people of Solomon Islands (SIG 1998c, 2009b). Similarly, the *Solomon Islands Aquaculture Development Plan 2009–2014* and *Solomon Islands Tilapia Aquaculture Action Plan 2010–2015* are designed to meet the country's current requirements for food and income (SIG 2009c, 2010a). All these initiatives conform to the *National Development Strategy 2011–2020*, which recognizes fisheries as a promising sector for contribution to national economic development (SIG 2011).

Other national plans of Solomon Islands related to the marine and fisheries sector include the 1999 *Solomon Islands National Tuna Management and Development Plan* (SIG 1999); the *Solomon Islands National Strategy for the Management of Inshore Fisheries and Marine Resources 2010–2012* (SIG 2010b); and the 2009 *Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security Regional Plan of Action* (CTI-CFF 2009; SIG-MECM/MFMR 2010).

Marine protected areas (MPAs) fall under the Solomon Islands locally managed marine areas (LMMAs). Govan (2009) identified 127 LMMAs in the country, while the recent geographic information system of the Coral Triangle Atlas recorded 162 LMMAs (Kauhiona and Vevekaramui 2013). The expansion of MPAs led to the 2007 establishment of the Solomon Islands Locally Managed Marine Area Network. This in turn spearheaded the creation of the Protected Areas Act 2010 (No. 4 of 2010), Protected Areas Regulation 2012, and various national plans and frameworks on community-based resource management stipulated in the 2010 *Solomon Islands National Plan of Action* (Kauhiona and Vevekaramui 2013, SIG 2010b, 2010c).

3. Climate Change

The Solomon Islands *National Climate Change Policy 2012–2017* was developed by the Ministry of Environment, Climate Change, Disaster Management and Meteorology (MECDM) in 2012 (SIG 2012a). The policy is guided by and linked to an existing framework of national, regional, and international policies and strategies. It aligns with the *Solomon Islands National Development Strategy 2011–2020* (SIG 2011), complements other national policies and strategies, and is an expression of the country's commitment to international and regional multilateral environment agreements. The *National Climate Change Policy 2012–2017* has identified fisheries/aquaculture as an important sector (SIG 2012a). However, specific climate change mitigation and adaptation strategies and their implementation in the sector are still very limited.

Before developing its *National Climate Change Policy 2012–2017,* the SIG created the Solomon Islands National Adaptation Programmes of Action (NAPA), established by the then Ministry of Environment, Conservation and Management (MECM) (currently MECDM) in 2008. The SIG created NAPA in response to the UNFCCC requirement to identify the country's specific needs resulting from the impacts of climatic change and the adaptation strategies being implemented to alleviate those impacts. The priority sectors of Solomon Islands for managing the effects of and enhancing resilience to climate change are agriculture and food security, water supply and sanitation, human settlements and human health, climate change adaptation on low-lying and artificially built-up islands, waste management, coastal protection, fisheries and marine resources, infrastructure development, and tourism (SIG-MECM 2008b; Kauhiona and Vevekaramui 2013).

D. Modeling the Effects of Climate Change and Climate Change Adaptation Strategies

Solomon Islands' fisheries sector can be placed into four broad categories: offshore capture (foreign-based and locally based), coastal capture (subsistence and commercial), freshwater capture, and aquaculture. About 85% of the total supply comes from offshore fisheries, and tuna constitutes about 95% of the offshore catch. The coastal fisheries capture a large variety of finfish and invertebrate species. Coastal finfish catch is dominated by snapper, grouper, rock cod, emperor, mackerel, and trevally. Important commercial invertebrate species are bêche-de-mer, trochus, green snail, giant clams, crabs, and lobsters. However, there has been a ban on the bêche-de-mer fisheries for close to 4 years, which was lifted only for 3 months during March through May 2013.

The Solomon Islands model that we have developed considers four main groups: tuna, other oceanic finfish, coastal finfish, and coastal invertebrates. These fish species are found in mostly oceanic and coastal fishing areas of Solomon Islands. However, given the recent emphasis on aquaculture in Solomon Islands, we have also considered two additional groups in the model: freshwater finfish and freshwater invertebrates.

We have used data collected from both primary and secondary sources to run our model. Primary data used in the modeling were gathered with the application of the EOS conducted in Honiara in August 2012. Experts from MECDM, the Ministry of Fisheries and Marine Resources, the National Project Management Unit-ANZDEC, and national research partners (NRPs) participated in the survey.

A field visit to Isabel province was made to pre-test the FGD for capture fishers in March 2012. A second round of the FGD survey for capture fishers was implemented in August 2012, in which more than 60 representatives participated as leaders and members of various groups from the coastal and upland/inland villages that are likewise users of the Maringe Lagoon. Representatives of coastal villages were from Buala, Hovikoilo, Jejevo, Kubolota, Maglau, Nareubu, Popoheo, Solona, Tasia, and Tithiro, while representatives of inland/upland villages were from Bara, Gneulahage, Kolomosa, Kolokofo, Kulosori, Sugolona, Tholana, and Tirotongga. The FGD for fish farmers was not conducted in Isabel province because fish farming is not yet practiced in Buala and other south-east-west villages. Section B, above, presents a list of existing and pipeline aquaculture/capture fisheries technologies in Solomon Islands.

Broadly speaking, Solomon Islands is implementing three main types of climate change adaptation strategies: (1) aquaculture; (2) natural resource conservation approaches, particularly MPAs; and (3) low-cost FADs. As more rains are expected as a result of climate change, inland aquaculture of tilapia and milkfish is a potential key adaptation strategy for the country. Natural resource conservation approaches include (1) conservation and restoration of mangroves, (2) upstream watershed management, and (3) MPAs. The benefits and costs of MPAs are yet to be studied, and the country is not aggressively pursuing MPAs as a climate change adaptation strategy. FADs are a priority for the country, with an aim to increase national fish supply by attracting tuna and other offshore fisheries to inshore areas. This is expected to alleviate pressure on coastal reef fish.

We considered three climate change adaptation scenarios in the modeling exercise: aquaculture development (AQ), low-cost FAD, and natural resource management (NRM) in particular MPAs and LMMAs. Scenario 1 (AQ) involves improvements in the productivity of freshwater (both finfish and invertebrate) aquaculture; scenario 2 (FAD) addresses the increase in tuna and oceanic fish catch; and scenario 3 (NRM) addresses production and productivity in coastal and oceanic capture fisheries due to management regime shifts and adoption of resource enhancement practices.

We ran these and baseline scenarios with two different growth rates of per capita real income: a moderate growth rate of 2% per annum and a high growth rate of 3% per annum. We used projected populations of 969,920 in 2035 and 1,245,774 in 2050.

We presented the model, the data used in the model, and the preliminary results to various stakeholders at a "model validation meeting" held in Honiara on 20 June 1013. Based on comments received at the validation meeting, as well as comments from other experts, we made some minor adjustments to the model. The validated baseline data (production, consumption, trade, and price), supply elasticities, and demand elasticities used in the fish sector model for the Solomon Islands model are given in Appendix Tables A.5, A.6, and A.7, respectively. As noted earlier, the supply volumes reported in Table A.5 and used in the analysis include catch by national fleets in both national and international waters, but do not include catch by foreign fleets in national waters. Unlike in Fiji and Vanuatu, tuna catch by foreign vessels is substantial in Solomon Islands.

The fish demand elasticities used in the model reflect consumers' preference patterns in Solomon Islands and the substitutability of various fish products with other sources of animal protein in the country. Given the artisanal nature of fisheries and relatively subsistence aquaculture, supply elasticities used in fish sector model for Solomon Islands are inelastic; absolute values of most of the supply elasticities are close to zero (the highest value is 0.30). We also used alternative sets of elasticities to test the sensitivity of the model and found that changes of elasticities within the possible range do not alter the main results.

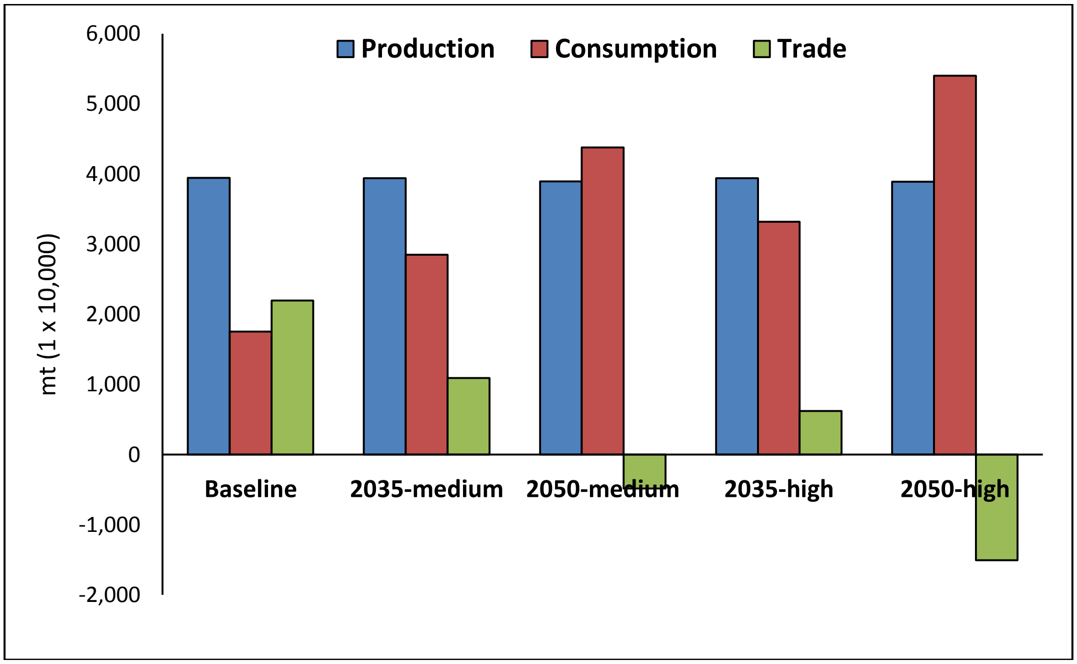
The overall shifts in the supply curve as a result of climate change (i.e., effect of climate change on fish production) and various climate change adaptation strategies in Solomon Islands in 2035 and 2050 are reported in Appendix Table A.8. We used the projection of the SEAPODYM (Spatial Ecosystem and Population Dynamics Model) for the likely effects of climate change on tuna catch under relatively low- and high-emission scenarios (Lehodey et al. 2008). Like in Fiji and other case study countries, the data on the likely effect of climate change under baseline conditions were taken (for 2035) or modified (for 2050) from Bell et al. (2011b), Gehrke et al. (2011), Lehodey et al. (2011), Pichering et al. (2011), and Prachett et al. (2011). Climate change is likely to have positive effects on tuna and oceanic fish production (Lehodey et al. 2011) and negative effects on coastal fish production (Prachett et al. 2011) in Solomon Islands. However, the likely positive effects of climate change on tuna catch are much smaller for Solomon Islands than those for Fiji and Vanuatu (Lehodey et al. 2011).

The likely effects of various climate change adaptation strategies on fish production, as denoted by (λ_1) in equation (2), were collected through the EOS and FGD, and are reported in columns 3, 4, 5, 7, 8, and 9 of Appendix Table A.8. The positive (or negative) values of the shift (λ) show an increase (or decrease) from the initial production level and/or a reduction (or increase) in the cost of fish production/capture. The use of FADs will allow costal fishers to catch tuna and other oceanic fish in coastal waters. This will increase the supply of tuna and other oceanic species, and will shift their supply curves to the right. Various NRM strategies (such as MPAs and LLMAs) are likely to mitigate some of the negative effects of climate change on coastal fisheries and shift the supply curves for coastal species to the right.

1. Effects of climate change on production, consumption, and trade (baseline scenario)

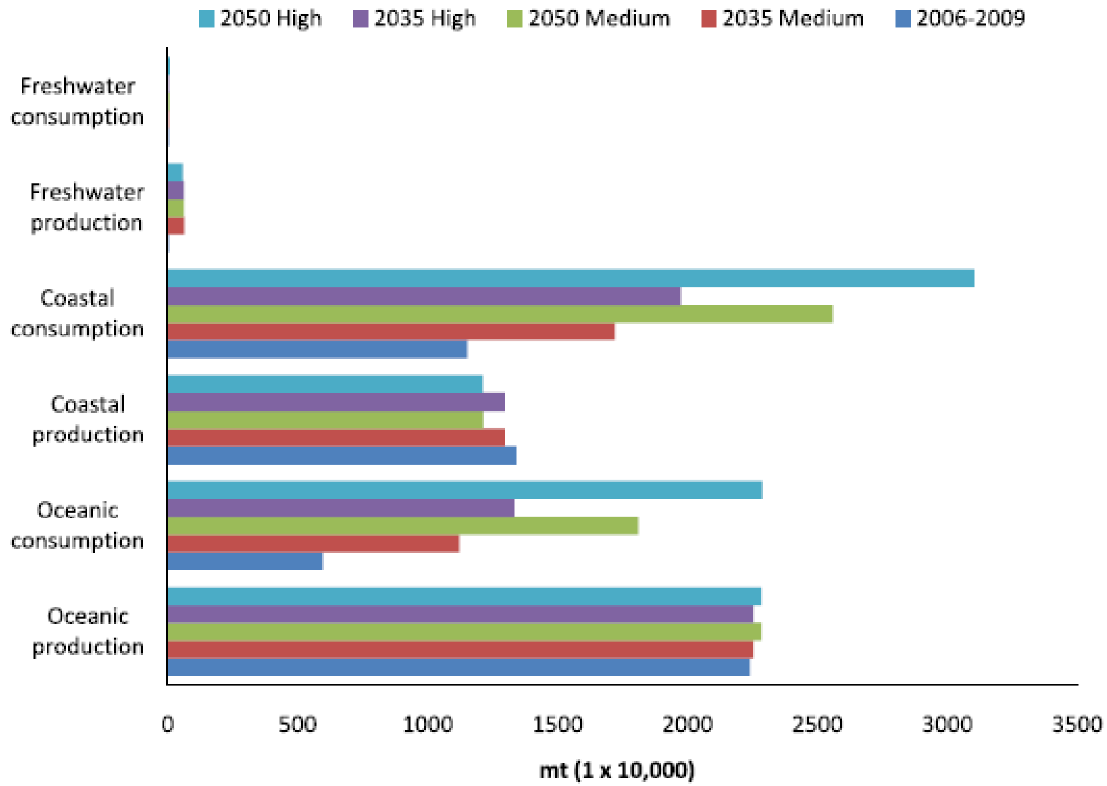
The model predicts that the supply of fish aggregate will increase marginally in the medium term (2035) and long term (2050) under the baseline scenarios. Among various species groups, we expect some increase in supply from oceanic and freshwater systems. However, the supply from coastal fisheries is likely to decrease over time. On the other hand, the demand for different types of fish will increase over time as a result of an increase in population and per capita real income (Figures 4.1 and 4.2). As expected, overall demand will be higher, with higher growth (3% per annum) in per capita real income. Results show that total domestic fish production is likely to surpass total demand in the long term (2050). Among various species groups, a major part of this increased demand will be for oceanic species, such as tuna. If Solomon Islands cannot catch more oceanic fish than otherwise harvested by foreign vessels, the country may have to import fish in large volumes to meet the projected demand.

Figure 4.1
Projected Fish Production, Consumption, and Trade under Two Baseline Scenarios (2% and 3% annual growth rate of per capita real income) in Solomon Islands, 2035 and 2050



medium = 2% annual growth rate of per capita real income; high = 3% annual growth rate of per capita real income.
Source: Model projections.

Figure 4.2
Projected Production and Consumption of Different Types of Fish under Two Baseline Scenarios (2% and 3% annual growth rate of per capita real income) in Solomon Islands, 2035 and 2050



medium = 2% annual growth rate of per capita real income; high = 3% annual growth rate of per capita real income.
Reprinted from "Analysis of the economic impact of climate change and climate change adaptation strategies for fisheries sector in Pacific coral triangle countries: Model, estimation strategy, and baseline results" by Dey, M.M., M.W. Rosegrant, K. Gosh, O.L Chen, and R.A. Valmonte-Santos. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Dey et al. 2016a.

It is important to note that foreign vessels currently catch most of the tuna caught in Solomon Islands, and almost all of these fish are exported by foreign companies (not by Solomon Islands). The domestic production and export reported in this section cover only the domestic industry. We have considered income from foreign vessels as an outside income.

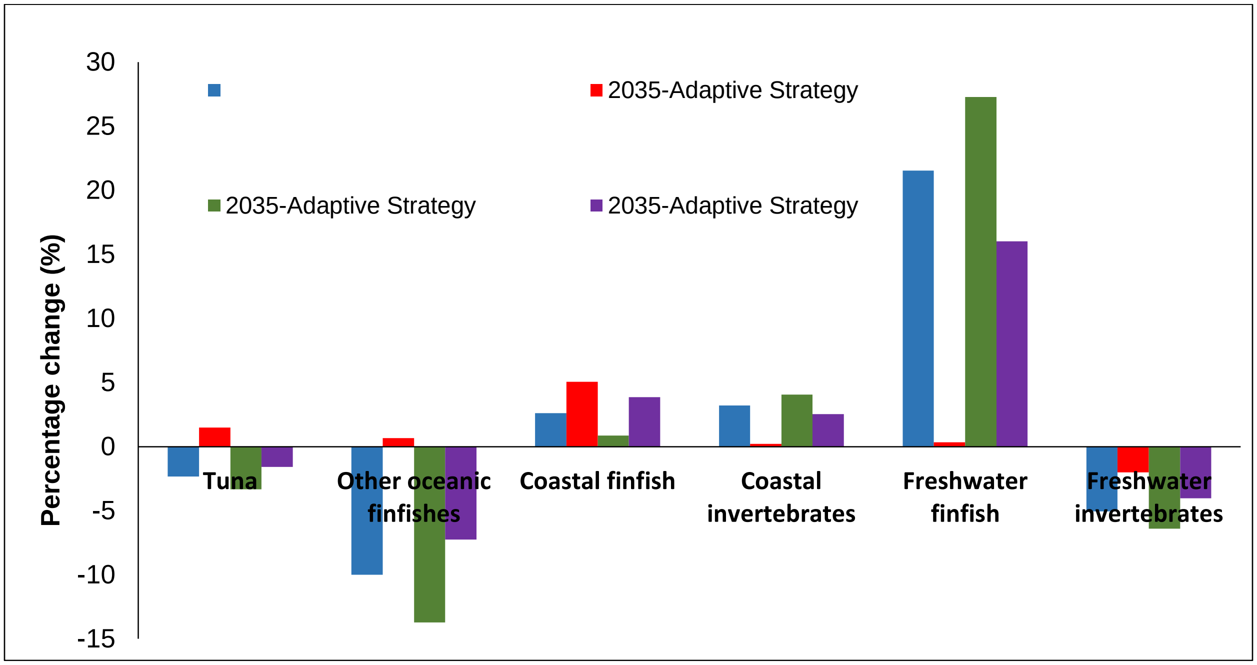
Our modeling results imply that increases in domestic supply of tuna and other oceanic species will be helpful to meet the growing demand for this category of fish. Strategies to increase the domestic supply of tuna may include harvest of tuna and other oceanic pelagic species by domestic fleets, use of FADs to capture tuna and other oceanic fish in coastal waters, and onshore processing of tuna for domestic markets.

2. Effects of climate change adaptation strategies

2.1. Changes in fish prices

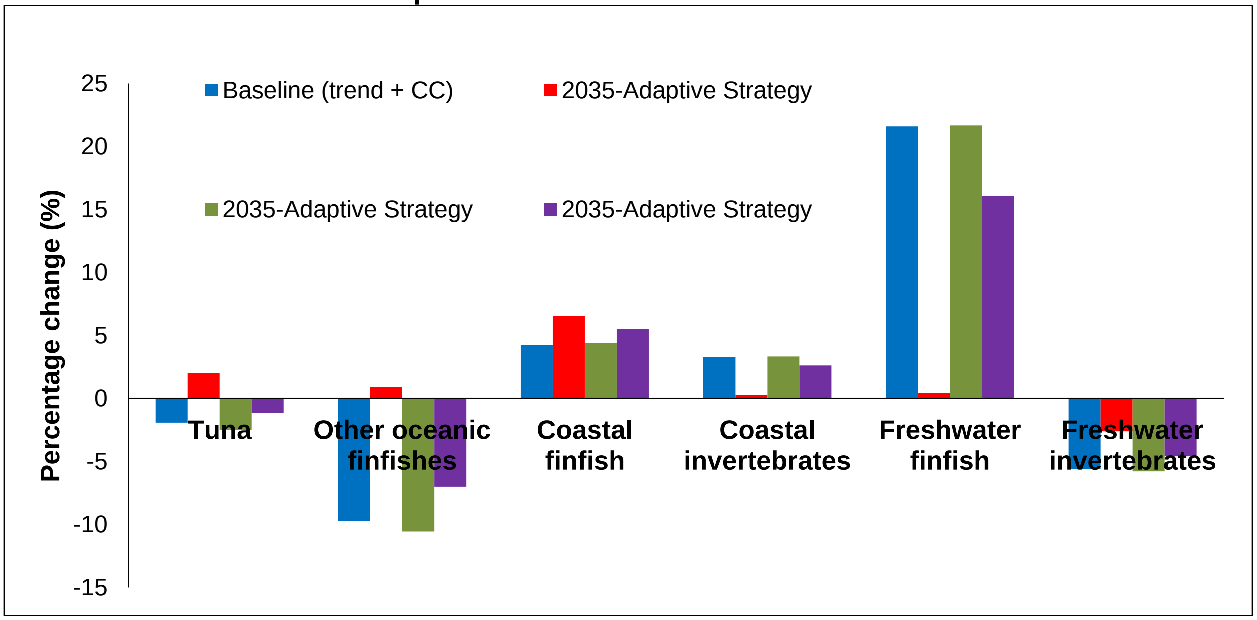
Figures 4.3 to 4.6 show projected changes in the real prices of different fish species groups in 2035 (medium term) and 2050 (long term). The model projects that the real price of tuna will decrease by about 2% during 2009–2035 under the baseline scenarios. The model predicts that the implementation of FADs will decrease the real price of tuna in 2035 and 2050 relative to other scenarios. Even with higher growth in per capita income, implementation of this adaptation strategy is expected to reduce tuna prices by 2050. Given the relatively high contribution of tuna to fish and seafood consumption in Solomon Islands, adoption of low-cost FADs is likely to substantially enhance the country's food security.

Figure 4.3
Percentage Change in Price from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Solomon Islands



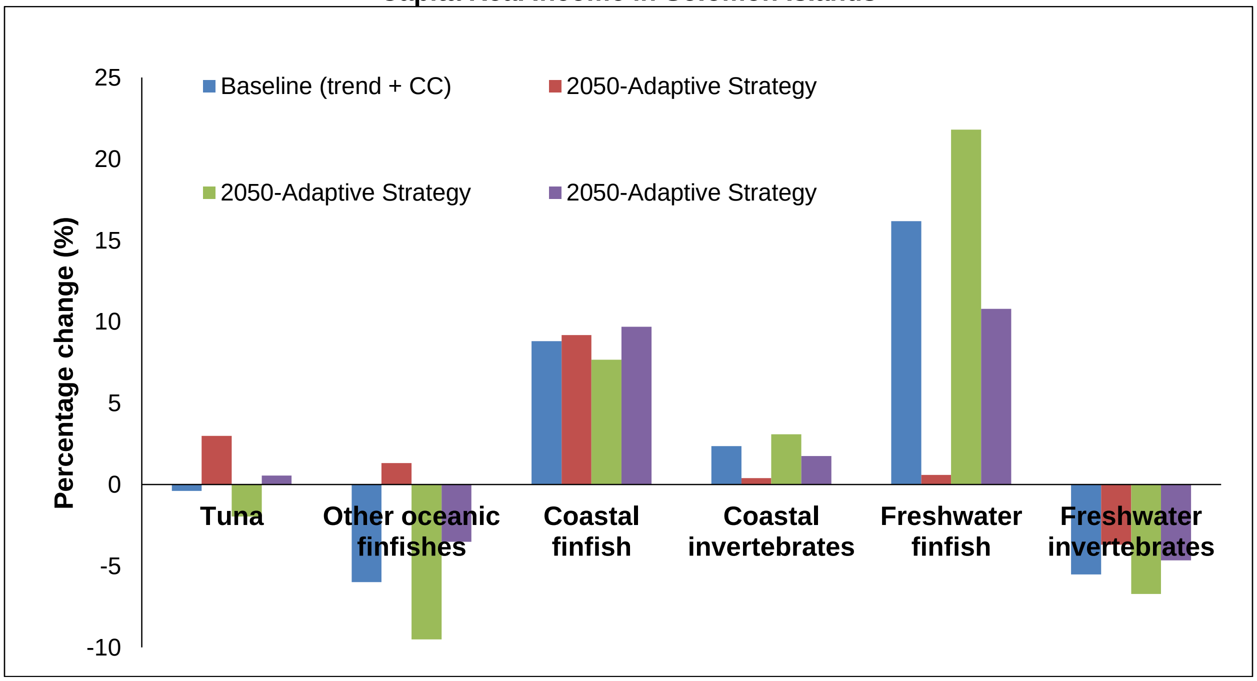
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.4
Percentage Change in Price from Baseline (2006–2009) to 2035 with 3% Annual Growth of Per Capita Real Income in Solomon Islands



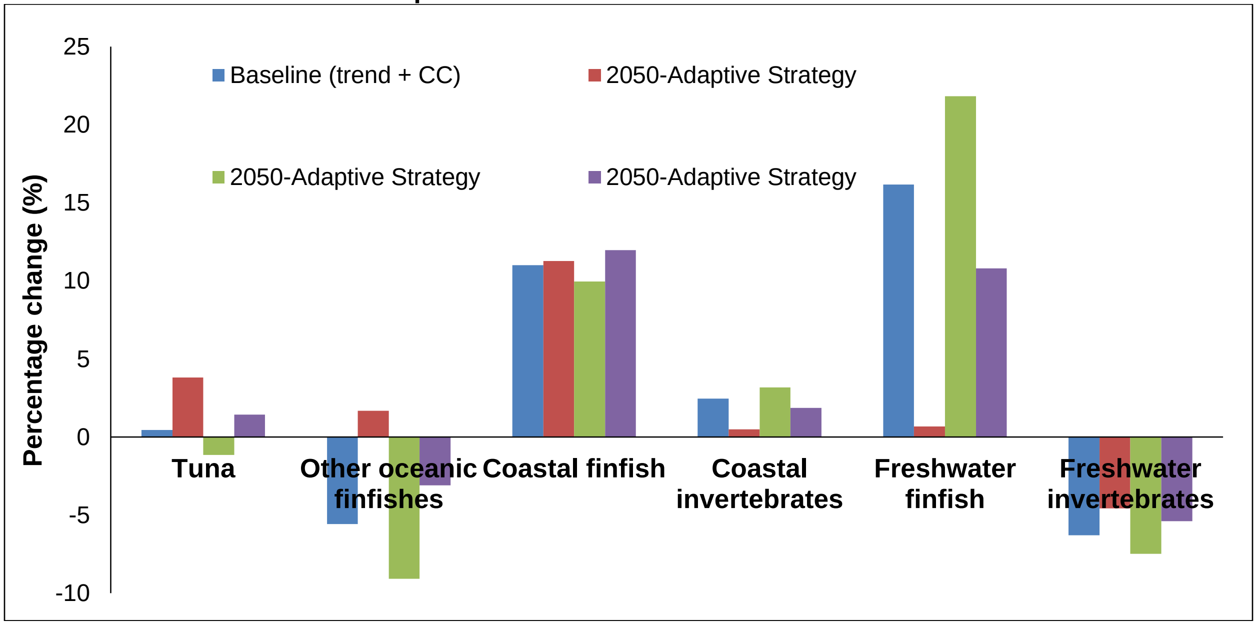
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.5
Percentage Change in Price from Baseline (2006–2009) to 2050 with 2% Annual Growth of Per Capita Real Income in Solomon Islands



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.6
Percentage Change in Price from Baseline (2006–2009) to 2050 with 3% Annual Growth of Per Capita Real Income in Solomon Islands



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c

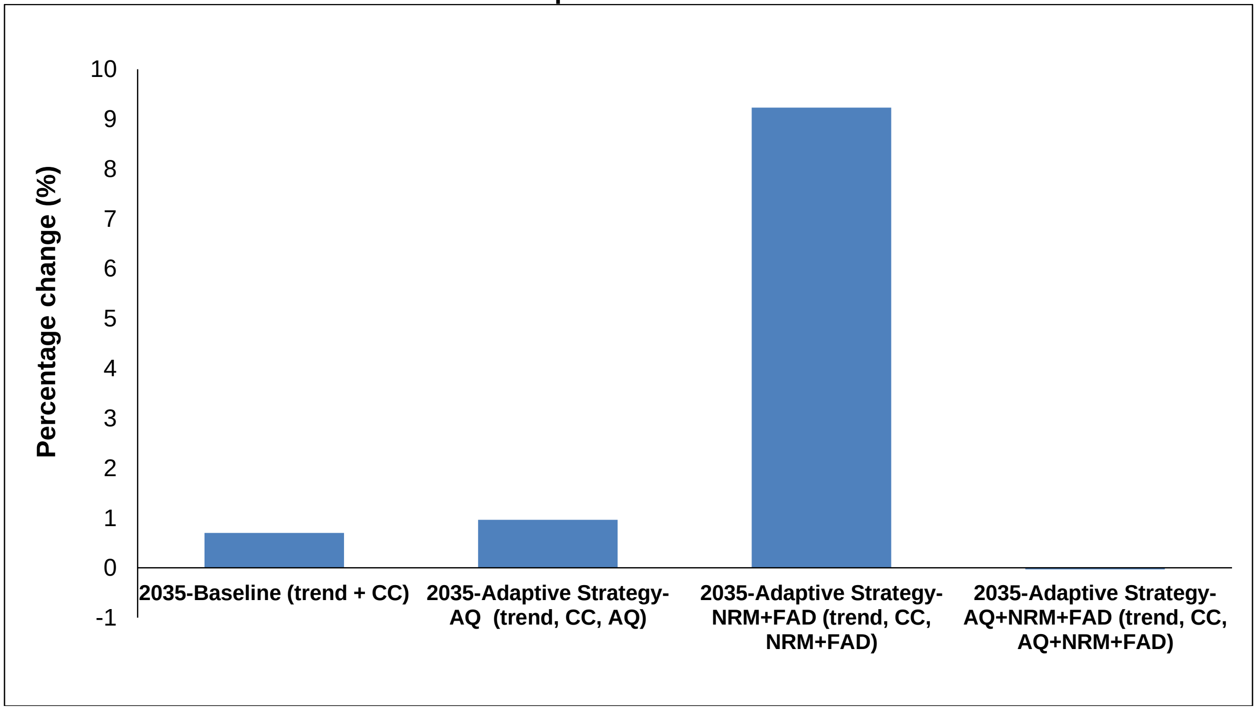
The projected decline in real prices of other oceanic fish species under the baseline scenarios is mainly the result of higher imports of this fish category. At present, Solomon Islands imports this category of fish primarily in the form of processed anchovies and sardines. Given the higher domestic price relative to the world price of this fish category, imports of this fish are likely to increase and real prices are likely to decline under the baseline scenarios.

The coastal finfish category is the most important fish type. The real price of coastal finfish and invertebrates are expected to increase in the medium term (2035) and long term (2050). Adoption of FADs is likely to halt the rise of coastal fish prices at least under the scenario of lower (2%) growth in per capita income. The model predicts that the aquaculture development strategy will reduce the real price of coastal fish.

2.2. Changes in fish production

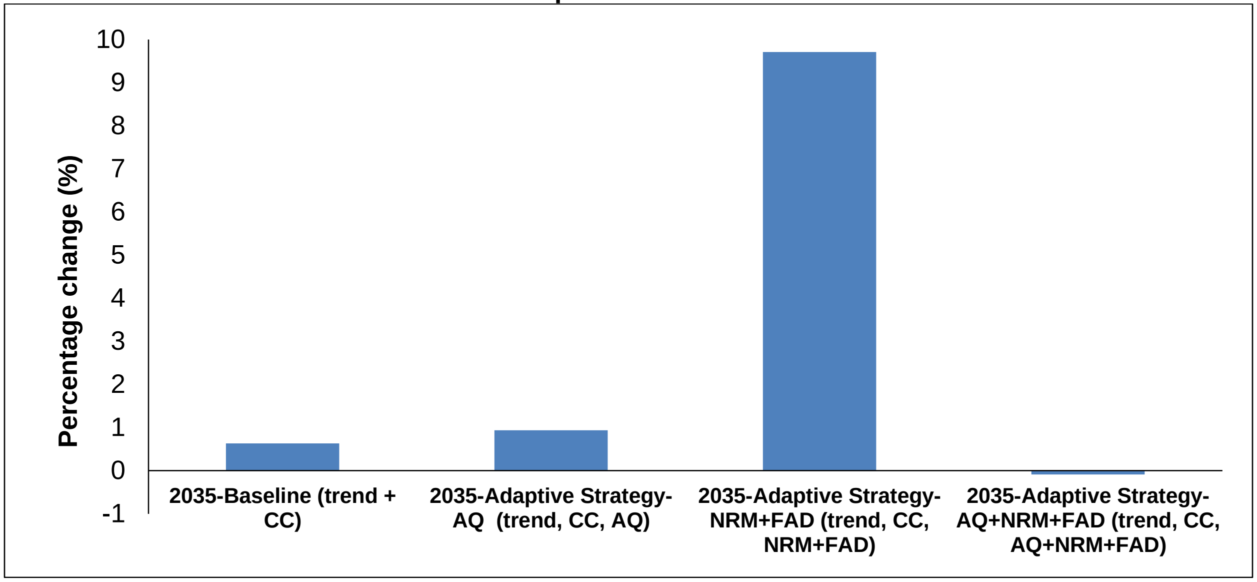
The model predicts that oceanic fish production will marginally increase over the period (2006/9 to 2035 and 2006/9 to 2050) under the baseline scenarios. Among the various adaptation strategies considered in the modeling exercise, adoption of FADs is likely to have the highest positive impact on oceanic fish supply (Figures 4.7 to 4.10). The model predicts that FADs will increase supply of oceanic fish by about 9%-10% of the current level in 2035 and by about 14%–15% in 2050. Given that oceanic fisheries is a main contributor of fish supply in Solomon Islands, use of FADs is expected to have a significant positive impact on the fisheries economy and food security of Solomon Islands. As in the assessment for the other countries, that projected rate of increase in national tuna production due to increased investment in FADs is well within the sustainable tuna catch, as noted in Chapter 2 (and see Lehodey 2011; Bell 2010). Other adaptation strategies (aquaculture and NRM) are not expected to have any significant positive impact on oceanic fish supply.

Figure 4.7
Percentage Change in Production of Oceanic Species from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Solomon Islands



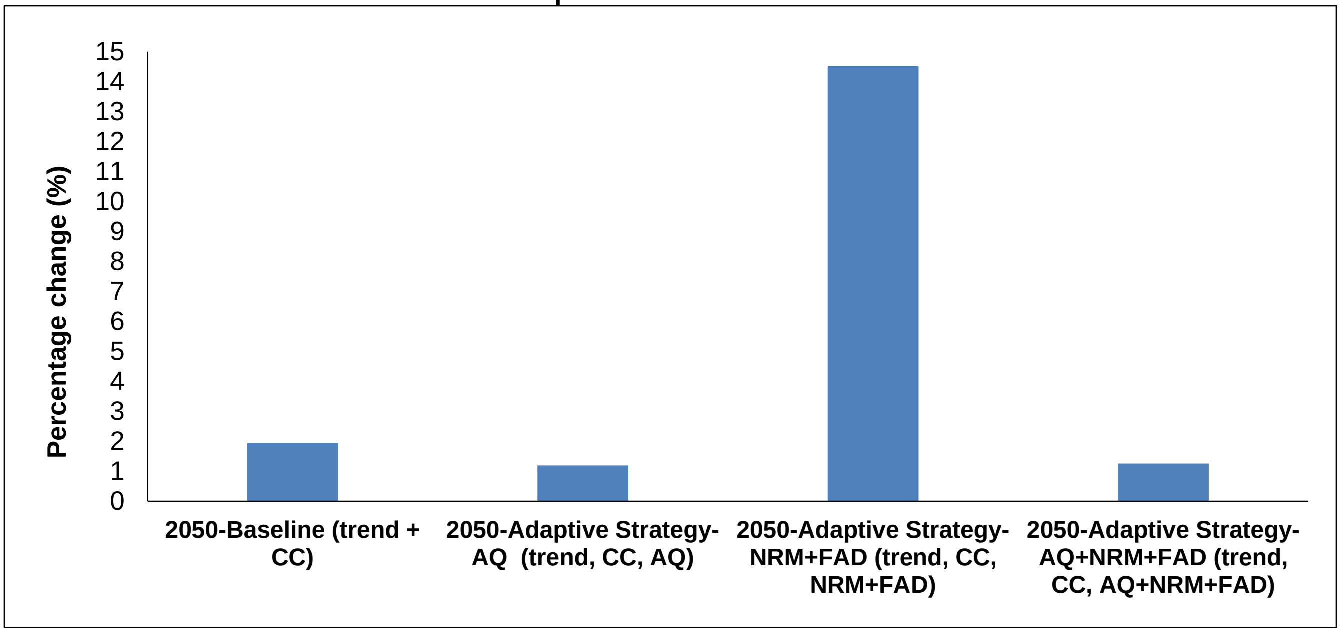
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.8
Percentage Change in Production of Oceanic Species from Baseline (2006–2009) to 2035 with 3% Annual Growth of Per Capita Real Income in Solomon Islands



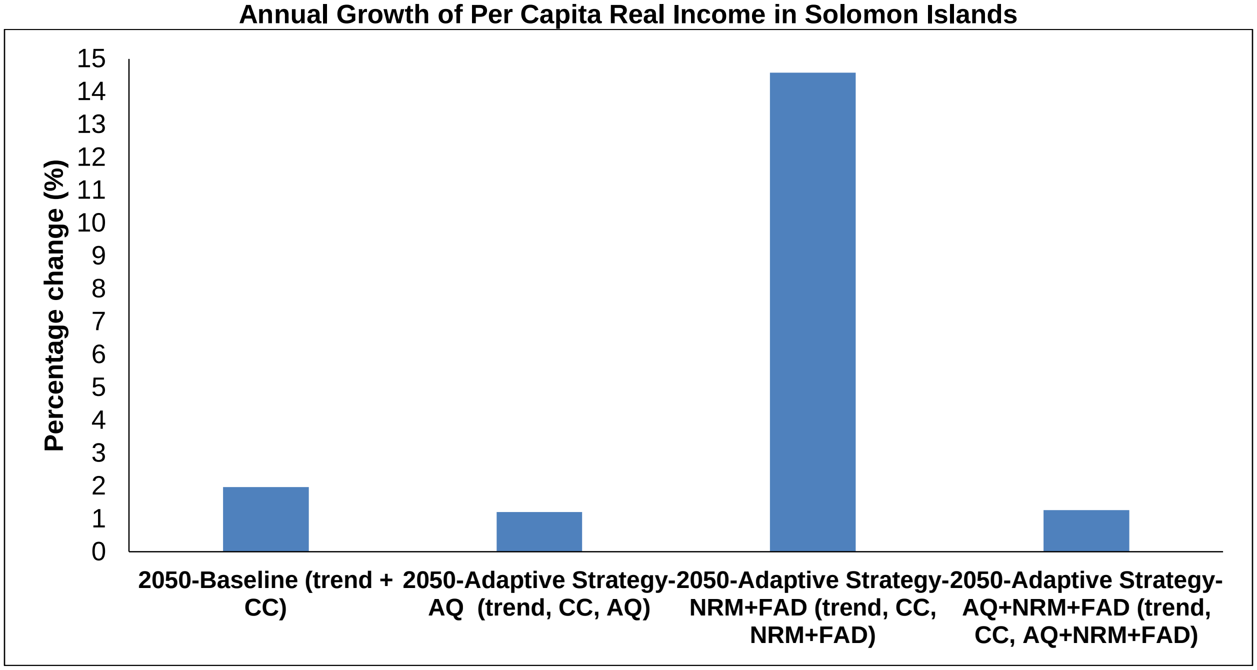
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.9
Percentage Change in Production of Oceanic Species from Baseline (2006–2009) to 2050 with 2% Annual Growth of Per Capita Real Income in Solomon Islands



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

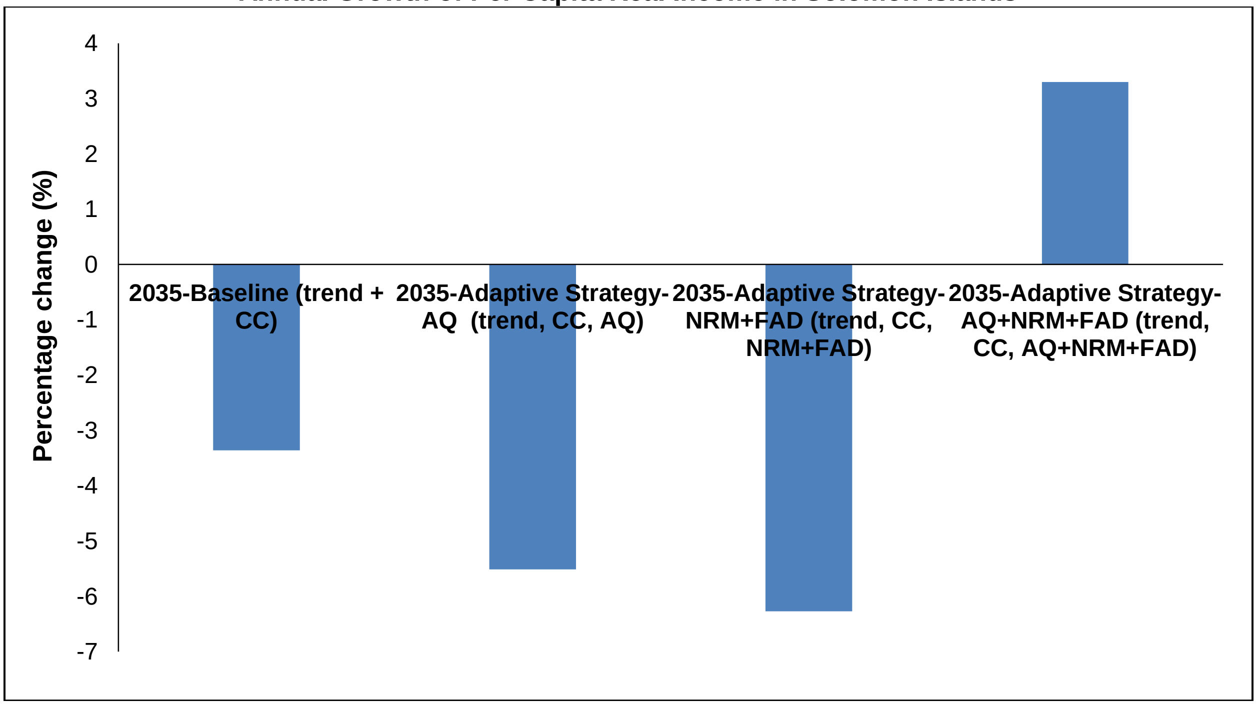
Figure 4.10
Percentage Change in Production of Oceanic Species from Baseline (2006–2009) to 2050 with 3% Annual Growth of Per Capita Real Income in Solomon Islands



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

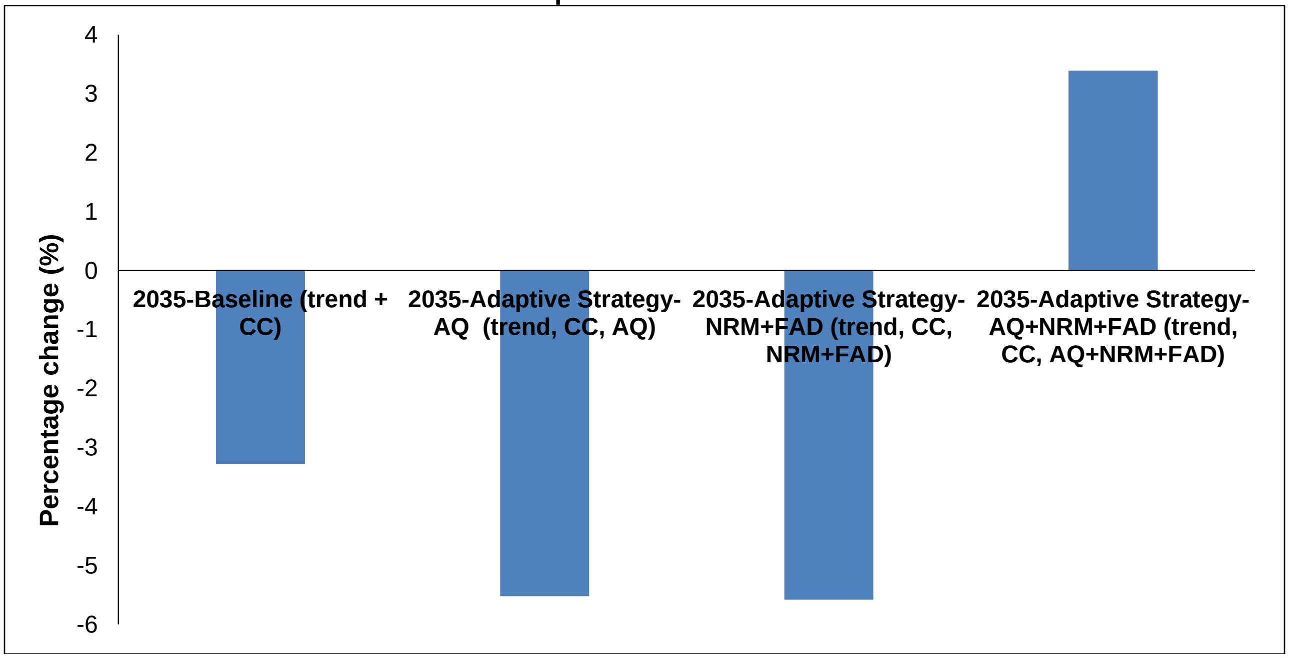
Figures 4.11 to 4.14 show the likely effect of different climate change adaptation strategies on coastal fish production in 2035 and 2050. The model predicts that NRM strategies is likely to have positive impacts on coastal fish supply in the medium term (2035) and long term (2050) (Figures 4.13 and 4.14). The model projects that FADs may have a negative impact on coastal fisheries supply in the long run, mainly because of the substitution effect between coastal and oceanic fish supplies.

Figure 4.11
Percentage Change in Production of Coastal Species from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Solomon Islands



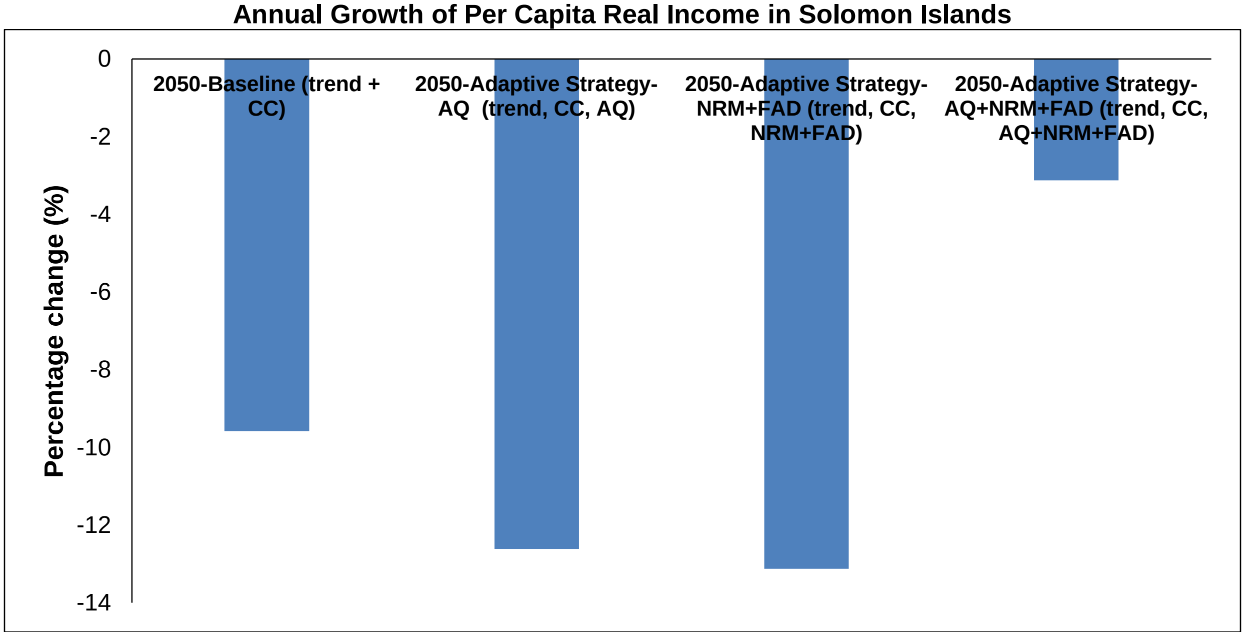
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.12
Percentage Change in Production of Coastal Species from Baseline (2006–2009) to 2035 with 3% Annual Growth of Per Capita Real Income in Solomon Islands



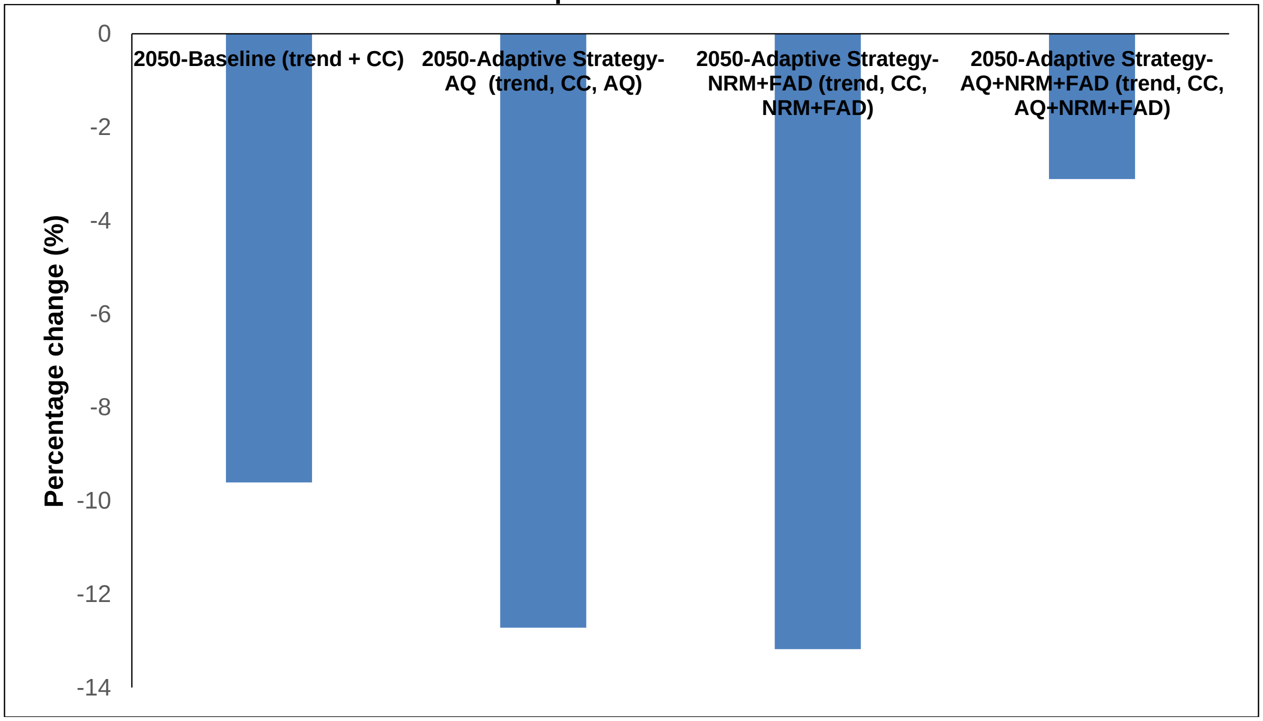
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.13
Percentage Change in Production of Coastal Species from Baseline (2006–2009) to 2050 with 2% Annual Growth of Per Capita Real Income in Solomon Islands



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.14
Percentage Change in Production of Coastal Species from Baseline (2006–2009) to 2050 with 3% Annual Growth of Per Capita Real Income in Solomon Islands



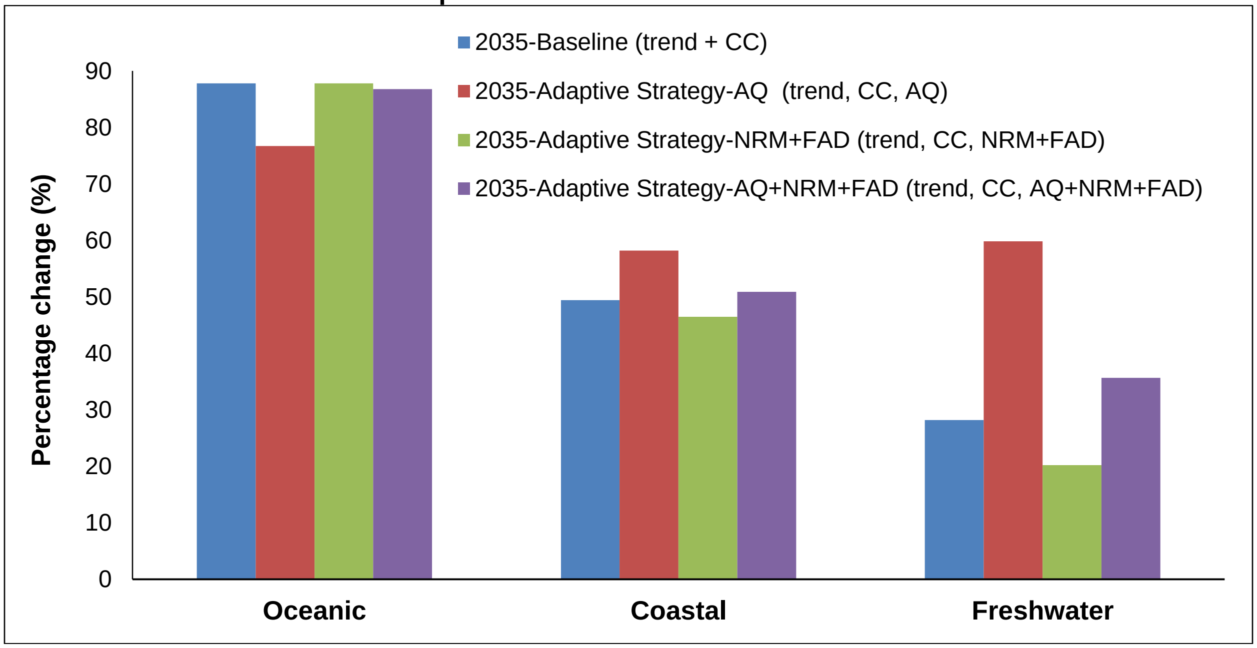
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

The freshwater fisheries/aquaculture sector is still a very minor supplier of fish in Solomon Islands. The model predicts that aquaculture development will increase freshwater fish production by about 31 to 33 times (from a very low base) in the medium term (2035) and by about 36-38 times in the long term.

2.3. Changes in fish consumption

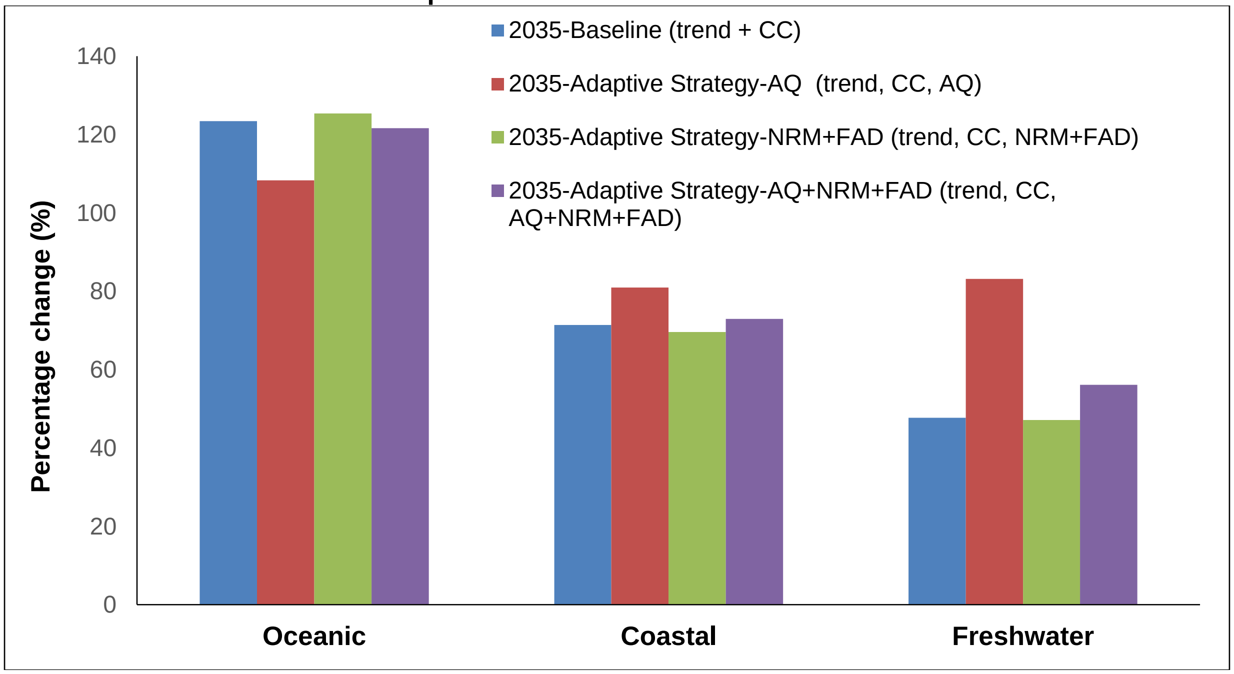
Figures 4.15 to 4.18 depict the likely effects of various climate change adaptation strategies on fish consumption (i.e., fish demand) in Solomon Islands in the medium term (2035) and long term. The model predicts that aquaculture development will increase consumption of freshwater fish in 2035 and 2050, and that the impact will increase over time along with per capita real income. While adoption of FADs and NRM strategies may not increase fish consumption, increased fish production from these strategies is likely to replace imports with domestic supply.

Figure 4.15
Percentage Change in Consumption from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Solomon Islands



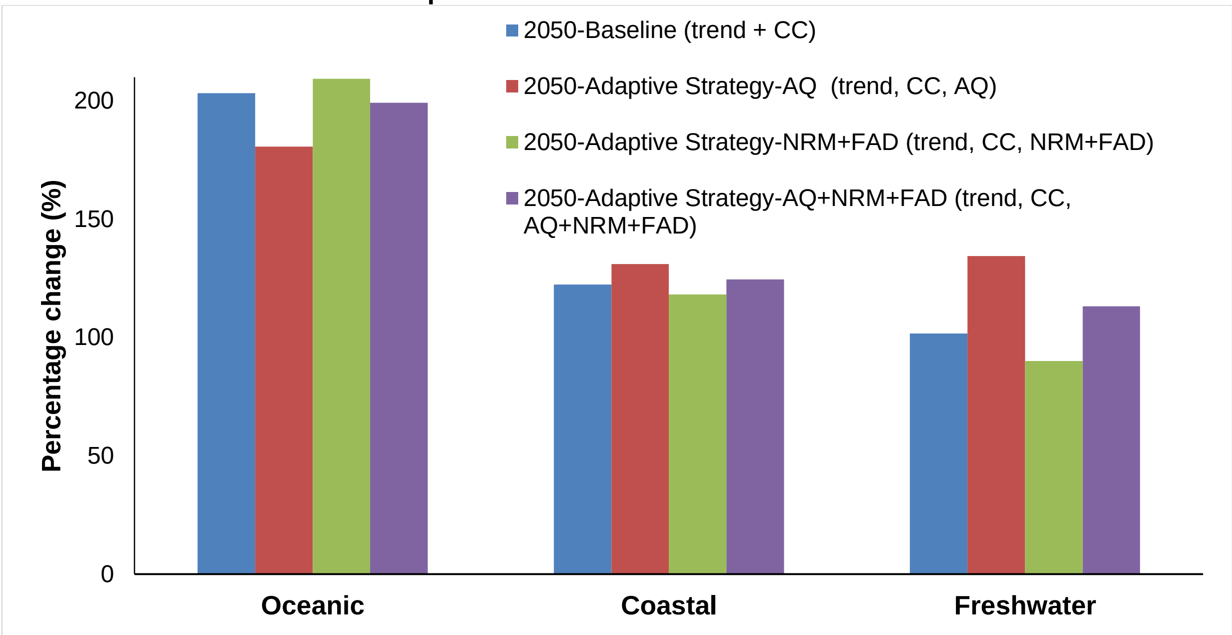
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.16
Percentage Change in Consumption from Baseline (2006–2009) to 2035 with 3% Annual Growth Of Per Capita Real Income in Solomon Islands



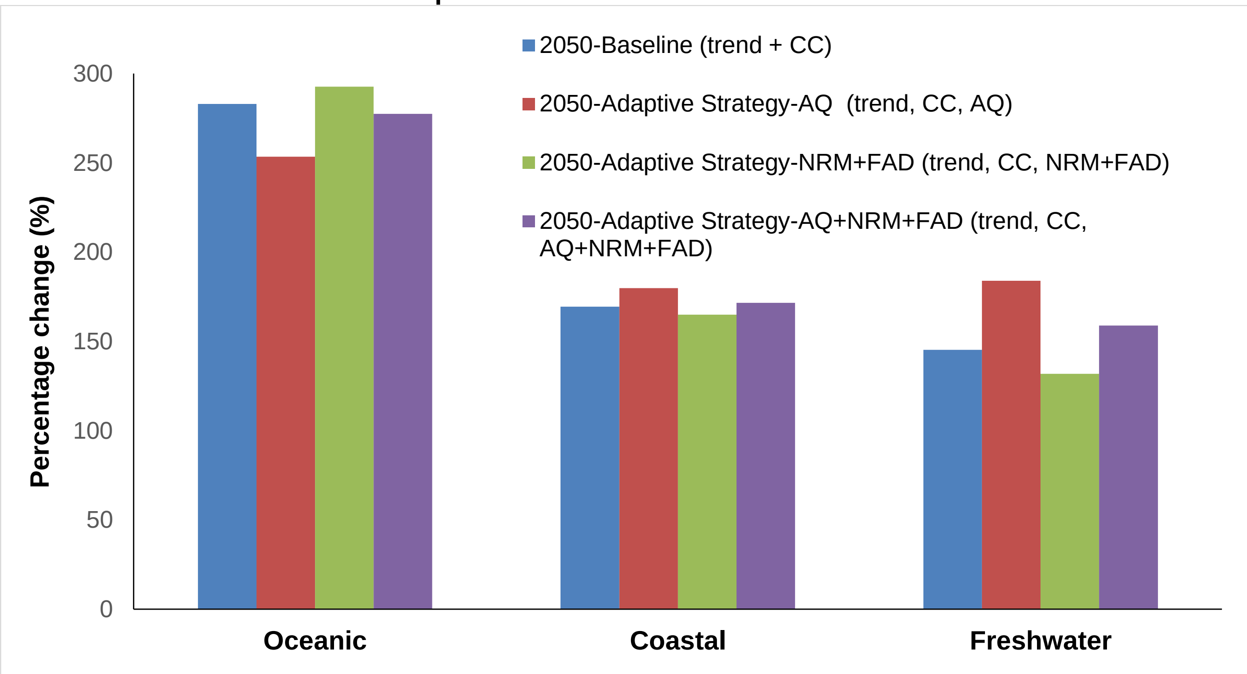
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.17
Percentage Change in Consumption from Baseline (2006–2009) to 2050 with 2% Annual Growth of Per Capita Real Income in Solomon Islands



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.18
Percentage Change in Consumption from Baseline (2006–2009) to 2050 with 3% Annual Growth of Per Capita Real Income in Solomon Islands

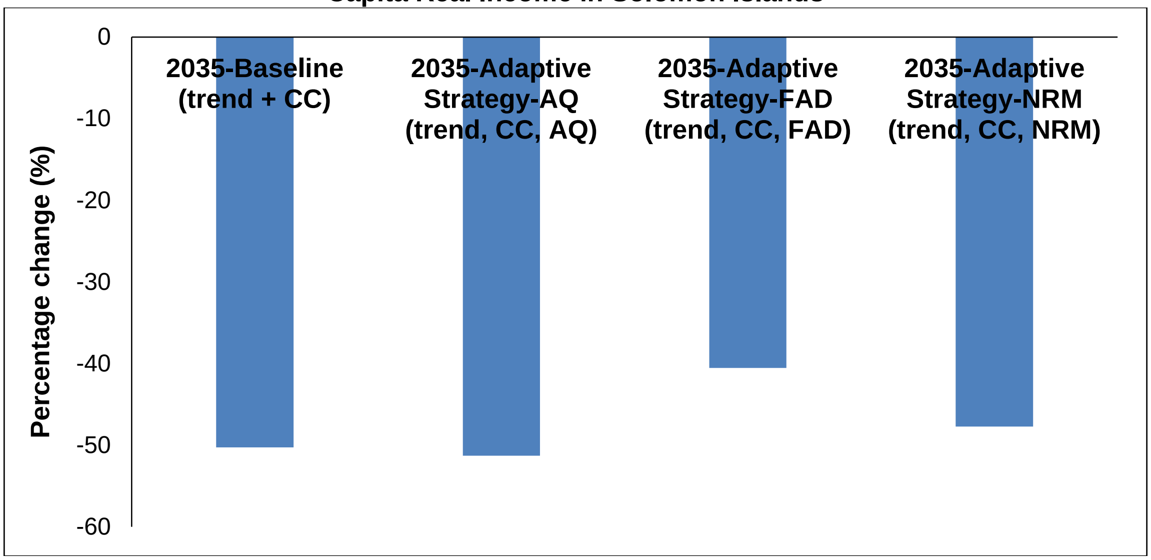


AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

2.4. Changes in net trade (export minus import)

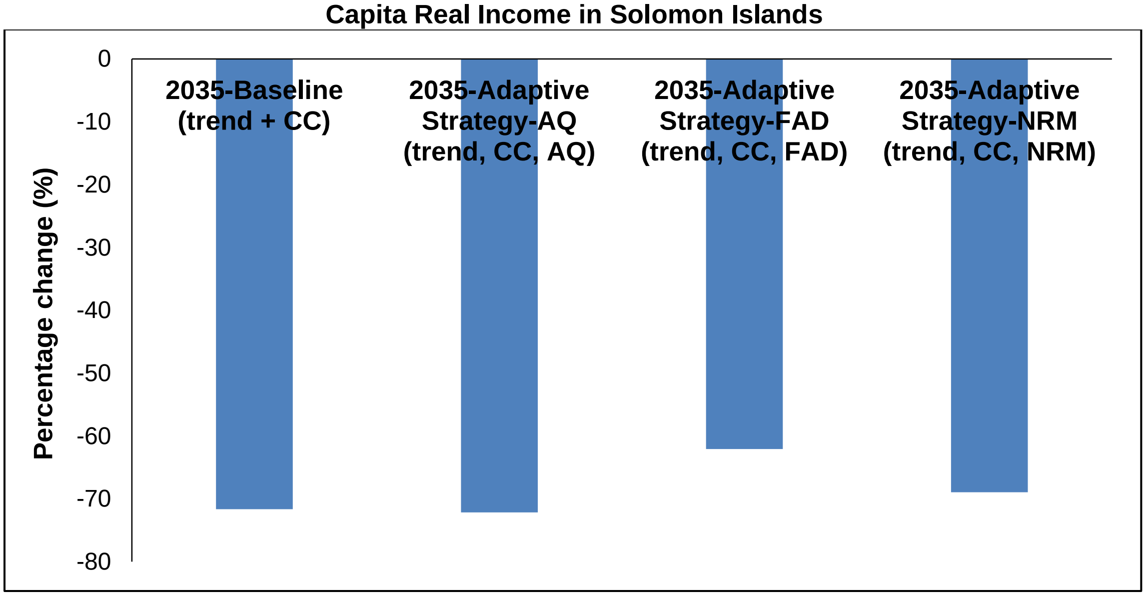
Figures 4.19 to 4.22 show the likely effects of different climate change adaptation strategies on fish trade in Solomon Islands in medium term (2035) and long term (2050). Among various adaptation strategies examined, FADs are expected to significantly reduce the country's likely dependence on fish imports in the long term. The role of FADs will be even more important if the country's per capita real income rises at a faster rate.

Figure 4.19
Percentage Change in Net Trade from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Solomon Islands



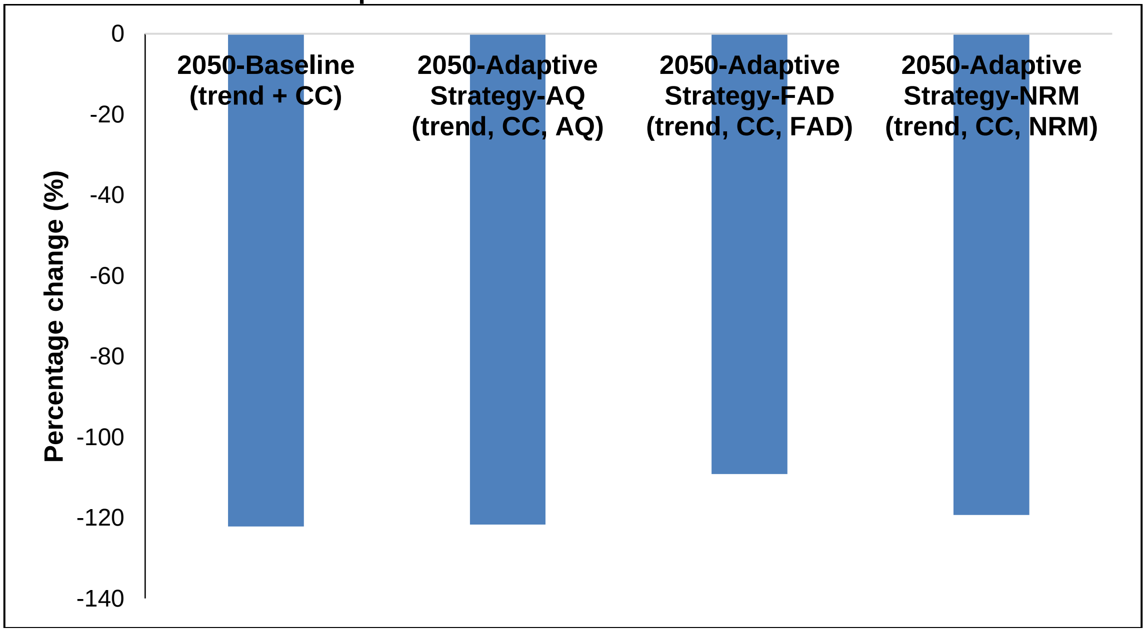
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.20
Percentage Change in Net Trade from Baseline (2006–2009) to 2035 with 3% Annual Growth of Per Capita Real Income in Solomon Islands



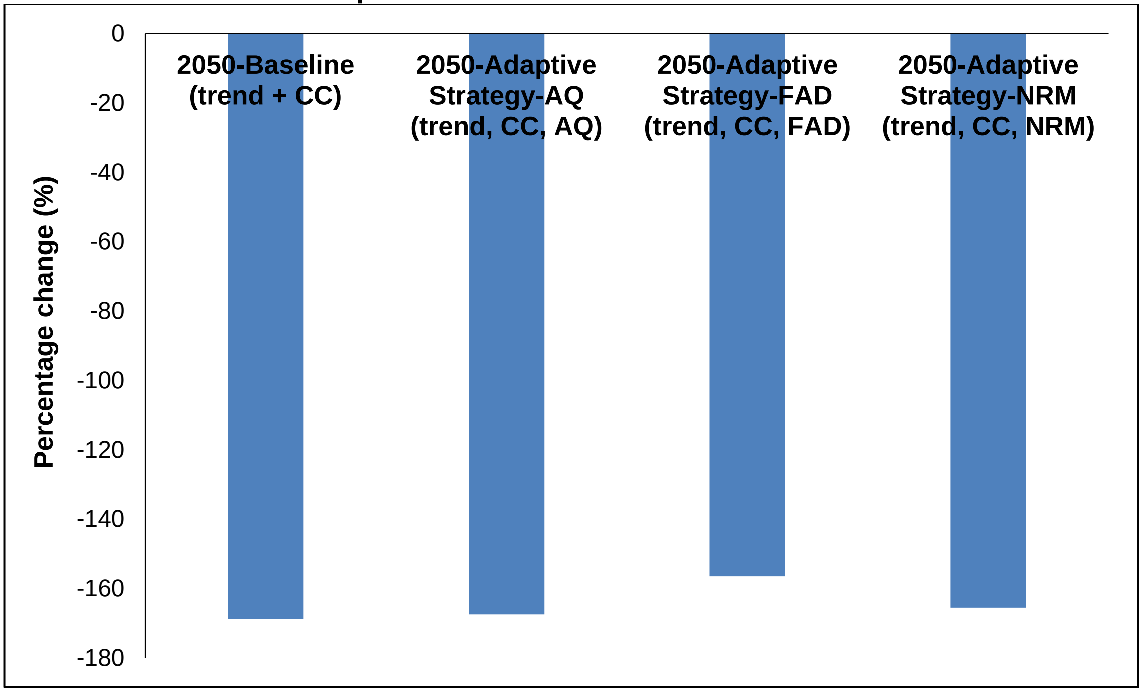
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.21
Percentage Change in Net Trade from Baseline (2006–2009) to 2050 with 2% Annual Growth of Per Capita Real Income in Solomon Islands



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

Figure 4.22
Percentage Change in Net Trade from Baseline (2006–2009) to 2050 with 3% Annual Growth of Per Capita Real Income in Solomon Islands



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Dey et al. 2016c.

2.5. National-level economic gains resulting from climate change adaptation strategies

Table 4.1 shows the estimated national-level net economic gains to both consumers and producers as a result of various climate change adaptation strategies in Solomon Islands. These estimates show that the yearly net economic gain from aquaculture, FAD, and NRM adaptation strategies are around $0.37 million, $10.08 million, and $2.57 million in 2050 (in 2009 constant price), respectively. These estimates are consistent with those from previous case studies described in Section 1 of this report. These estimated net economic gains from various adaptation strategies are significantly higher compared with their investment costs. Among the various adaptation strategies, FADs appear to be the most economically attractive adaptation strategy for Solomon Islands. The production increase (supply curve shift) resulting from FADs that we assumed in the model will require a yearly investment[14] of about $230,000 and is expected to generate a yearly income of more than $6.95 million in 2035 (a more than 30-fold increase in yearly net return).

Table 4.1
National-Level Economic Gain (equivalent variation) Resulting from Climate Change Adaptation Strategies in Solomon Islands

Climate Change Adaptation Strategy	Economic Gain per Year (US$ in 2009 prices)	
	2035	2050
Aquaculture	228,620	370,466
Fish aggregating devices	6,955,473	10,079,458
Natural resource management	2,620,743	2,571,135

Source: Dey et al. 2016c.

E. Summary

The review and analysis of available literature; the discussions at the national, provincial, and community levels through the EOS and FGD; and the modeling results and assessment carried out for this study generated key messages for Solomon Islands with and without climate change adaptation strategies.

1. The baseline scenario predicted the following likely situations:
   - Total demand is likely to surpass domestic fish production in 2050, and the major part of this increased demand will be for oceanic fish species, such as tuna. If Solomon Islands cannot catch more oceanic fish than otherwise harvested by foreign vessels, the country may have to import fish in large volumes to meet the projected demand.
   - Increases in the domestic supply of tuna and other oceanic species will be helpful to meet the growing demand for this category of fish. Strategies to increase domestic supply may include harvest of tuna and other oceanic pelagic species by domestic fleets, use of FADs to capture tuna and other oceanic fish in coastal waters, and onshore processing of tuna for domestic markets.

2. With adoption of climate change adaptation strategies, likely modeling outcomes are:
   - Implementation of FADs will decrease the real price of tuna in 2035 and 2050. Even with higher growth in per capita income, FADs are expected to reduce tuna prices by 2050. Given the high contribution of tuna to fish and seafood consumption in Solomon Islands, adoption of FADs is likely to substantially enhance the country's food security.

[14] Refer to Sharp (2011) for detailed discussions on the cost of FADs in the Pacific.

- The real price of coastal finfish and invertebrates are projected to rise in 2035 and 2050. Adoption of NRM strategies is likely to halt the rise of coastal finfish prices. Also, aquaculture development strategies will reduce the real price of coastal invertebrates.
- Among the various adaptation strategies considered in the modeling, adoption of FADs is likely to have the highest positive impact on oceanic fish supply, which will increase by about 9%–10% of the current level in 2035 and by about 14%–15% in 2050. Use of FADs is expected to significantly enhance the country's fisheries economy and food security.
- NRM strategies are likely to have some positive impact on coastal fish supply. The model projects that FADs may have a negative impact on coastal fisheries supply, because of the substitution effect between coastal and oceanic fish supplies.
- Aquaculture development will increase consumption of freshwater fish in 2035 and 2050. This impact will increase over time, along with per capita real income. Although FADs and NRM may not increase fish consumption, increased fish production from these strategies are likely to replace imports with domestic supply.
- Among various adaptation strategies examined, FADs are expected to significantly reduce the country's likely dependence on fish imports. The role of FADs will be even more important if the country's per capita real income rises at a faster rate.
- The national-level net economic gains were calculated at $ 0.37 million for aquaculture, $10.08 million for FAD, and $2.57 million for NRM strategies in 2050 (in 2009 constant price). Of these three climate change adaptation strategies, FAD appears to be the most economically viable adaptation strategy for Solomon Islands. Modeling results indicated that an annual investment of about $230,000 will eventually generate annual income of more than $7 million in 2035.

5. CASE STUDY: VANUATU[15]

A. Overview of Fisheries Sector

Among the Melanesian countries, Vanuatu has the smallest total water area and exclusive economic zone of 680,000 square kilometers (km^2) (Table 1.1). Fisheries resources supplied an average of 1.3% to the total gross domestic product in 2000–2008 (Gillett 2009; Ahmed et al. 2011) and provided an estimated $62.7 million in fish exports in 2007 (Gillett 2009). Four species of tuna dominate fish exports within Vanuatu's exclusive economic zone: bigeye, yellowfin, skipjack, and albacore (FAO 2010c). Approximately 72% of the country's rural households are involved in some form of fishing (FAO 2010c).

Gillett (2009) categorized Vanuatu's fisheries resources into six groups: coastal commercial fisheries, coastal subsistence fisheries, offshore foreign-based fisheries, offshore locally based or domestic fisheries, freshwater fisheries, and aquaculture. Unlike Fiji and Solomon Islands, the highest value of fish harvest in Vanuatu is in coastal subsistence fisheries, which yielded $5.74 million (2,830 metric tons [t]) in 2007. The same year, the fish harvests of offshore foreign-based vessels (12,858 t) were valued at $2.6 million; coastal commercial fisheries (538 t), $2.18 million; aquaculture (31 t and 2,500 pieces), $0.39 million; and freshwater fisheries (80 t), $0.17 million (Gillett 2009).

B. Common Fishing Practices and Gears

1. Offshore capture fisheries

Survey results from the expert opinion survey (EOS) and focus group discussion (FGD) carried out in 2012 showed that long-lines and hand-lines are commonly used for offshore fisheries by both domestic and foreign-based fishing vessels. These findings were similar to those reported by Preston (1996) in addition to purse seines.

2. Coastal or inshore capture fisheries

Fishing lines, spears and masks, and reef gleaning are the most popular fishing gears used for subsistence fishing in the coastal areas, as reflected from the EOS and FGD in 2012. In addition, commercial fishers in the coastal areas apply gillnets, hand-lines, cast nets, and trolling. Preston (1996) found the same gears used by fishers along the coasts of Vanuatu.

Comparable with the other South Pacific countries, Fiji, and Solomon Islands, women and children normally practice reef gleaning to collect shells and other edible invertebrates during low tide.

In 1997, Chapman reported that fish aggregating devices (FADs) had been in operation in Vanuatu offshore waters for the previous 15 years. However, reduction in funding from both financial agencies and government institutions led to a decreased number of FADs in the 1990s, and these became totally absent in 1996–1997. In recent years, low-cost inshore FADs have been established in various areas of Vanuatu (Williams 2013).

[15] This Chapter draws extensively from Rosegrant et al. 2016.

3. *Freshwater and estuarine fisheries*

Traps and spears are the most common methods practiced by fishers in freshwater and estuarine areas in Vanuatu.

4. *Aquaculture*

Amos (2007) reported that Pacific oyster and the Malaysian freshwater prawn were introduced in the 1980s for aquaculture in Vanuatu. During their early development, oysters were grown primarily for tourism. This was followed by interest from investors that led to the establishment of the Teouma marine shrimp farm in 2004, which is currently the largest commercial farm in operation in Vanuatu. Red tilapia culture commenced in 2006, while small-scale aquaculture operations have utilized the genetically improved farmed tilapia and freshwater prawns in rural communities (VDOF 2008). Backyard tilapia farming is being carried out primarily for subsistence purposes in the country (Williams 2013).

The Vanuatu Department of Fisheries (VDOF 2008) reported that induced spawning, rearing, and reseeding of Trochus is the most extensive aquaculture activity in the country because of its importance as an export commodity. The Trochus hatchery and reseeding program started in the 1990s. Reseeding is carried out in the community reefs for replenishment and long-term sustainable reef fishery management through community-based management systems (VDOF 2008). Trochus is utilized for furniture decorations, buttons, and ornamental wares.

Other cultured species that attract the interest of investors are giant clams and corals (VDOF 2008). Additional details follow.

C. National Development Plans

The Government of the Republic of Vanuatu established the *First National Development Plan* (DP1, 1982–1986), which was primarily for the “diversification and strengthening and expansion of the productive economic base, particularly the reduction on copra dependence” (Amos 2007). The *Second National Development Plan* (DP2, 1987–1991) moved to supporting and boosting the achievements made in DP1 by focusing on human power development and improved management (Amos 2007). Under DP2, the fisheries sector focused on activities with the highest potential to generate or sustain income-generating opportunities and employment to stabilize or reduce imports, expand exports, and enhance government revenue (Amos 2007). The *Third National Development Plan* (DP3, 1992–1996) identified the Environment Unit as the “responsible entity for the coordination of all activities across sectors, government agencies, NGOs and the private sector that deal with environmental matters; it also provides technical advice and specialist attention on environmental matters" (National Planning and Statistics Office, undated in Amos 2007).

Similar to Fiji and Solomon Islands, Vanuatu developed these plans in compliance with regional and international agreements on economic development and environmental preservation. National sectoral plans further supported these objectives along the three main areas that are the major thrust of this research study (i.e., environment, marine and fisheries, and climate change). Discussions of these plans are presented in the following subsections.

1. Biodiversity and environment

The Environmental Management and Conservation Act (EMCA) No. 12 of 2002 is an "Act to provide for the conservation, sustainable development and management of the environment of Vanuatu, and the regulation of related activities" (Tavala and Hakwa 2004). The EMCA was endorsed and became a law in 2003 to provide an affordable framework for environmental protection and compliance in Vanuatu (Amos 2007). It includes a requirement for undertaking environmental impact assessments (EIAs) before commencing any development projects in the country (Tavala and Hakwa 2004; Amos 2007).

In addition to the EIA requirement, bioprospecting,[16] community conservation areas, and biodiversity are embedded in the EMCA. Bioprospecting allows communities to consider registering their conservation areas at the national level. Community conservation areas are similar to marine protected areas (MPAs). In Vanuatu, customary areas encompass both land and sea, and traditional customs of managing the resources of these areas depend on the chieftains and the communities (Valmonte-Santos, Rosegrant and Dey 2016).

2. Marine and freshwater fisheries

The Fisheries Act 1982 was enacted in 1983 and amended in 1989 to embrace and adopt regional fisheries treaties of the Government of the Republic of Vanuatu, and to add regulations and other ministerial guidelines from time to time (Amos 2007). The act, which provides for "the control, development and management of fisheries and matters related to fisheries" (Amos 2007), is currently under review.

The Fisheries Act deals with fisheries management plans, such as the 2000 *National Tuna Fishery Management Plan* (VDOF 2009b), enforced in December 2008; the *National Marine Aquarium Trade Management Plan* (VDOF 2009a); the *Trochus Management Plan (*VDOF 2003); and the *Sea Cucumber Management Plan*. The act also considers access agreements, foreign and local fishing vessel licenses, exports, investments, fishing policies on explosives and poisons, and marine reserves. The recent *FAD Management Plan* (GRV 2012) is also included under the Fisheries Act.

Subsistence fisheries from marine and freshwater ecosystems are managed through customary tenure, which is legally recognized under Chapter 12 of the Vanuatu Constitution (Hickey and Johannes 2002). As mentioned earlier, MPAs fall under customary tenure and traditional laws.

Aquaculture was initiated in Vanuatu in the 1970s with the introduction of oysters from Japan and the United States (VDOF 2008). From then on, other species were cultured in rivers, ponds, or marine waters. Culture species are classified based on high-, medium-, and low-priority species. Classifications are based on technology, capital, marketing, food security, and restocking of cultures (VDOF 2008). High-priority species are marine shrimps, giant clams, freshwater prawns, tilapia, Trochus, green snails, and corals. Medium-priority species, for which technologies are under development, include sea cucumber, eel, and mud crab. For low-priority species, available natural seed supply, existing technologies, market access, and cultural perceptions place them at a relative disadvantage for producers (VDOF 2008). The *Vanuatu*

[16] "Bioprospecting means any activity undertaken to harvest or exploit all or any of the following: (a) samples of genetic resources; (b) samples of any derivatives of genetic resources; (c) the knowledge, innovations, and customary practices of local communities associated with those genetic resources; for purposes of research, product development, conservation or industrial or commercial application, and includes investigative research and sampling, but does not include customary uses of genetic resources and derivatives" (Tavala and Hakwa 2004).

Aquaculture Development Plan 2008–2013 was designed to identify and address the needs of the critical areas to produce development frameworks for high-priority species (VDOF 2008).

3. Climate change

The Republic of Vanuatu ratified the United Nations Framework Convention on Climate Change (UNFCCC) on March 9, 1993 (Valmonte-Santos, Rosegrant and Dey 2016). During the last quarter of 1999, Vanuatu presented its *Initial National Communication to the UNFCCC* and facilitated the development of institutional set-ups to ensure mainstreaming climate change into national legal frameworks (GRV-NACCC 2009). In 2001, Vanuatu ratified the Kyoto Protocol and was also a party to other UN conventions (GRV-NACCC 2009).

Vanuatu has a number of national programs and projects addressing climate change. These include programs to reduce and/or mitigate greenhouse gas emissions; impacts on health, biosafety, and biological diversity; persistent organic pollutants; desertification; and programs related to the *Second National Communication to the UNFCCC* (GRV under preparation).

The *Vanuatu National Adaptation Programme of Action* (NAPA) was developed by the Vanuatu National Meteorological Services under the supervision of the National Advisory Committee on Climate Change (NACCC) to identify and organize countrywide adaptation project-based activities in response to the extreme effects of climate change (GRV-NACCC 2009). NAPA will also characterize and prioritize adaptation strategies based on the urgency and applicability of these strategies at the grassroots level, where most impacts are felt. NAPA is intended to increase the awareness, understanding, and dissemination of relevant information on the potential adverse effects of climate change, and thus expedite open dialogue and consultation at all levels of society.

At the international level, NAPA is Vanuatu's direct response to the UNFCCC, recognizing the extreme effects of climate change and the adaptation strategies for addressing them. Priority sectors identified under NAPA are agriculture and food security (preservation, processing, and marketing, modern and traditional practices, bartering); water management policies and programs (including rainwater harvesting); sustainable tourism; community-based marine resource management programs (modern and traditional, aquaculture); and sustainable forestry management (GRV-NACCC 2009).

D. Modeling the Effects of Climate Change and Climate Change Adaptation Strategies

Similar to Fiji and Solomon Islands, we used data from both primary and secondary sources to run the fisheries sector model in Vanuatu. Primary data were collected through the EOS and FGD. Questions from the EOS survey were discussed and sent to VDOF staff, as well as PFO staff in the Luganville provincial capital, Sanma province, and Santo Island in August 2012. Another round of discussions was carried out with the PFO staff in October 2012. A field visit to Sanma was made to conduct an FGD survey for capture fishers in Port Olry, Luganville, on 29 August 2012. Survey participants included the leaders of various groups from the coastal village. An FGD survey for fish farmers was conducted on 24 October 2012.

Over the last four years (2009–2012), real per capita income in Vanuatu grew by –0.9% to +0.9% (World Bank 2013). For both the medium term (2035) and long term (2050), we implemented two baseline (most plausible) scenarios representing two annual growth rates of real per capita income: medium (1.5% per year) and high (2.5% per year). We assumed populations of 424,122 in 2035 and 538,707 in 2050. During the validation meeting organized by the project on 17 June 2013 in Vanuatu, experts suggested that if no adaptation strategy is applied, in 20 years, coastal marine resources will be depleted by 15%–20% as a result of increasing population and climate change. We implemented the baseline models with the assumption that coastal fisheries harvest will decline by 10% in 2035 and by 15% in 2050.

The validated baseline data (production, consumption, trade, and price), supply elasticities, and demand elasticities used in the Vanuatu model are presented in Appendix Tables A.9, A.10, and A.11, respectively. The supply quantities reported in Table A.9 do not include catch by foreign fleets, which is small in Vanuatu. The supply volumes reported in the Table A.9 and used in the analysis include catch by national fleets in both national and international waters. The fish demand elasticities used in the model reflect consumers' preference patterns in Vanuatu and the substitutability of various fish products with other sources of animal protein in the country. We have also used alternative sets of elasticities to test the sensitivity of our modeling results, but those detailed results have not been presented in this report for the sake of brevity. As in other countries, variation in elasticities within a feasible range does not change the results.

Vanuatu has adopted four main climate change adaptation strategies: (1) aquaculture (coastal and freshwater); (2) regulations concerning habitat protection in MPAs, seasonal closure, traditional management of natural resources, control of critical species (sea cucumber, Trochus, parrot fish, giant clam), and selective control of fishing methods and gears; (3) low-cost FADs; and (4) implementation of the ridge-to-reef concept.

Given that many of these strategies are still in the formative stage, we modeled three climate change adaptation scenarios combining some of the strategies mentioned above. Scenario 1 (aquaculture development [AQ]) involves improvements in the productivity of freshwater (both finfish and invertebrate) aquaculture. Scenario 2 (natural resource management [NRM] particularly MPAs and LMMAs + FAD) addresses the changes in production and productivity in coastal and oceanic capture fisheries resulting from FADs, various management regime shifts, and adoption of resource enhancement practices. Scenario 3 is a combination of scenarios 1 and 2.

Appendix Table A12 reports the coefficients of supply shifters that were used in the Vanuatu model to represent climate change and climate change adaptation strategies. The coefficients for climate change, as reported in column 2 and column 6 of Table A.12, were taken or modified from Bell et al. (2011b), Gehrke et al. (2011), Lehodey et al. (2011), Pichering et al. (2011), and Prachett et al. (2011)[17]. Climate change is likely to have positive effects on tuna and oceanic fish production (Lehodey et al. 2011) and negative effect on coastal fish production (Prachett et al. 2011) in Vanuatu.

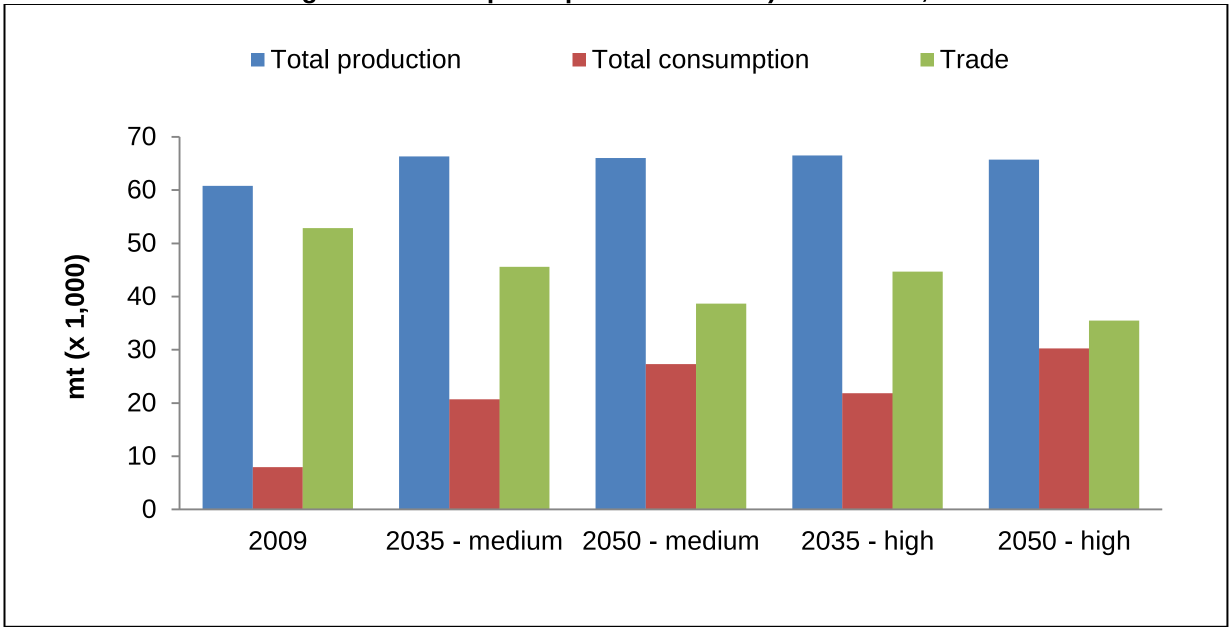
The likely effects of various climate change adaptation strategies on fish production, as reported in columns 3, 4, 5, 7, 8, and 9 of Table A.12, were collected through the EOS and FGD. The use of FADs is expected to increase tuna and other oceanic fish catch in coastal waters. On the other hand, various NRM strategies (such as MPAs and LLMAs) are likely to mitigate some of the negative effects of climate change on coastal fisheries. Therefore, NRM and FAD strategies are expected to increase the supply of all four capture fisheries groups (tuna, other oceanic species, coastal finfish, and coastal invertebrates) and to shift their supply curves to the right.

[17] Bell et al. (2011a), Gehrke et al. (2011), Lehodey et al. (2011), Pichering et al. (2011), and Prachett et al. (2011) focus on 2035 and 2100, but do not have climate change scenarios for 2050. We generated the data for 2050 from the data ranges for 2035 and 2100, based on the opinions of the experts in Vanuatu and the Pacific region.

1. Effects of climate change on production, consumption, and trade (baseline scenario)

Figure 5.1 shows the projected production, consumption, and net trade of fish aggregate[18] in Vanuatu for 2035 and 2050 under two baseline scenarios, with 1.5% and 2.5% annual growth rates of real per capita income. Currently, Vanuatu is a net exporter of fish and seafood, with domestic production far exceeding domestic consumption. The model analysis projects that the aggregated fish consumption in Vanuatu will rise substantially in 2035 and 2050, but the country will remain a net exporter by 2050.

Figure 5.1
Projected Fish Production, Consumption, and Trade under Two Baseline Scenarios (1.5% and 2.5% annual growth rate of per capita real income) in Vanuatu, 2035 and 2050

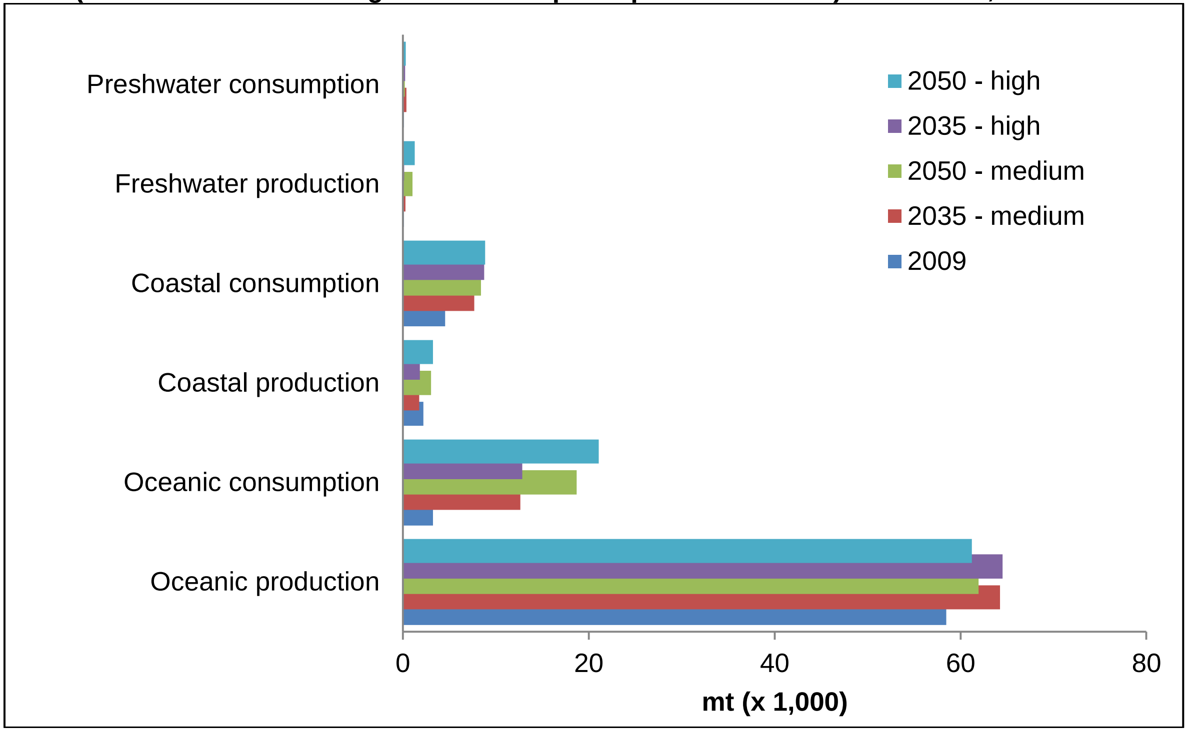


medium = 1.5% annual growth rate of per capita real income; high = 2.5% annual growth rate of per capita real income.
Source: Model projections.

As shown in Figure 5.2, the performance of various fisheries subsectors will not be uniform. During 2010–2050, production of oceanic fish is expected to increase, but production of coastal fish is projected to decline. Though the consumption of oceanic fish is expected to rise at a faster rate than any other sector, the model predicts that the oceanic fisheries sector will continue to be a net exporter. However, Vanuatu will have to import coastal fish to meet the increasing demand from population and income growth. Given that many of the poorer households rely on coastal fisheries for their consumption needs, this likely scenario has serious food security implications. The model projects that demand for freshwater fish will exceed domestic production in 2035 and 2050 under the baseline scenarios, and Vanuatu will need to rely on imports to meet this demand.

[18] Fish aggregate means the sum of the six fish groups (tuna, other oceanic fish, coastal finfish, coastal invertebrates, freshwater finfish, and freshwater invertebrates) of this study.

Figure 5.2
Projected Production and Consumption of Different Types of Fish under Two Baseline Scenarios (1.5% and 2.5% annual growth rate of per capita real income) in Vanuatu, 2035 and 2050



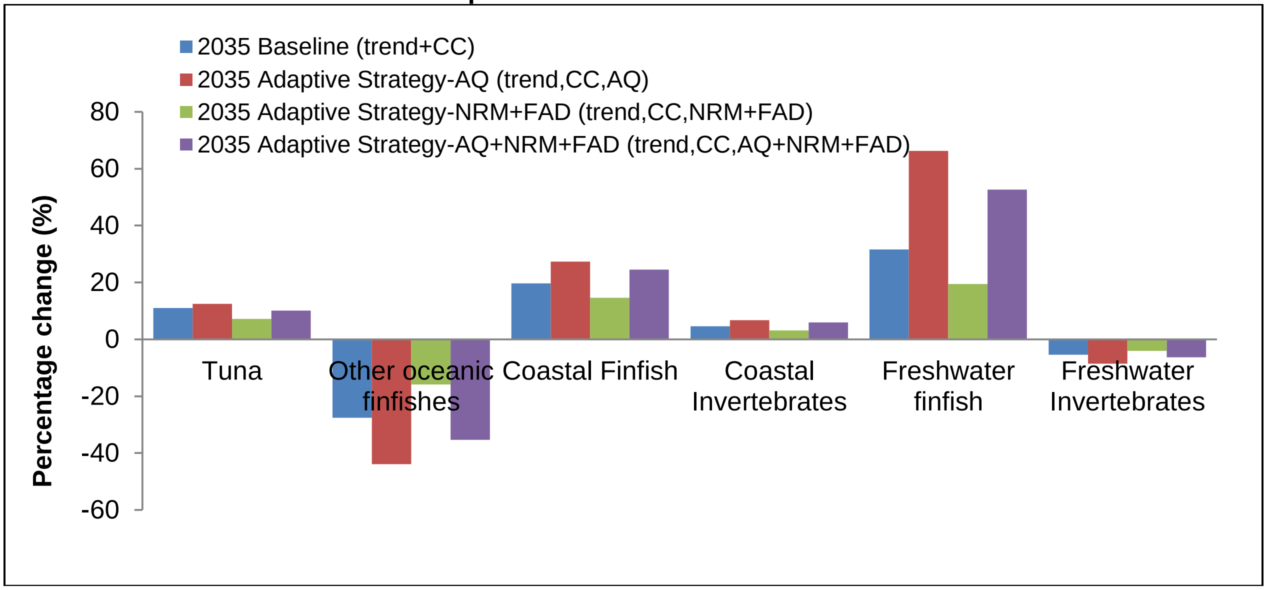
medium = 1.5% annual growth rate of per capita real income; high = 2.5% annual growth rate of per capita real income.
Reprinted from "Economic impacts of climate change and climate change adaptation strategies in Vanuatu and Timor-Leste" by Rosegrant, M.W., M.M. Dey, R.A. Valmonte-Santos, and O.L Chen, 2016. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Rosegrant et al. 2016.

2. *Effects of climate change adaptation strategies*

2.1. Changes in fish prices

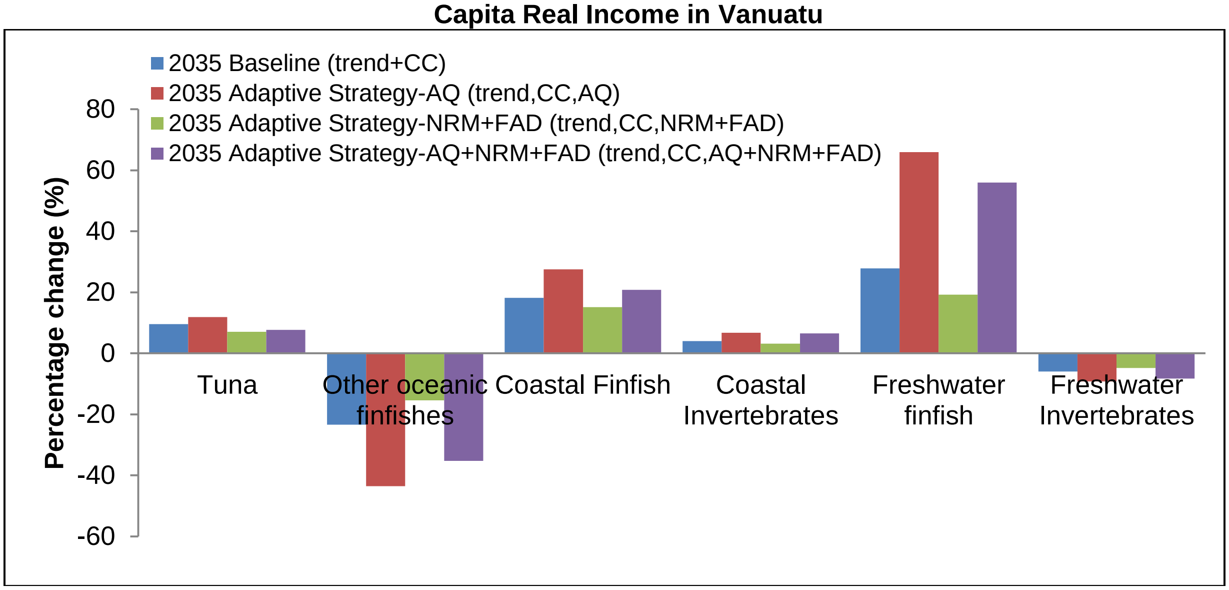
Figures 5.3 to 5.6 present the projected real prices of different types of fish in 2030 (medium-term) and 2050 (long term) under different scenarios. The model predicts that the real price of most types of fish (including coastal finfish, which contribute about 54% of current fish consumption) will increase in 2035 and 2050 under the baseline scenarios. Adoption of NRM strategies and FADs is expected to decrease the prices of tuna, coastal finfish, coastal invertebrates, and freshwater finfish in the medium term. Coastal finfish and tuna are the two most important sources of fish and seafood in Vanuatu, contributing about 77% of current consumption. Coastal finfish are widely consumed by poorer households in the country. Thus, the FAD+NRM adaptation strategy is likely to have a positive impact on poorer consumers. However, with its current pace of implementation, this adaptation strategy will not be able to halt the rise of fish prices in the long term (2050).

Figure 5.3
Percentage Change in Price from Baseline (2006–2009) to 2035 with 1.5% Annual Growth of Per Capita Real Income in Vanuatu



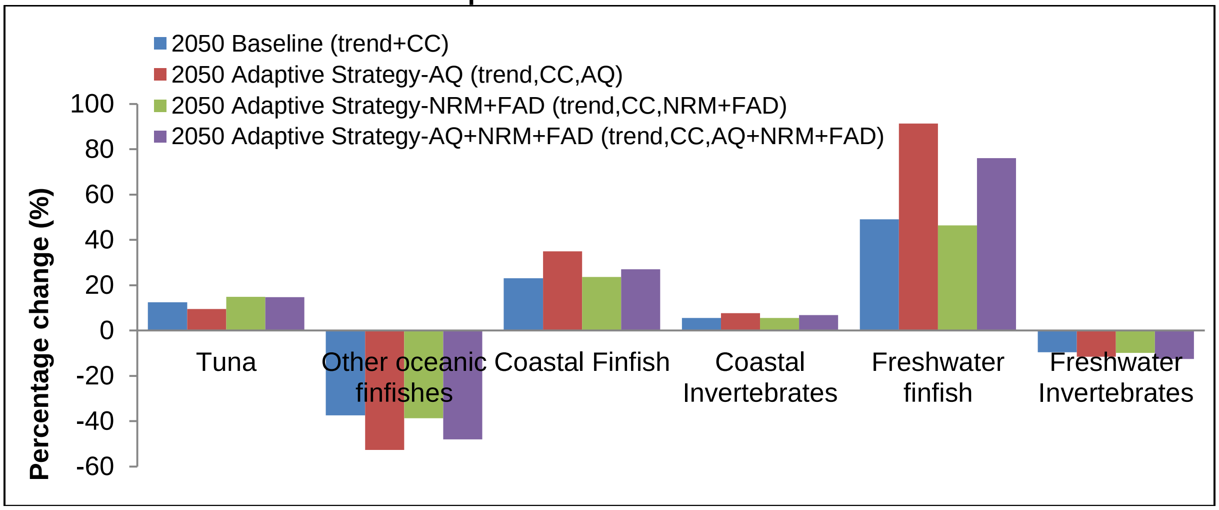
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.4
Percentage Change in Price from Baseline (2006–2009) to 2035 with 2.5% Annual Growth of Per Capita Real Income in Vanuatu



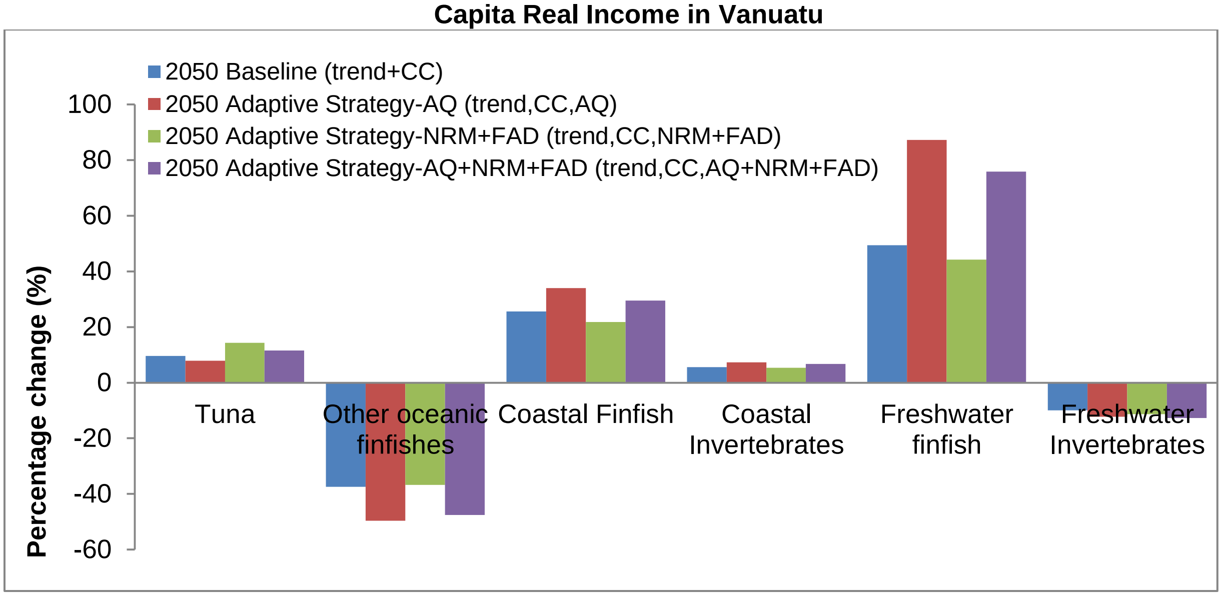
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.5
Percentage Change in Price from Baseline (2006–2009) to 2050 with 1.5% Annual Growth of Per Capita Real Income in Vanuatu



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.6
Percentage Change in Price from Baseline (2006–2009) to 2050 with 2.5% Annual Growth of Per Capita Real Income in Vanuatu

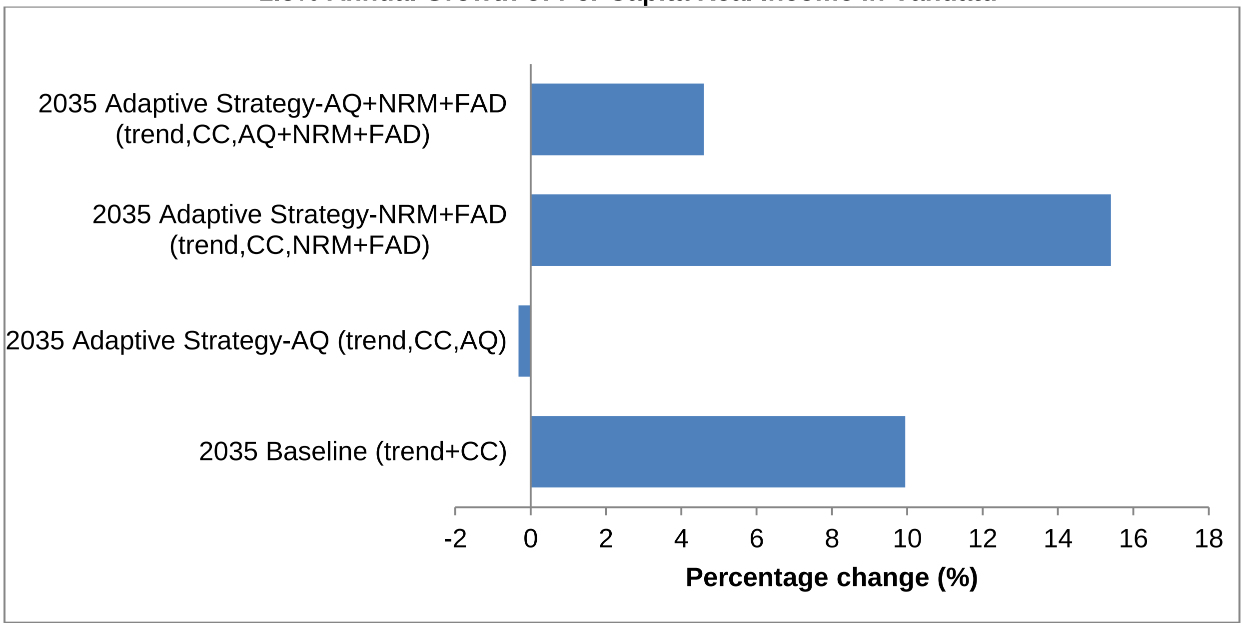


AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

2.2. Changes in fish production

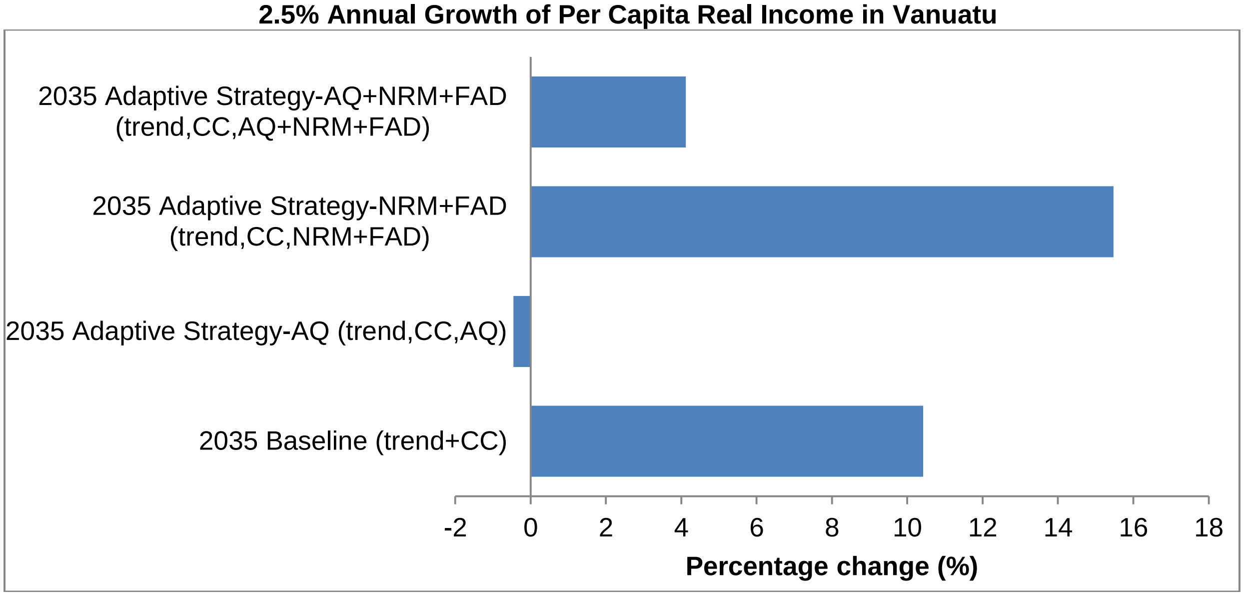
Among the various adaptation strategies examined, adoption of the FAD+NRM strategy is projected to have the highest positive impact on oceanic fish supply (Figures 5.7 to 5.10). The model results reveal that the FAD+NRM strategy is expected to increase the current supply of oceanic fish by about 14% in 2035 and about 19%–20% in 2050. As in the assessment for the other countries, that projected rate of increase in national tuna production due to increased investment in FADs is well within the sustainable tuna catch, as noted in Chapter 2 (and see Lehodey 2011; Bell 2010).

Figure 5.7
Percentage Change in Production of Oceanic Species from Baseline (2006–2009) to 2035 with 1.5% Annual Growth of Per Capita Real Income in Vanuatu



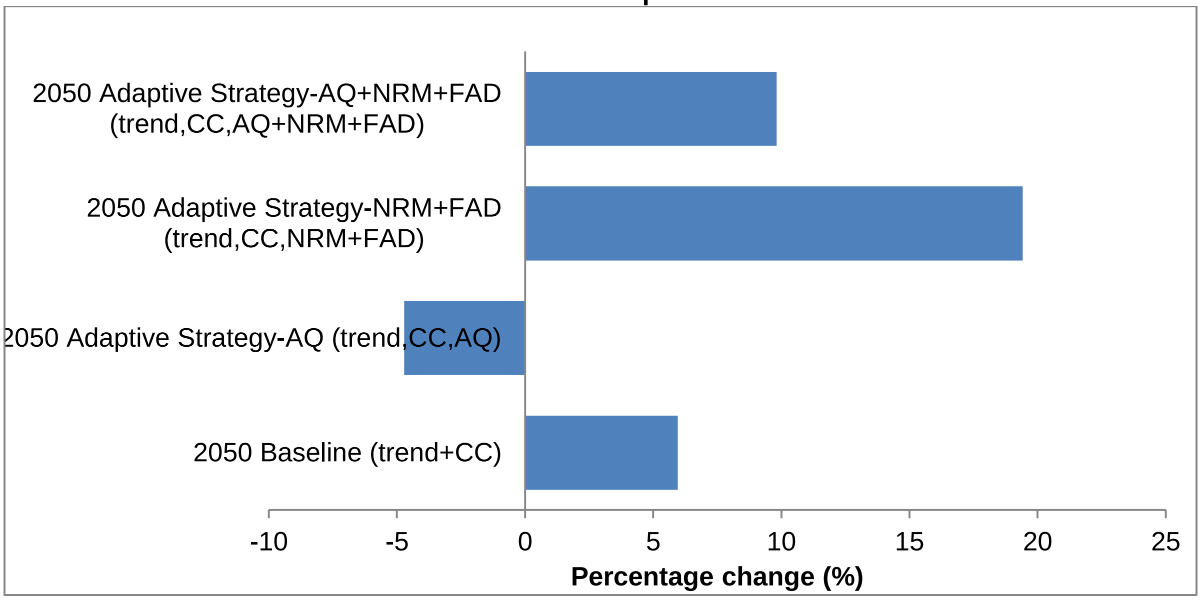
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.8
Percentage Change in Production of Oceanic Species from Baseline (2006–2009) to 2035 with 2.5% Annual Growth of Per Capita Real Income in Vanuatu



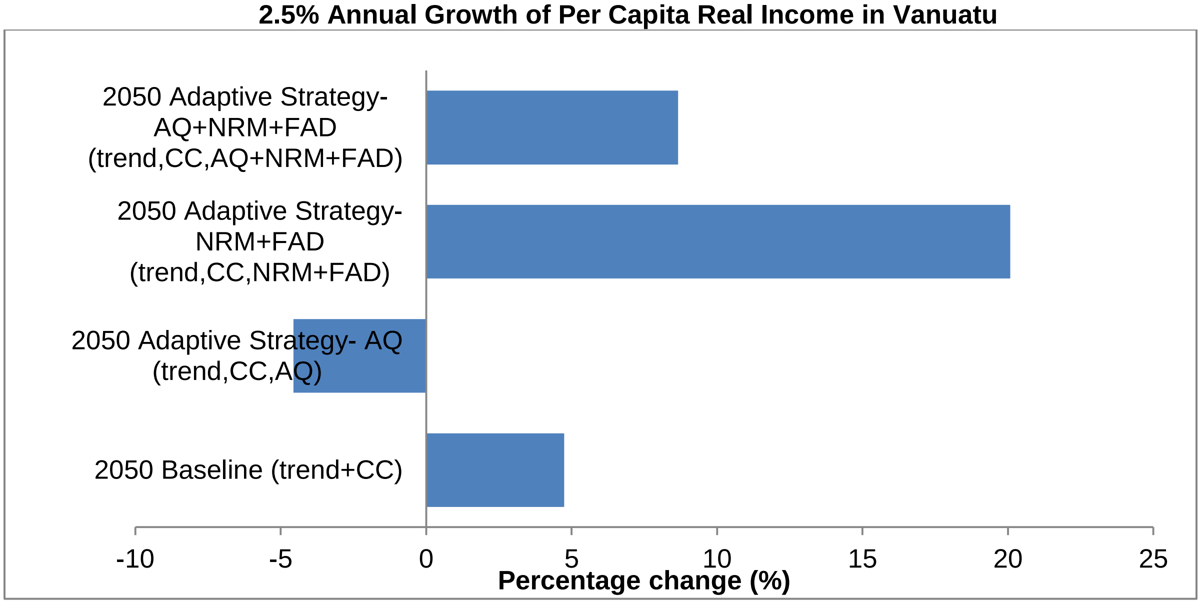
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.9
Percentage Change in Production of Oceanic Species from Baseline (2006–2009) to 2050 with 1.5% Annual Growth of Per Capita Real Income in Vanuatu



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

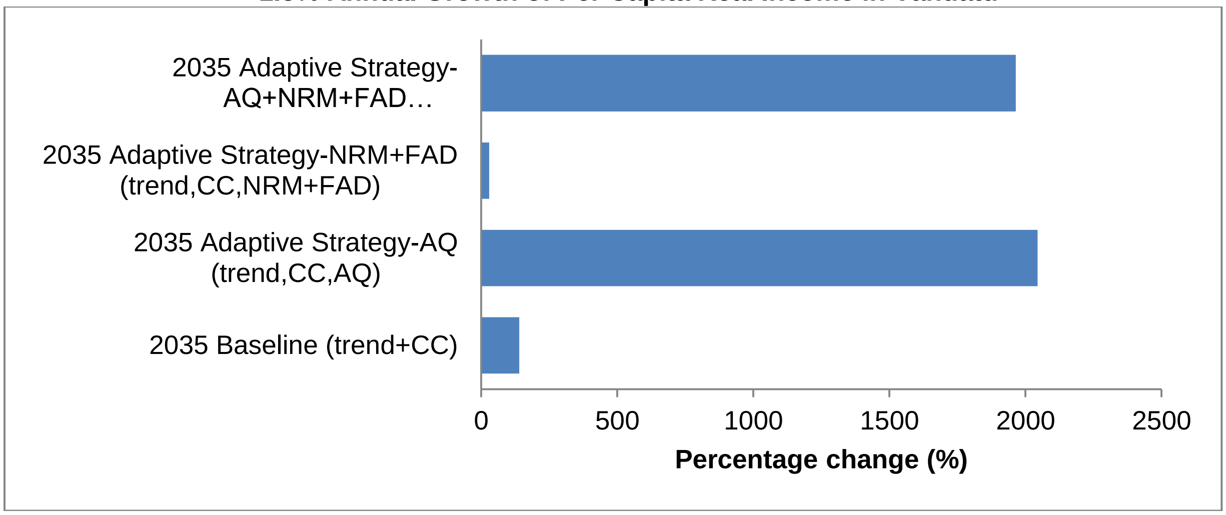
Figure 5.10
Percentage Change in Production of Oceanic Species from Baseline (2006–2009) to 2050 with 2.5% Annual Growth of Per Capita Real Income in Vanuatu



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

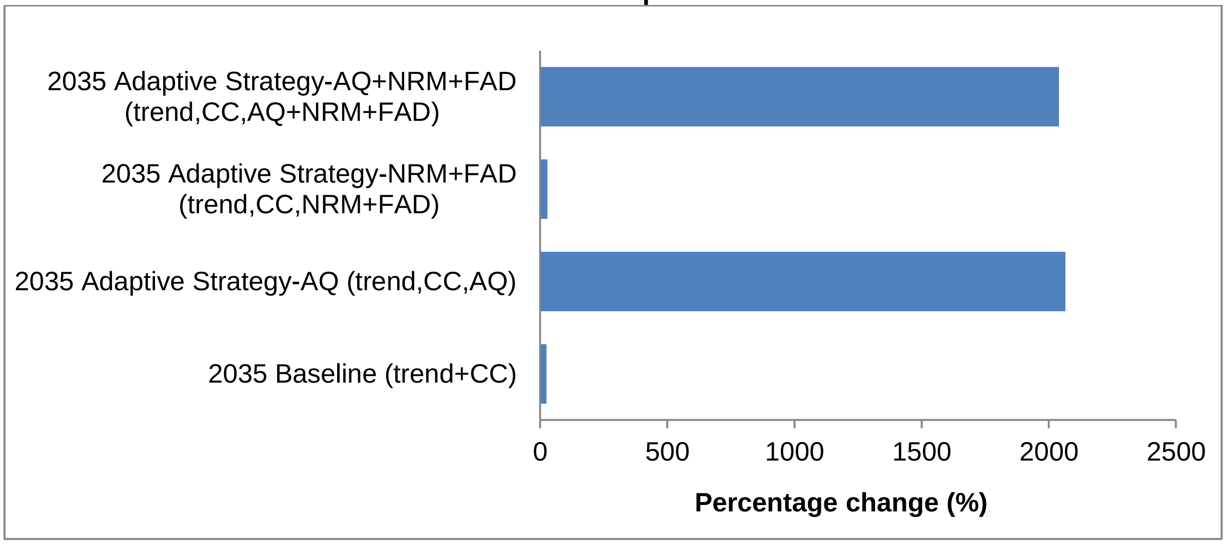
Figures 5.11 to 5.14 show the likely effects of different climate change adaptation strategies on freshwater fish production in 2035 and 2050. The freshwater and marine aquaculture sector is a minor supplier of fish in Vanuatu. The Government of Vanuatu has placed a high priority on developing the aquaculture sector (both freshwater and marine), and has taken various initiatives for improving the sector. To assess the potential for aggressive adaptation policies, we used highly optimistic productivity growth scenarios for aquaculture in the model: 75% growth in productivity from 2009 to 2035, and 125% growth from 2009 to 2050. The model projects that with this high growth, production from freshwater aquaculture is likely to increase by about 20 times in the medium term (2035) and about 30 times in the long term.

Figure 5.11
Percentage Change in Production of Freshwater Species from Baseline (2006–2009) to 2035 with 1.5% Annual Growth of Per Capita Real Income in Vanuatu



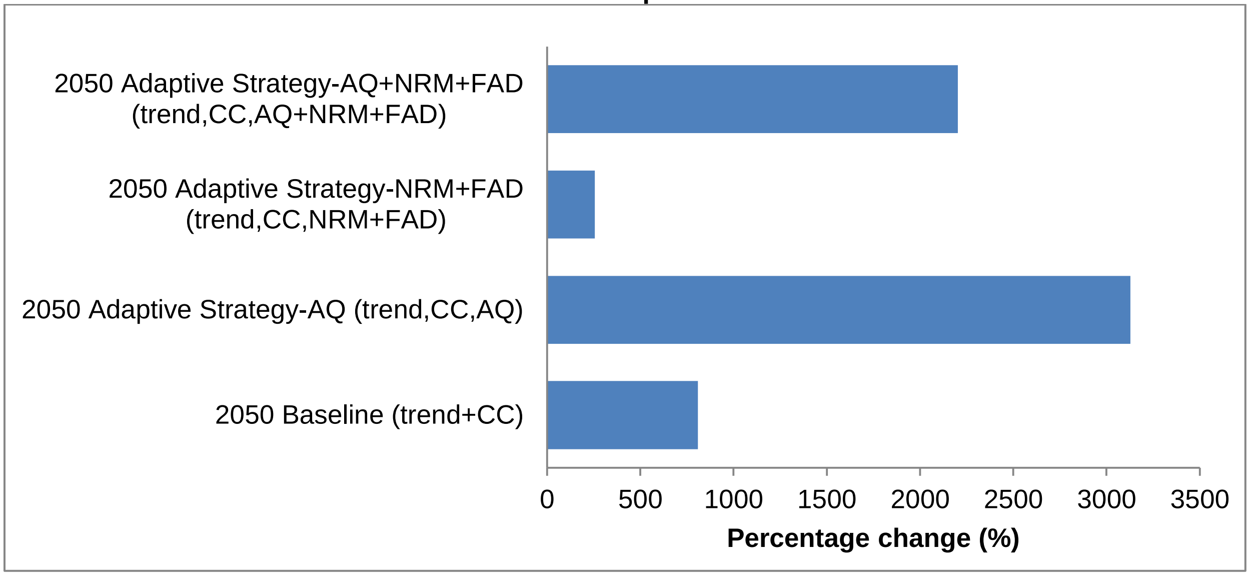
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.12
Percentage Change in Production of Freshwater Species from Baseline (2006–2009) to 2035 with 2.5% Annual Growth of Per Capita Real Income in Vanuatu



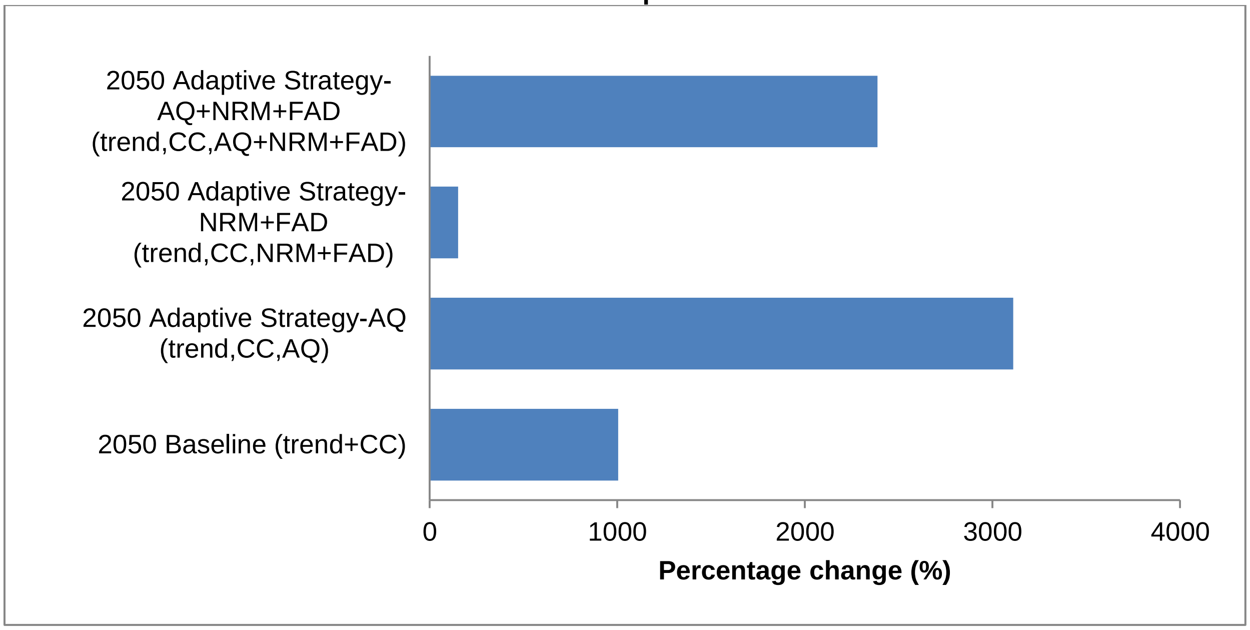
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.13
Percentage Change in Production of Freshwater Species from Baseline (2006–2009) to 2050 with 1.5% Annual Growth of Per Capita Real Income in Vanuatu



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.14
Percentage Change in Production of Freshwater Species from Baseline (2006–2009) to 2050 with 2.5% Annual Growth of Per Capita Real Income in Vanuatu

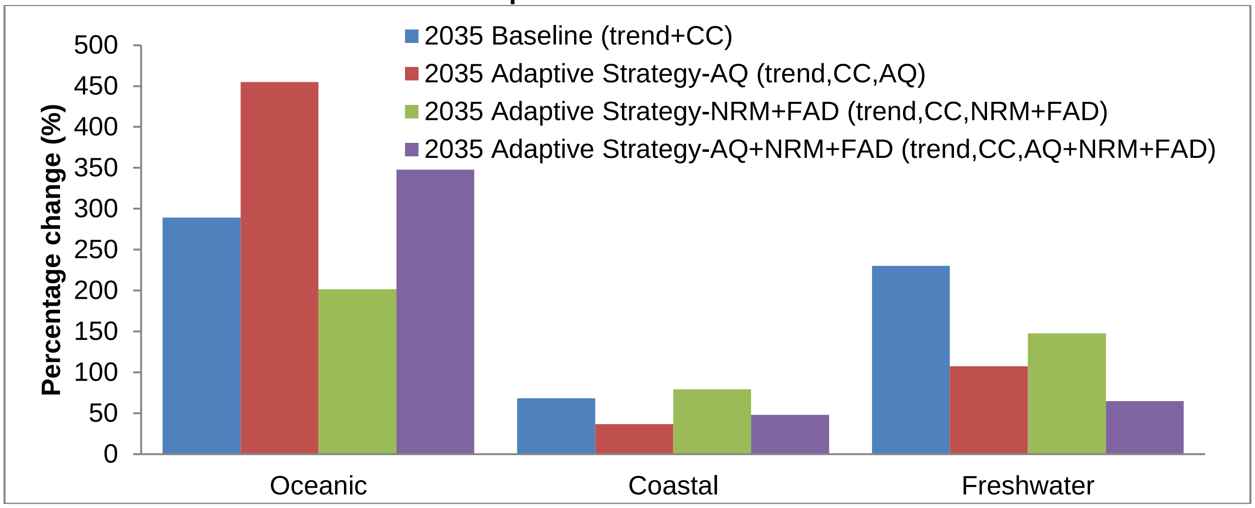


AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

2.3. Changes in fish consumption

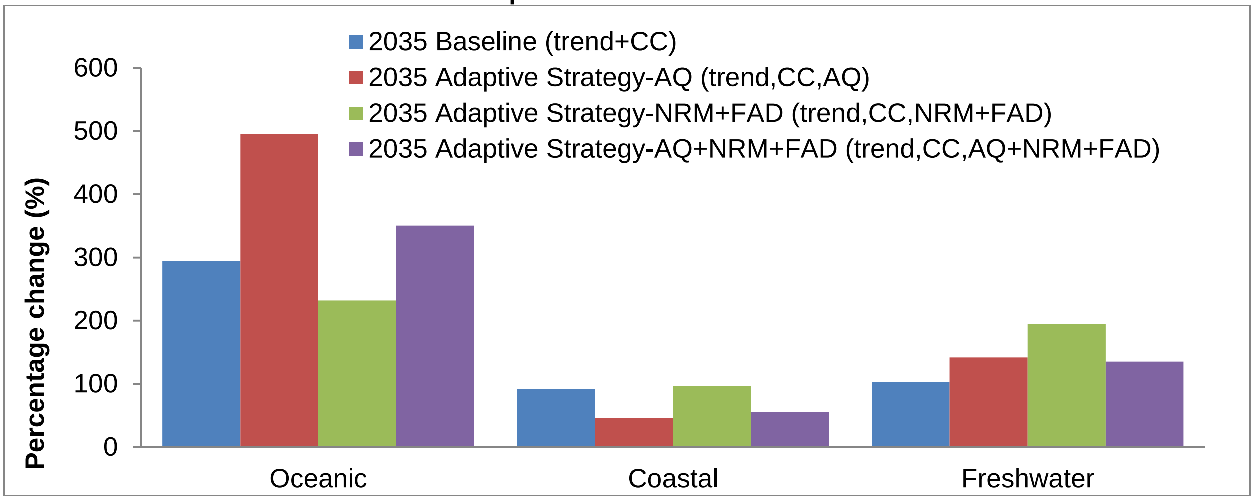
Figures 5.15 to 5.18 show projected demand for various fish categories in Vanuatu under the baseline scenarios and other adaptation strategies in 2035 and 2050. The model projects that demand for all types of fish will increase over time under the baseline scenarios, and the level of increase will be higher, with faster growth in per capita real income. Among various fish categories, tuna and other oceanic fish are expected to experience the highest increase in demand. With growth in population and income, oceanic fish demand may increase from current levels (2006–2009) by about 3 times in 2035 and about 5 times in 2050.

Figure 5.15
Percentage Change in Consumption from Baseline (2006–2009) to 2035 with 1.5% Annual Growth of Per Capita Real Income in Vanuatu



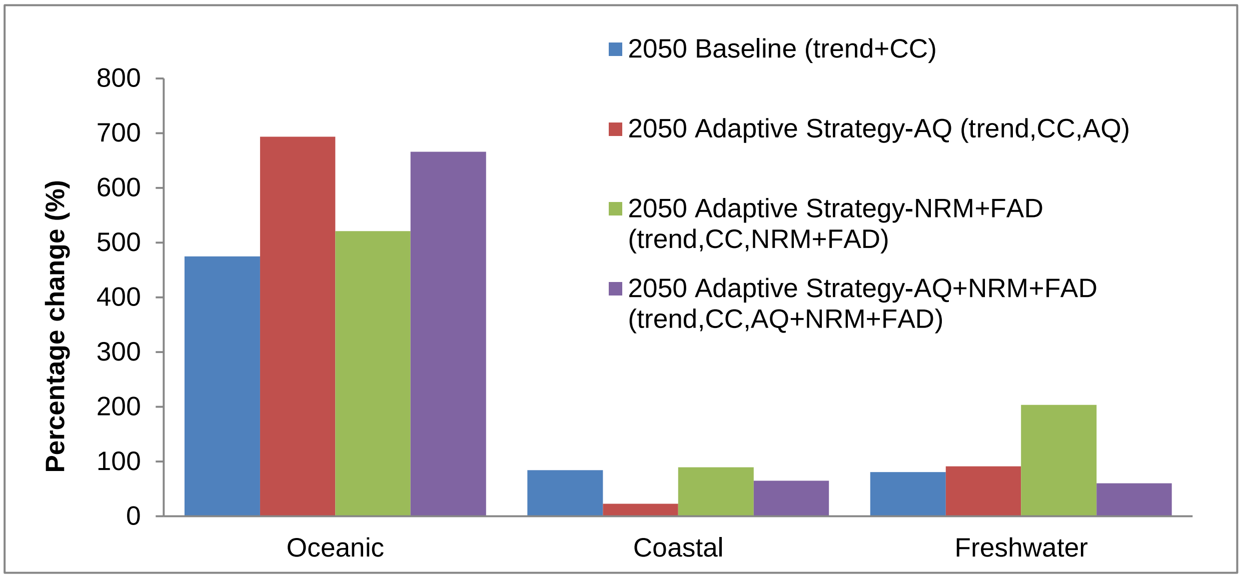
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.16
Percentage Change in Consumption from Baseline (2006–2009) to 2035 with 2.5% Annual Growth of Per Capita Real Income in Vanuatu



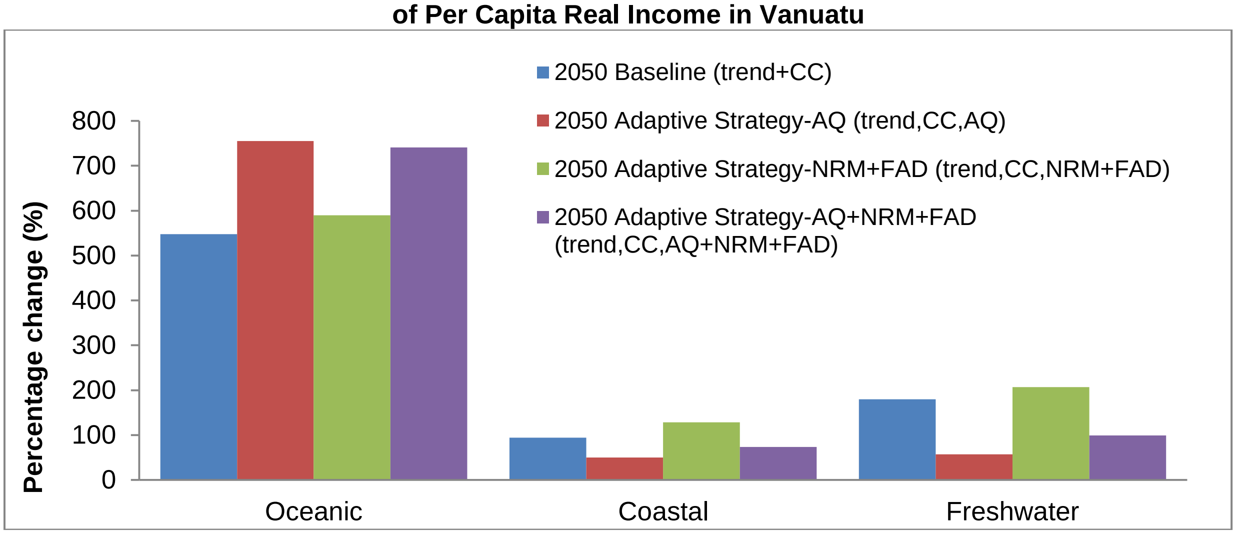
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.17
Percentage Change in Consumption from Baseline (2006–2009) to 2050 with 1.5% Annual Growth of Per Capita Real Income in Vanuatu



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.18
Percentage Change in Consumption from Baseline (2006–2009) to 2050 with 2.5% Annual Growth of Per Capita Real Income in Vanuatu



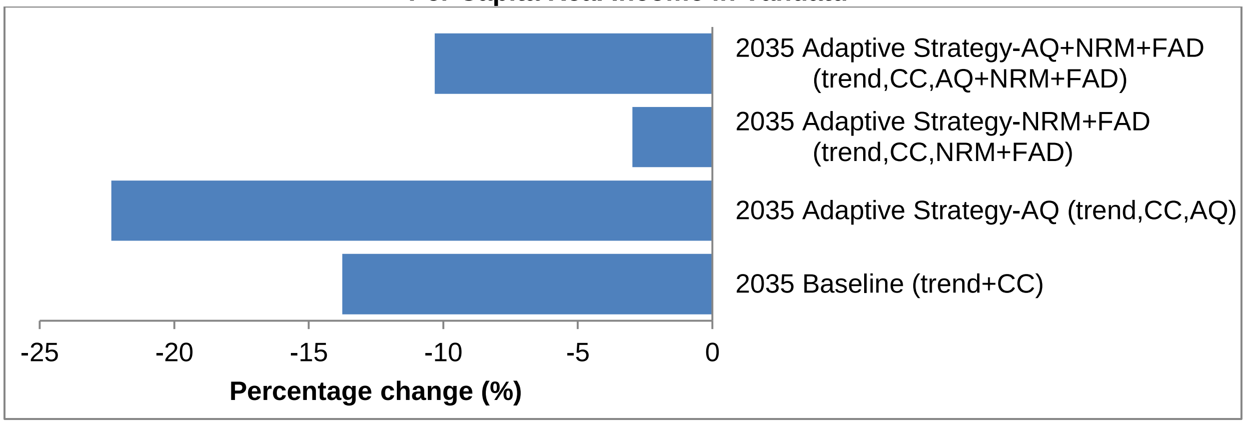
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Among various climate change adaptation strategies, expanding aquaculture is likely to increase demand for tuna and other oceanic fish, mainly as a result of higher income from aquaculture growth. The model predicts that the NRM+FAD strategy will increase demand for all categories of fish in the long term and for coastal and freshwater fish in the medium term. The NRM+FAD strategy is likely to increase consumption through expected reduction in the real price of these fish categories (Figures 5.3 to 5.6).

2.4. Changes in net trade (export minus import)

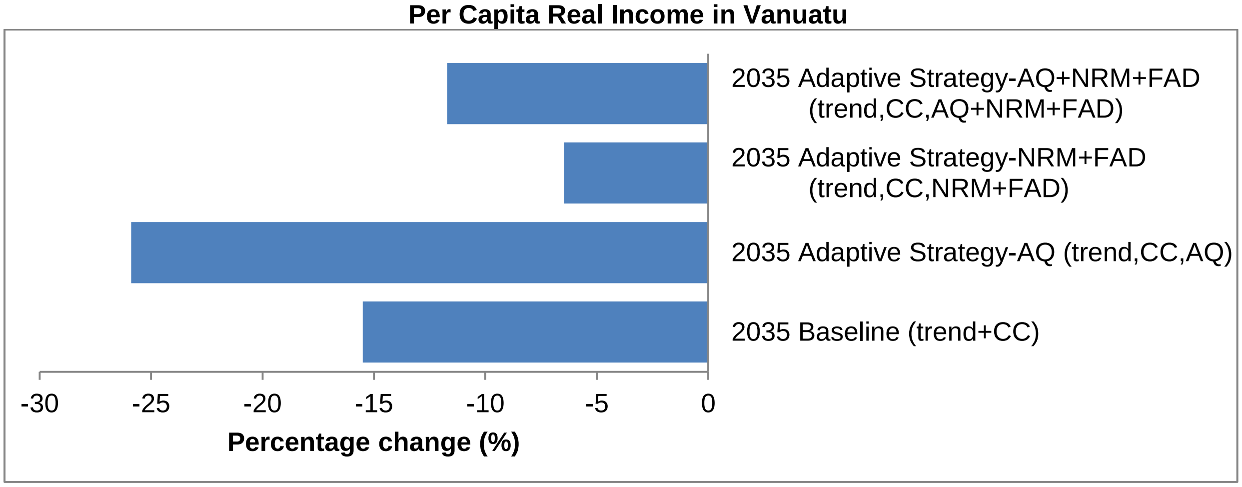
Figures 5.19 to 5.22 show the projected effects of different climate change adaptation strategies on fish trade in Vanuatu in the medium term (2035) and long term (2050). Though Vanuatu is expected to remain a net exporter of fish in the long term, the volume of net exports (export minus import) is likely to decrease over time under the baseline scenarios (Figure 5.1). Thus, the volume of net imports is expected to increase with higher growth in real income.

Figure 5.19
Percentage Change in Net Trade from Baseline (2006–2009) to 2035 with 1.5% Annual Growth of Per Capita Real Income in Vanuatu



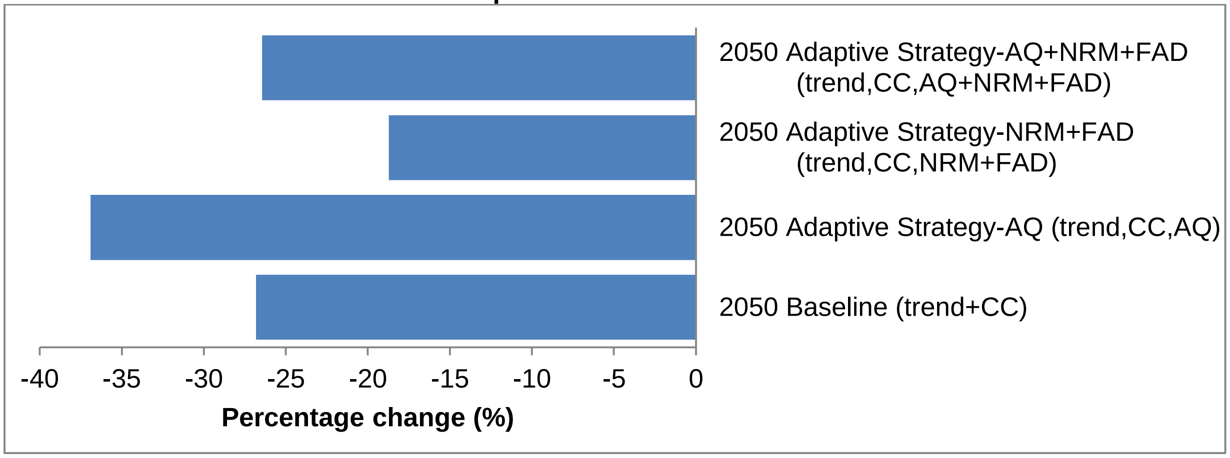
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.20
Percentage Change in Net Trade from Baseline (2006–2009) to 2035 with 2.5% Annual Growth of Per Capita Real Income in Vanuatu



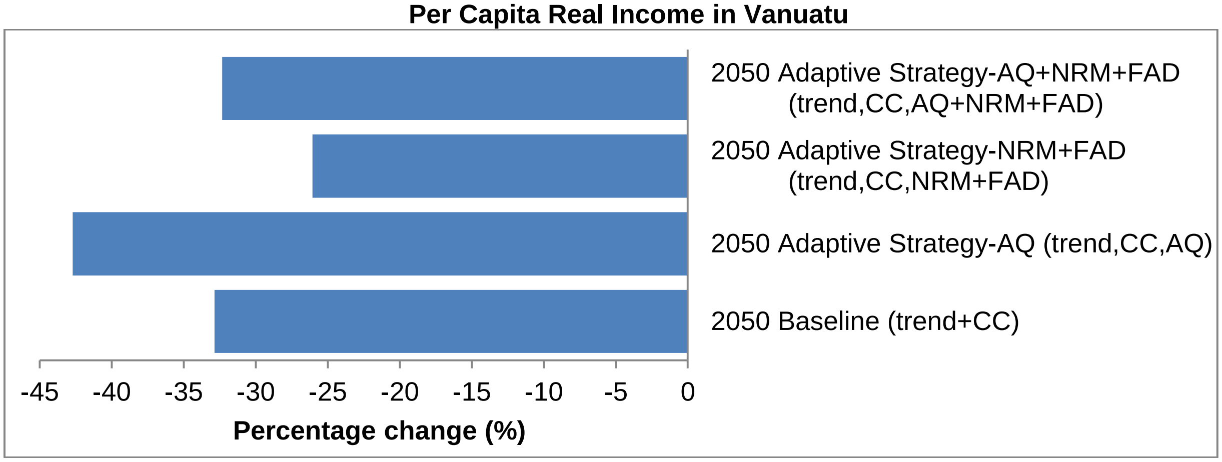
AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.21
Percentage Change in Net Trade from Baseline (2006–2009) to 2050 with 1.5% Annual Growth of Per Capita Real Income in Vanuatu



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 5.22
Percentage Change in Net Trade from Baseline (2006–2009) to 2050 with 2.5% Annual Growth of Per Capita Real Income in Vanuatu



AQ = aquaculture development; CC = climate change; FAD = fish aggregating device; NRM = natural resource management.
Source: Rosegrant et al. 2016.

2.5. National-level economic gains resulting from climate change adaptation strategies

Table 5.1 reports the estimated national-level net economic gains to both consumers and producers from adopting various climate change adaptation strategies in Vanuatu. These estimates show that substantial net incomes are likely to be generated. Both the aquaculture and the NRM+FAD strategies are expected to generate several million dollars in annual net incomes in both the short and long terms. Even under very generous estimates of costs and conservative estimates of returns, the yearly net returns from these adaptation strategies are likely to be at least 20- to 50-fold higher than their yearly investment costs[19].

[19] *See* Pascal, Seidl, and Tiwok (2012) for details on the cost of MPAs and LLMAs, and Sharp (2011) for details on the cost of FADs in the Pacific.

Table 5.1
National-Level Economic Gain (equivalent variation) Resulting from Climate Change Adaptation Strategies in Vanuatu

Climate Change Adaptation Strategy	Economic Gain per Year (US$ in 2009 prices) 2035	2050
Aquaculture	4,093,545	4,531,688
NRM + FAD	17,488,902	34,594,460
Aquaculture + NRM + FAD	22,262,116	38,247,642

FAD = fish aggregating device; NRM = natural resource management.
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Source: Rosegrant et al. 2016.

E. Summary

The review and analysis of available literature; the discussions at the national, provincial, and community levels through the EOS and FGD; and the modeling results and assessment carried out for this study generated key messages for Vanuatu Islands with and without climate change adaptation strategies.

1. The baseline scenario predicted the following likely situations:
   - Currently, Vanuatu is a net exporter of fish and seafood, with domestic production far exceeding domestic consumption. Aggregate fish consumption in Vanuatu is projected to rise substantially in 2035 and 2050, but the country will remain a net exporter by 2050.
   - During 2010–2050, production of oceanic fish is expected to increase, but production of coastal fish is expected to decline.
   - Though the consumption of oceanic fish is expected to rise at a faster rate than any other sector, the model predicts that this fisheries sector will continue to be a net exporter.
   - However, Vanuatu will most likely have to import coastal fish to meet the increasing demand from population and income growth. Given that many of Vanuatu's poorer households rely on coastal fisheries for their consumption needs, this likely scenario has serious food security implications.
   - The model projects also that demand for freshwater fish will exceed domestic production in 2035 and 2050, and Vanuatu will need to rely on imports to meet this demand.

2. With adoption of climate change adaptation strategies, likely modeling outcomes are:
   - The real price of most types of fish—including coastal finfish, which contribute about 54% of current fish consumption—will increase in 2035 and 2050 under the baseline scenarios. However, adoption of NRM strategies and FADs is expected to decrease the prices of tuna, coastal finfish, coastal invertebrates, and freshwater finfish in 2035. Coastal finfish and tuna are the two most important sources of fish and seafood in Vanuatu, contributing about 77% of current consumption. Because coastal finfish are widely consumed by Vanuatu's poorer households, the FAD+NRM adaptation strategy is likely to have a positive impact on these consumers. However, with its current pace of implementation, this adaptation strategy will not be able to halt the rise of fish prices in 2050; more aggressive investments are required.
   - Adoption of the FAD+NRM strategy will have the highest positive impact on oceanic fish supply. This strategy is expected to increase the supply of oceanic fish by about 14% from the present (2006–2009) level in 2035 and by about 19%–20% in 2050.

- Demand for all types of fish will increase over time under the baseline scenarios, and the level of increase will be higher with faster growth in per capita real income. Among various fish categories, tuna and other oceanic fish are expected to experience the highest increase in demand. With growth in population and income, oceanic fish demand may increase by about 3 times in 2035 and about 5 times in 2050.
- Projected higher income from aquaculture development is likely to increase the demand for tuna and other oceanic fish. The model predicts that the NRM+FAD strategy will increase demand for all categories of fish in 2050 and for coastal and freshwater fish in 2035. The NRM+FAD strategy is likely to increase consumption through expected reduction in the real price of these fish categories.
- With higher income from aquaculture development, Vanuatu's net export is predicted to decrease. The FAD+NRM strategy is projected to reduce the country's fish imports and to increase its net exports.
- The calculated values of national-level economic gains are $4 million for aquaculture, $18 million for NRM+FAD, and $22 million for AQ+NRM+FAD (in 2009 US$ constant price) in 2035; and $4.5 million for aquaculture, $35 million for NRM+FAD, and $38 million for AQ+NRM+FAD (in 2009 US$ constant price) in 2050.

6. CASE STUDY: TIMOR-LESTE[20]

A. Overview of Fisheries Sector

Information on the fisheries sector of Timor-Leste, is scanty, as the country only gained its independence in 2002 (Valmonte-Santos, Rosegrant and Dey 2016). Prior to independence, most information and data are highly aggregated from Indonesia; hence, assessing Timor-Leste's fisheries sector is difficult (FAO 2010d).

Timor-Leste has a total land area of approximately 14,874 square kilometers (km^2) (Table 1.1). Unlike Fiji, Solomon Islands, and Vanuatu, which have numerous islands, Timor-Leste has only two islands: the 144-km^2 Atauro Island and the 8-km^2 Jaco Island at (NCTICCTL 2012). The country has an exclusive economic zone of 72,000 km^2 (FAO 2010d), with GDP contribution of $5.7 million in 2004 (GDRTL-SSF 2006).

In 2008, Timor-Leste's fisheries sector employed 7,600 people, including aquaculture (FAO 2010d). The country's most dominant fish category is coastal fisheries for small-scale fishing activities, due to the absence of domestic commercial fishing vessels exploring offshore fishing grounds (Valmonte-Santos, Rosegrant and Dey 2016). To augment this, Timor-Leste signed bilateral agreements in the mid-2000s allowing foreign fishing vessels limited access to fish in the country's deep-sea fishing grounds, with the conditions that fish landings and shipment should be conducted through Timor-Leste ports (FAO 2010d). However, noncompliance led to the cancellation of these agreements (Valmonte-Santos, Rosegrant and Dey 2016). Freshwater fishing is restricted during monsoon season and is mostly for subsistence.

The Government of the Democratic Republic of Timor-Leste has identified aquaculture as a means to improve food and nutrition security, as well as an income-generating activity for both inland and coastal communities. Because of its cost and infrastructure needs, aquaculture is predominantly a government-led activity (Valmonte-Santos, Rosegrant and Dey 2016), with assistance from other international research agencies.

B. Common Fishing Practices and Gears

1. Offshore capture fisheries

To date, there is no information on offshore fishing practices and gears due to the absence of offshore domestic fishing vessels.

2. Coastal or inshore capture fisheries

Based on information from the focus group discussion (FGD) conducted in 2012, the traditional fishing gears in coastal areas of Timor-Leste are gillnets, fish traps, hook-and-line, and spear guns. In addition, FAO (2010d) identified crab pots and small enclosing nets as other fishing gears. Nets, including hand nets and trammel nets, are provided by the National Directorate of Fisheries and Aquaculture (NDFA) via the fisher's assistance program (Stacey et al. 2011).

Similar to Fiji, Solomon Islands, and Vanuatu, reef gleaning, spears, and skin diving are applied to collect shells, small fish, and other invertebrates. Women and children carry out reef gleaning

[20] This Chapter draws considerably from Rosegrant et al. 2016.

during low tide, although the major fishing activities of women are fish processing and selling (Valmonte-Santos, Rosegrant and Dey 2016).

Fish aggregating devices (FADs) and marine protected areas (MPAs) continue to be prevalent in Timor-Leste. These activities and responsibilities fall with the NDFA and are implemented in collaboration with other international and regional research agencies.

3. Freshwater and estuarine fisheries

Information on specific fishing gear used in streams and rivers of Timor-Leste is lacking.

4. Aquaculture

Aquaculture began in 1987 for milkfish culture and shrimp (Andrew, Suan Pheng, and Philips 2011). In 1989, seaweed farming commenced and became the dominant cultured crop, supporting around 257 households and livelihoods for 1,255 people (Andrew, Suan Pheng, and Philips 2011). In 2010, seaweed remained the prevailing cultured crop in Atauro Island for 1,500 farmers (GRDTL-NDFA and WFC 2013). Mud crab farming was recently introduced in Timor-Leste.

C. National Development Plans

Since achieving its independence in 2002, Timor-Leste has faced a wide range of challenges, including poverty, rapid population growth, inadequate education, peacekeeping, degraded environment and natural resources, climate change, lack of trained and skilled personnel, shortage of job opportunities, and low interest of investors and the private sector. Despite these issues, Timor-Leste has shown its commitment to its people by creating development plans and policies to alleviate poor economic conditions and at the same time ensure environmental preservation and conservation. Three main areas—environment, marine and fisheries, and climate change—and their sectoral plans, which are directly related to current projects on climate change and development strategies, are described in the following subsections.

To acknowledge its responsibility to the global community, Timor-Leste has ratified international conventions—namely, the United Nations Framework Convention on Climate Change, the UN Convention on Biological Diversity, and the UN Convention to Combat Desertification in 2010 (GDRTL-MED 2012). At the national level, the country has developed national resource management plans.

1. Biodiversity and environment

Unlike Fiji, Solomon Islands, and Vanuatu, Timor-Leste does not have a National Sustainable Development Strategy. Instead, the *National Strategic Development Plan (NSDP) 2011–2030* (NSDP) encompasses sustainable development and protection of the environment, together with the other interdependent factors associated with it (GDRTL-MED 2011a). Furthermore, the Government of Timor-Leste has implemented multilateral environmental agreements to achieve its Millennium Development Goals, as articulated in the NSDP.

The Government of Timor-Leste also approved and adopted the *National Development Plan 2002* and the *Timor-Leste National Adaptation Programme of Action (NAPA) on Climate Change* (GDRTL-SSE 2010) as national strategies forming the basis of the country's framework on sustainable development (GDRTL 2010). The *National Biodiversity Strategic Action Plan*

(GDRTL-MED 2011b) is closely linked to NSDP 2011–2030 and conforms to other sectoral policy frameworks, such as NAPA for climate change and land degradation, the *Fisheries Sector Plan* (GDRTL-MED 2012), and the *Forestry Sector Plan* (GDRTL-MED 2012).

Although the Environmental Licensing Decree-Law and legislation on environmental impact assessment (EIA) have been approved since 2011, the Environmental Basic Law is still in the legislative process, and the *Policy and Strategic Plan for Environment* needs to be presented to and approved by the Council of Ministers (GDRTL-MED 2012). EIAs are not being implemented because of a lack of sanctions, and enforcement of other existing laws and regulations is weak (GDRTL-MED 2012).

The UN Transitional Administration in East Timor regulation designates protected areas, prohibits logging and exports of tree products, protects marine and terrestrial areas, includes the 2007 *National Forestry Policy and Strategies* (GDRTL-MED 2012) and the 2011 fisheries quarantine, and strengthens traditional laws, or *Tara Bandu,*[21] to protect and conserve the country's natural resources (GDRTL-MED 2012).

2. *Marine and freshwater fisheries*

The Government of Timor-Leste has established fisheries laws and ministerial decrees for the management of fisheries and protected area, as well as to help local fishers exploit their rich fishing grounds (NCTICCTL 2012; FAO 2010d). The first national policy developed during the transitional period is the *Fish for the Future* (GDRTL-MAF 2001, cited in Alonso et al. 2013). Its main agenda is setting development-oriented priorities involving basic management and industry development needs for the fisheries sector. The policy focuses on asserting jurisdiction, developing legislation, enhancing marine administration, and building the capacity of the staff in the capture, recreational fishing, and aquaculture sections (Alonso et al. 2013).

A new fisheries strategy was drafted in 2005 and released in 2007 as *Policy and Strategy for Fisheries Development in Timor-Leste* (GDRTL-MAF 2007, as cited in Alonso et al. 2013). This approach was oriented more to fisheries' sustainability. However, it was not approved by the Council of Ministers nor legally endorsed (Alonso et al. 2013). Rather, the establishment of a legal framework for the fisheries sector and the provisional assertion of jurisdiction and control over living marine resources in the seas surrounding Timor-Leste were the management priorities (Alonso et al. 2013). Fisheries were then developed through technical assistance and funding support from the Regional Fisheries Livelihoods Programme.

In 2012, the National Coral Triangle Initiative Coordinating Committee of Timor-Leste (NCTICCTL) reported the preparation of an integrated fisheries policy for the country. This policy, *The Future of Fisheries: A Policy and Strategy for the Responsible Development and Management of Fisheries in Timor-Leste*, encompasses optimal use and management of living resources, habitat conservation, and development of fishing and aquaculture industries and fisheries institutions (GDRTL-NCTICCTL 2012).

[21] *Tara Bandu* is a customary law described as traditional ecological wisdom in Timor-Leste, which regulates the relationships between humans and their surrounding environment. The local community manages its environment, including forests, crops, marine, and inland resources, and areas for hunting and fishing. *Tara Bandu* is a major instrument used to create respect for the environment, manage natural resources sustainably, and resolve conflicts within the community. It is highly regarded as a tool for environmental preservation, sustainable use and management of natural resources, and conflict resolution and peacekeeping (GDRTL-MED 2012).

Timor-Leste is a member of the Coral Triangle Initiative (CTI) (with five other member countries), which implements five main components: seascapes, an ecological approach for fisheries management, MPAs, threatened species, and climate change. The main objective of CTI is to develop and strengthen cooperation among the six CTI countries for marine and coastal resource preservation (GDRTL-MED 2012). Furthermore, an MPA network is being proposed under the Coral Triangle Support Program with the Nino Konis Santana National Park, Timor-Leste's declared national park, as the initial site for an MPA (GDRTL-NCTICCTL 2012).

Timor-Leste is also a participant in the Partnership in Environmental Management for the Seas of East Asia, which focuses on coastal areas, coastal management, and improving livelihoods in coastal areas. Timor-Leste is a member of the Arafura and Timor Seas Expert Forum (ATSEF), whose members collaborate to identify existing gaps, particularly on the transboundary issues of the Arafura and Timor Seas. ATSEF deals more with governance issues in the institutional, legal, and policy environments at the national and regional levels.

NDFA recently launched the 2012–2030 *National Aquaculture Development Strategy* (NADS) (GDRTL-NDFA and WRC 2013). The NADS is designed to create a strong role of aquaculture in the economy to diversify and improve livelihoods and to build resilience among rural households and agro-ecological systems. The NADS endorses inland and coastal aquaculture with freshwater, focusing on improving the food and nutrition security of inland communities, while brackish aquaculture and mariculture target small business and enhancing the revenues and economic opportunities of coastal communities.

FADs were newly launched by the Secretariat of the Pacific Community (SPC) in Atauro Island in July 2013. SPC offered technical support in the development and deployment of FADs along the coasts of Atauro Island. Since Atauro Island is a locally managed marine area, FAD management will be the community's responsibility under the guidance of NDFA.

3. Climate change

The NAPA is the first national document that identifies the urgent and immediate climate change adaptation needs of the most vulnerable groups **(**GDRTL-SSE 2010). Mainstreaming adaptation strategies into development plans is the initial step to achieve sustainable development and poverty reduction (GDRTL-MOF 2010). Some of the proposed strategies for freshwater, marine ecosystems, and biodiversity include education and awareness and national legislation for disaster management, including improving physical infrastructure; establishing early-warning systems, particularly in vulnerable and risky areas; and strengthening government strategies for responding to climate change.

The *National Plan of Action for Coral Triangle Initiative* (NPoA-CTI) is a working document developed by the Ministry of Agriculture and Fisheries (MAF) and the Secretary of State for Fisheries and Aquaculture (SSAF). The plan has five specific goals: (1) designate and effectively manage priority coastal and marine areas; (2) develop an ecosystem approach to fisheries management; (3) propose, manage, and establish MPAs; (4) develop an early-warning system for and increase awareness of climate change; and (5) improve the status of threatened species. These goals of the NPoA-CTI conform to existing and proposed government policies and financial systems and to Government of Timor-Leste annual action plans, including ongoing and proposed programs of development partners, and are in accordance with Timor-Leste Millennium Development Goals and Poverty Alleviation Schemes and Plans (GDRTL-MAA-SSFA 2009).

D. Modeling the Effects of Climate Change and Climate Change Adaptation Strategies

As in the other country modeling assessments, we utilized secondary data and FGDs to develop the parameters for the model for Timor-Leste. For each time period (2035 and 2050), we implemented two baseline (most plausible) scenarios representing two annual growth rates of real per capita income: medium (2% per year) and high (3% per year) growth of real per capita income. We assumed populations of 1,724,683 in 2035 and 2,040,271 in 2050.

The baseline data (production, consumption, trade and price), supply elasticities, and demand elasticities used in the fish sector model for Timor-Leste are given in Appendix Tables A.13, A.14, and A.15, respectively. Similar to other countries under study in this research, the supply volumes reported in Table A.15 and used in the analysis include catch by national fleets in both national and international waters, but do not include catch by foreign fleets in national waters. Supply elasticities used in the model for Timor-Leste are very inelastic (that is, close to zero), reflecting the artisanal/subsistence nature of fisheries and aquaculture. We used alternative sets of elasticities to test the sensitivity of the model, and found that changes in elasticities within possible range do not alter the main results, a finding parallel to all of the four project countries.

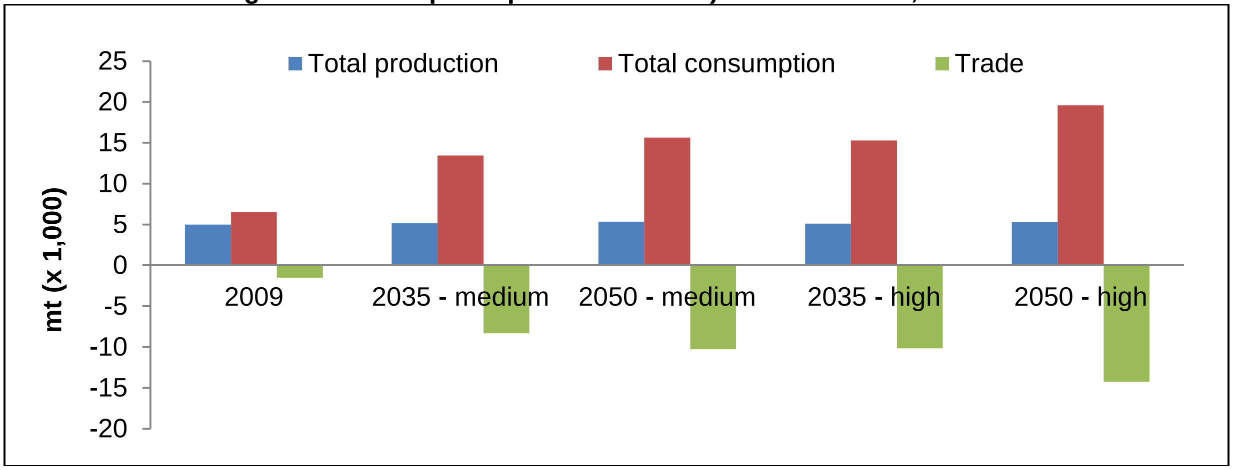
We considered three climate change adaptation scenarios: aquaculture (AQ), natural resource management (NRM) with emphasis on MPA, and a combination of AQ+NRM. Scenario 1 (AQ) involves improvements in the productivity of freshwater (both finfish and invertebrate) aquaculture. Scenario 2 (NRM) addresses the changes in production and productivity of coastal and oceanic capture fisheries resulting from management regime shifts and adoption of resource enhancement practices.

The overall shifts in the supply curve resulting from climate change (i.e., effect of climate change on fish production) and various climate change adaptation strategies used in Timor-Leste model are reported in Appendix Table A.16. We used the projection of the Spatial Ecosystem and Population Dynamics Model (SEAPODYM) for the likely effects of climate change on tuna catch (Lehodey et al. 2008), which show that tuna stock is likely to move to the eastern Pacific Ocean. Unlike in other case study countries, we assumed that tuna stock and catch are not likely to increase in Timor-Leste because of climate change. However, our model uses the baseline projection of declining catch of coastal fisheries in Timor-Leste due to climate change. Various NRM strategies are likely to mitigate some of the negative effects on climate change on coastal fisheries and to shift the supply curves for the coastal species to the right. The likely effects of NRM and other climate change adaptation strategies on fish production are reported in columns 3, 4, 5, 7, 8, and 9 of Appendix Table A.16.

1. Effects of climate change on production, consumption, and trade (baseline scenario)

Figure 6.1 shows the projected production, consumption, and net trade of fish aggregate in Timor-Leste for 2035 and 2050 under two baseline scenarios, with 2% and 3% annual growth rates of real per capita income. Currently, Timor-Leste is a net importer of fish and seafood. The model predicts that total fish production will increase only marginally in the medium term (2035) and long term (2050) under the baseline scenarios. Aggregate fish demand is expected to rise substantially over time due to growth in population and real per capita income. This implies that the country will have to import more fish to fill this increasing deficit in domestic fish supply.

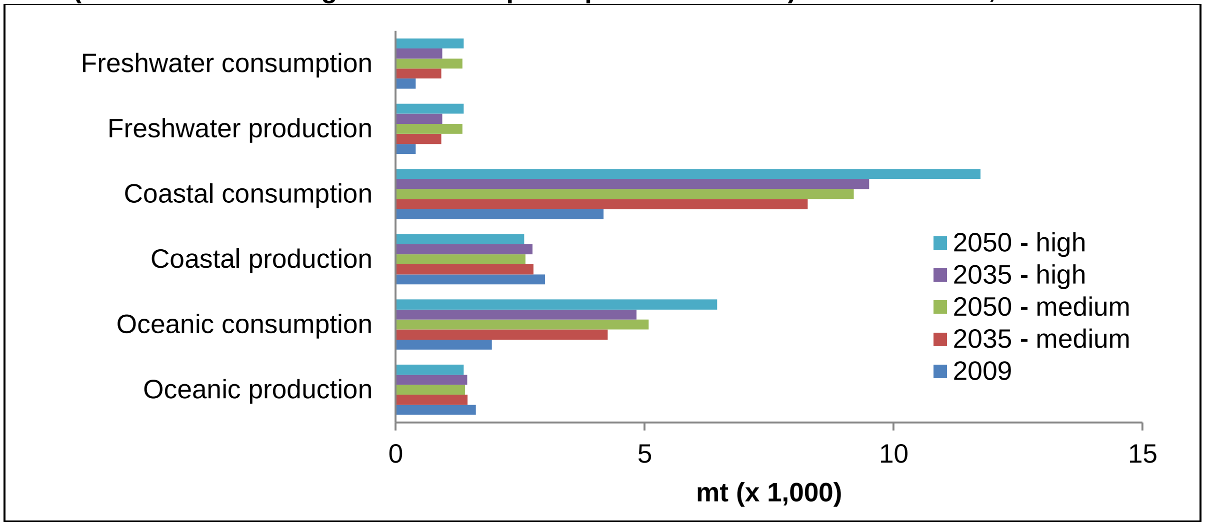
Figure 6.1
Projected Fish Production, Consumption, and Trade under Two Baseline Scenarios (2% and 3% annual growth rate of per capita real income) in Timor-Leste, 2035 and 2050



medium = 2% annual growth rate of per capita real income; high = 3% annual growth rate of per capita real income.
Source: Model projections.

Figure 6.2 shows the projected quantities of production and consumption of different fish groups. The results indicate that fish supplies from oceanic and coastal ecosystems are likely to decrease during 2010–2050. The model predicts that only freshwater ecosystems will be able to supply more fish in the future. Given that oceanic and coastal fisheries supply about 94% of current fish consumption in Timor-Leste, this projected fish supply scenario has serious food security implications for the country.

Figure 6.2
Projected Production and Consumption of Different Types of Fish under Two Baseline Scenarios (2% and 3% annual growth rate of per capita real income) in Timor-Leste, 2035 and 2050



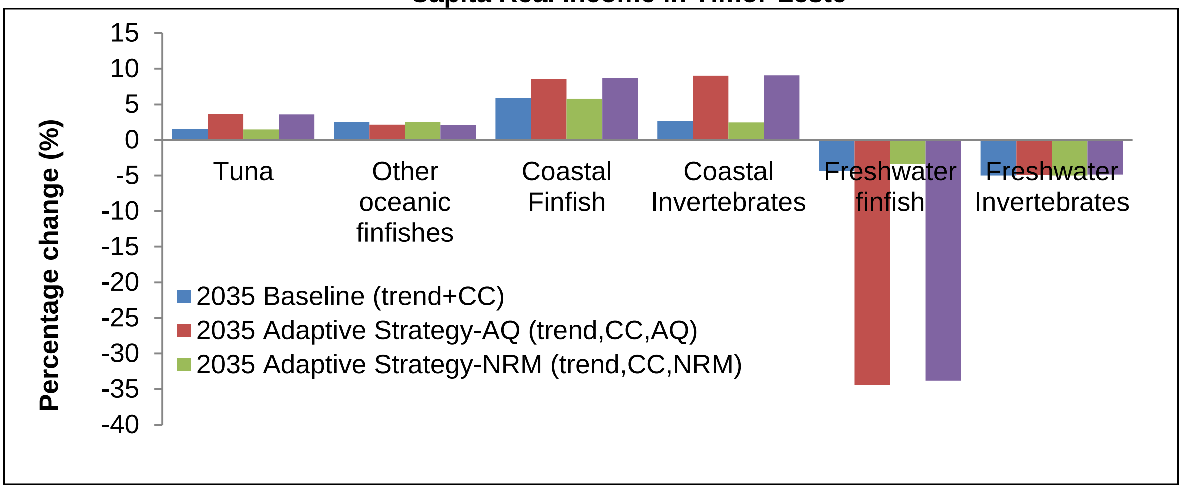
medium = 2% annual growth rate of per capita real income; high = 3% annual growth rate of per capita real income.
Reprinted from "Analysis of the economic impact of climate change and climate change adaptation strategies for fisheries sector in Pacific coral triangle countries: Model, estimation strategy, and baseline results" by Dey, M.M., M.W. Rosegrant, K. Gosh, O.L Chen, and R.A. Valmonte-Santos. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Dey et al. 2016a.

2. Effects of climate change adaptation strategies

2.1. Changes in fish prices

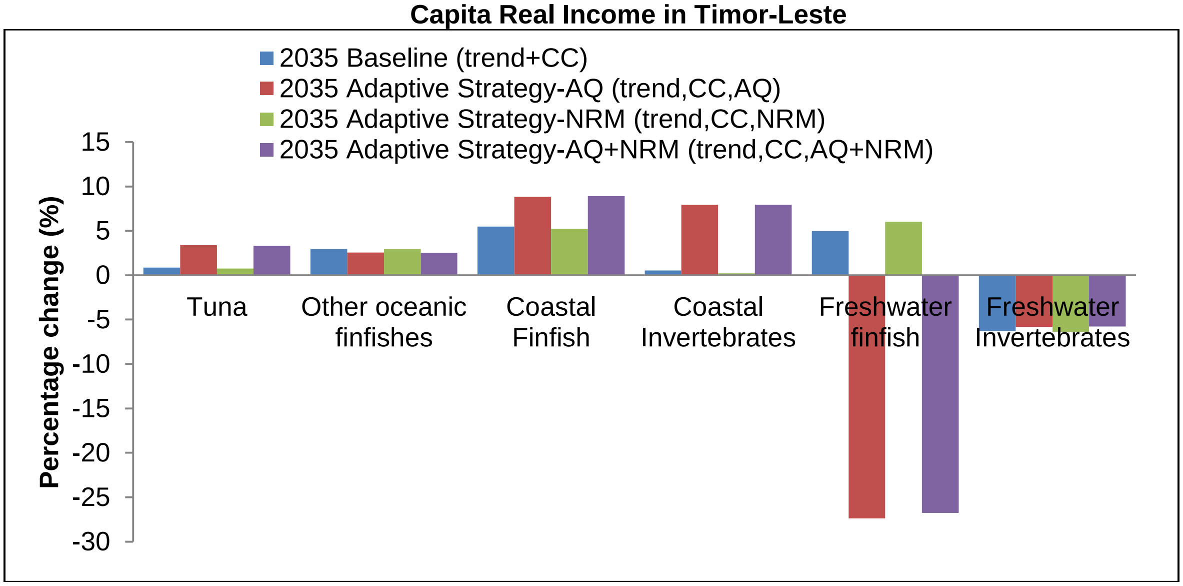
Figures 6.3 to 6.6 show the projected real prices of different types of fish in Timor-Leste in 2030 (medium term) and 2050 (long term) under different scenarios. The model projects that the real price of most categories of fish will increase only marginally during 2009–2050 under the baseline scenarios, because increased imports of fish are likely to keep real fish prices under check. The real price of freshwater fish is expected to decrease over time under the baseline scenarios, mainly because of higher supply within the sector.

Figure 6.3
Percentage Change in Price from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Timor-Leste



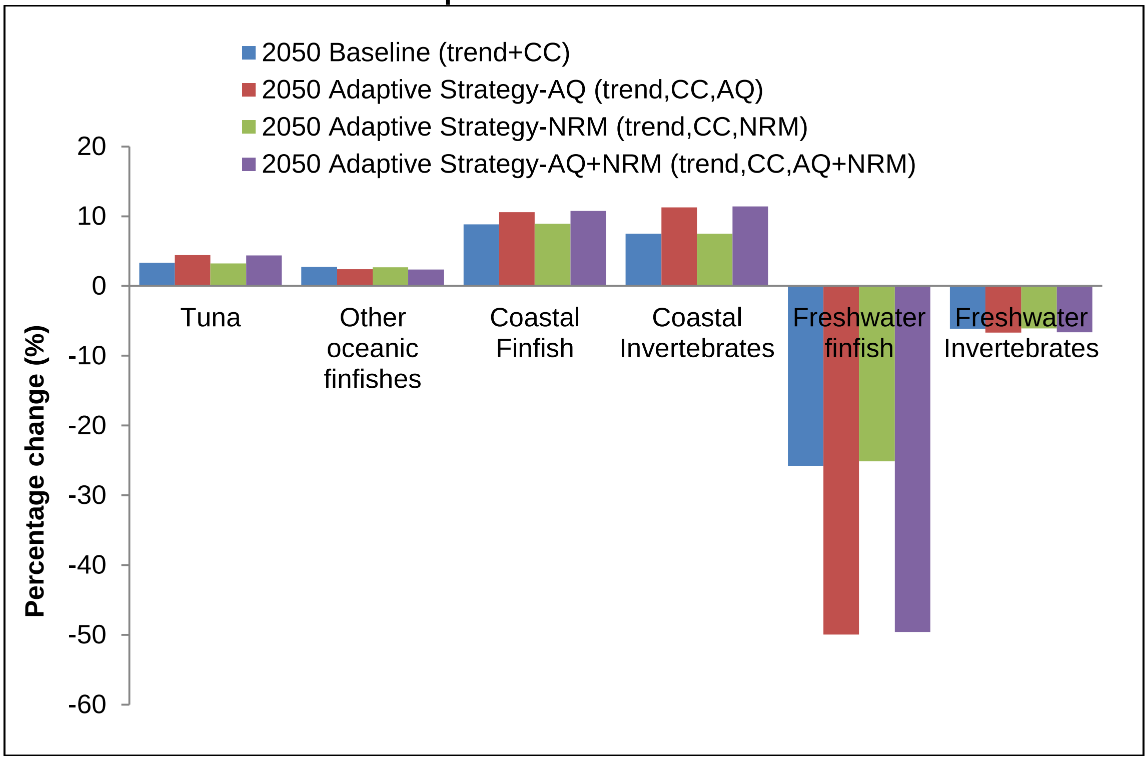
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.4
Percentage Change in Price from Baseline (2006–2009) to 2035 with 3% Annual Growth of Per Capita Real Income in Timor-Leste



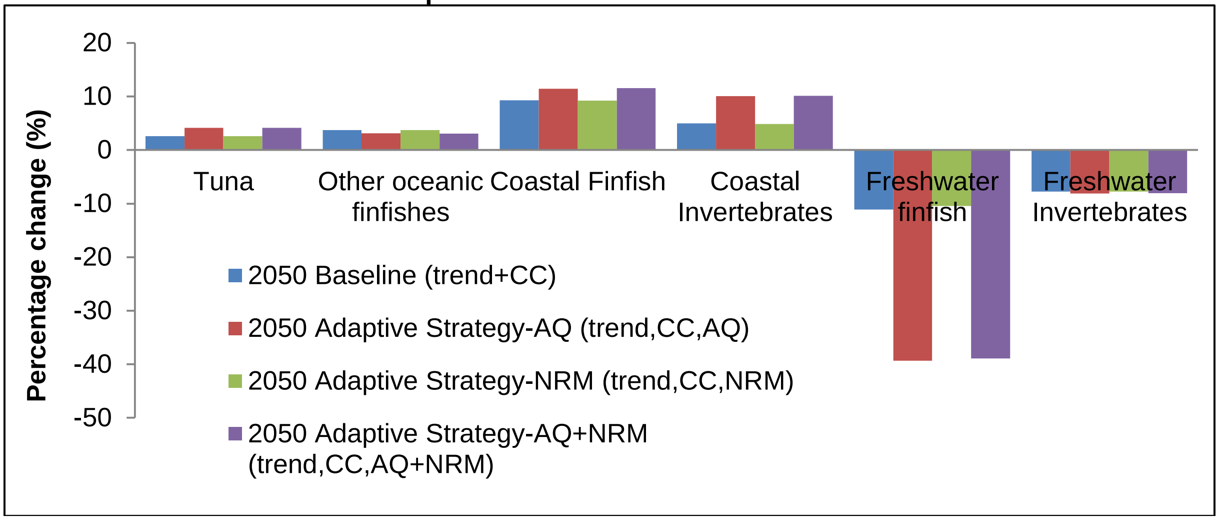
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.5
Percentage Change in Price from Baseline (2006–2009) to 2050 with 2% Annual Growth of Per Capita Real Income in Timor-Leste



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.6
Percentage Change in Price from Baseline (2006–2009) to 2050 with 3% Annual Growth of Per Capita Real Income in Timor-Leste



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

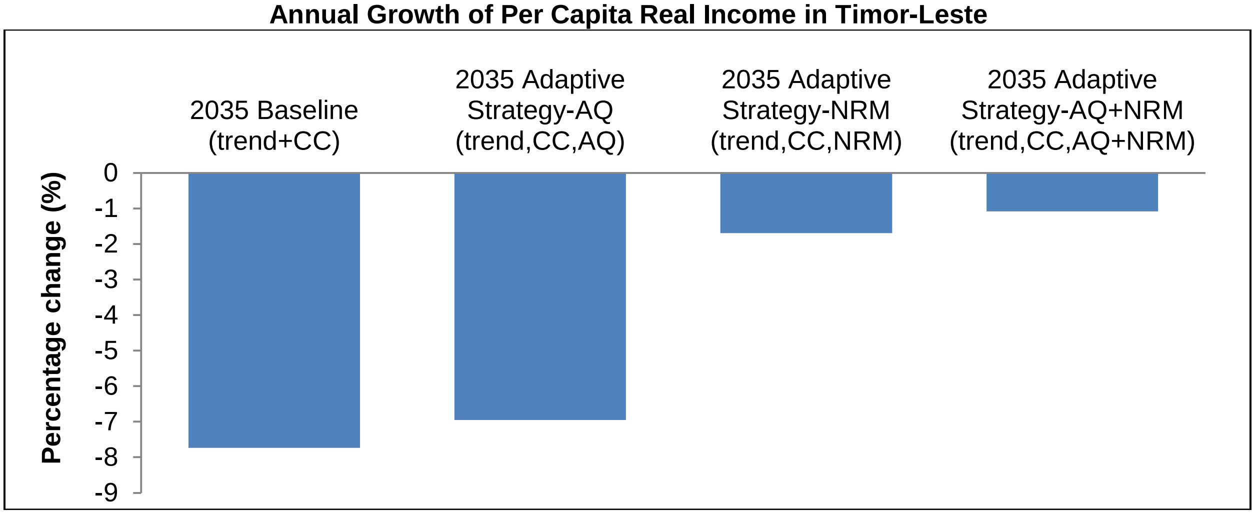
Among various climate change adaptation strategies analyzed, aquaculture development is expected to reduce the real price of freshwater fish, and is likely to raise the real price of other fish categories, mainly because of the higher incomes associated with aquaculture development.

2.2. Changes in fish production

Among the various adaptation strategies considered in the modeling exercise, adoption of the NRM strategy is likely to affect production of coastal fish, while aquaculture development is expected to affect freshwater production in Timor-Leste. The model projects that these strategies will not have any significant effects on oceanic fish production in Timor-Leste.

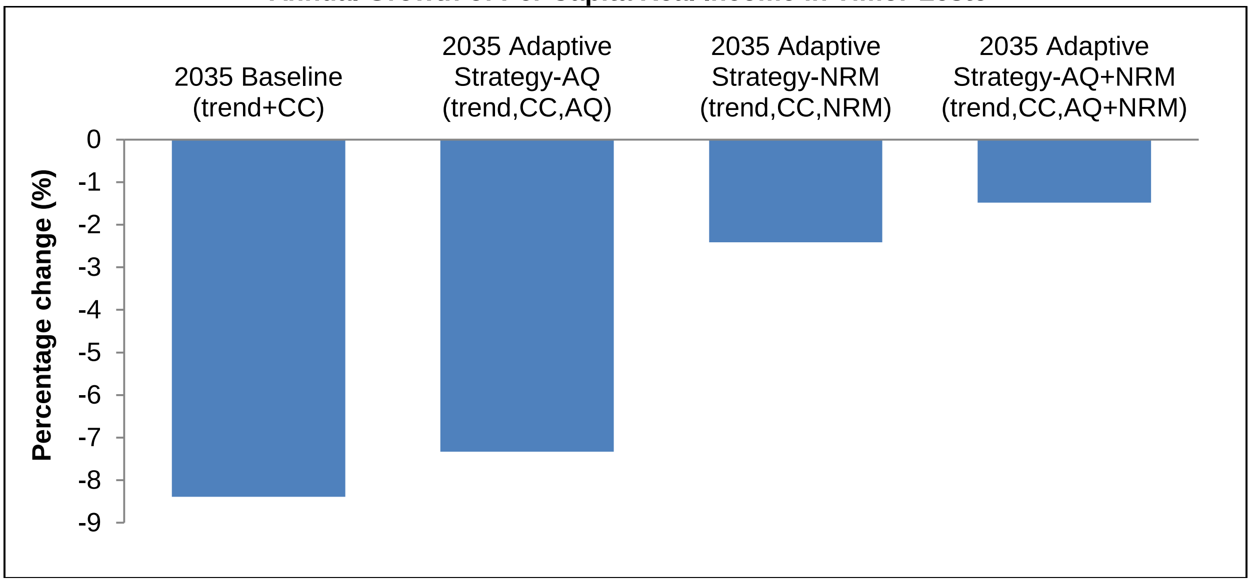
Figures 6.7 to 6.10 show the likely effects of different climate change adaptation strategies on coastal fish production in 2035 and 2050. The model predicts that the NRM strategy will have a positive impact on coastal fish supply, and will reverse the negative supply trend within coastal fisheries.

Figure 6.7
Percentage Change in Production of Coastal Species from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Timor-Leste



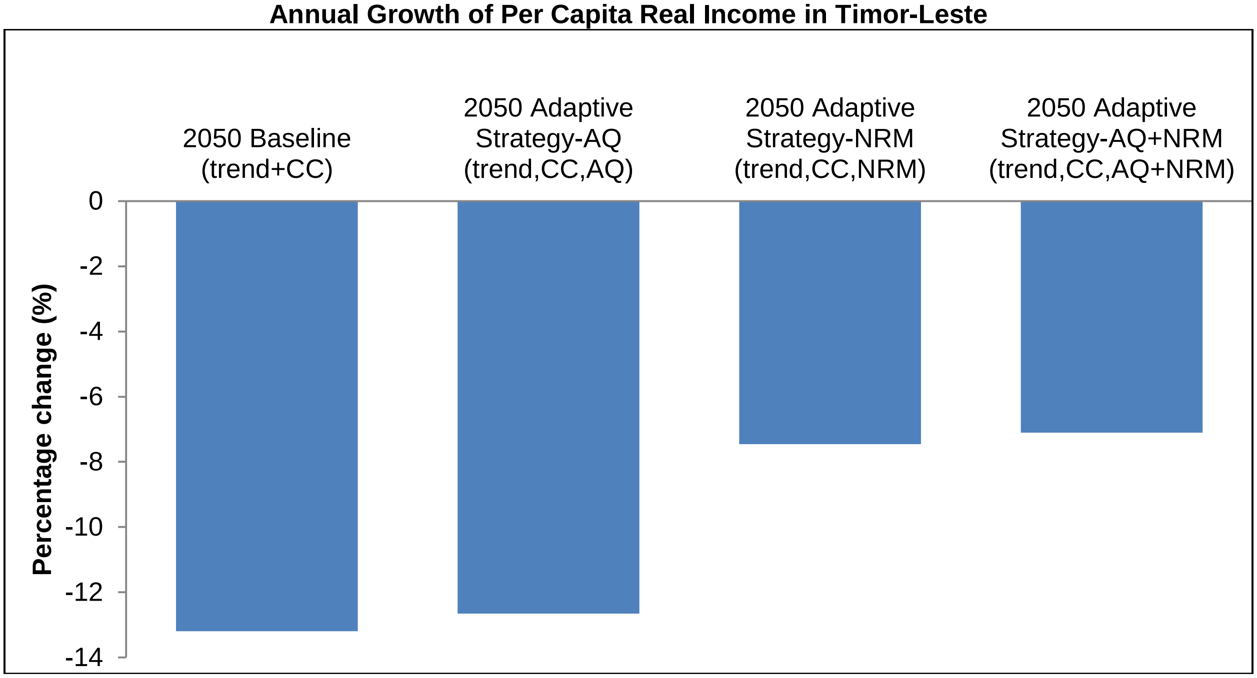
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.8
Percentage Change in Production of Coastal Species from Baseline (2006–2009) to 2035 with 3% Annual Growth of Per Capita Real Income in Timor-Leste



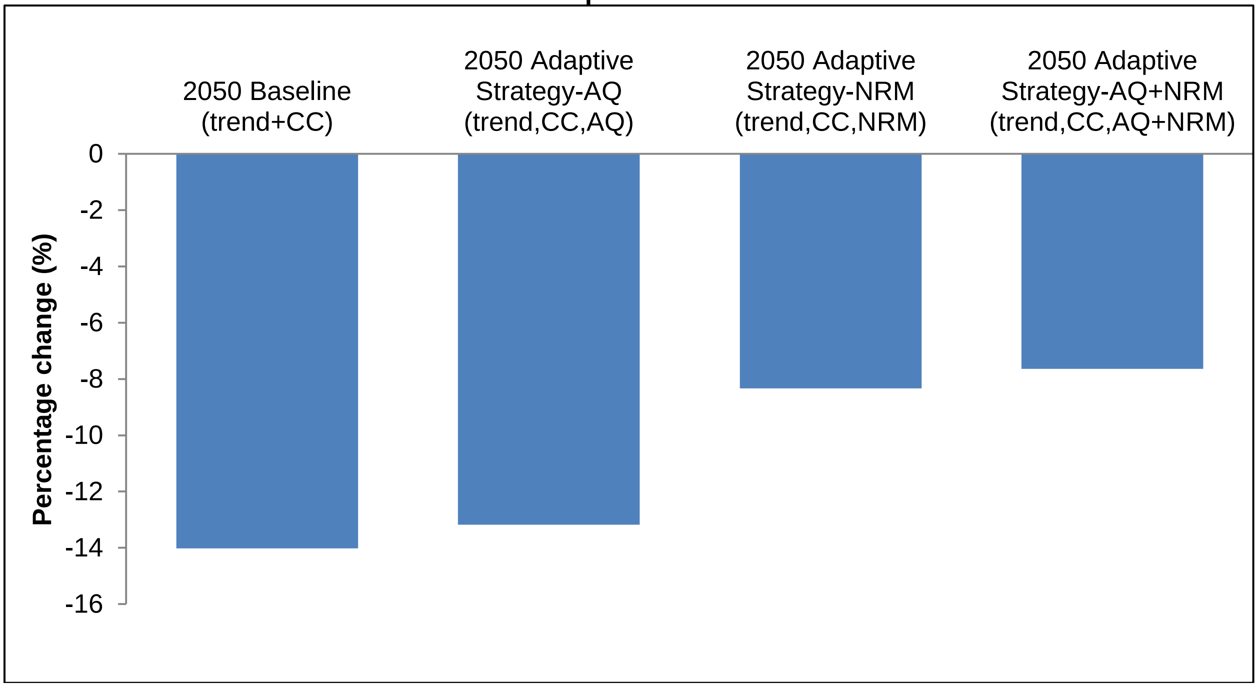
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.9
Percentage Change in Production of Coastal Species from Baseline (2006–2009) to 2050 with 2% Annual Growth of Per Capita Real Income in Timor-Leste



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

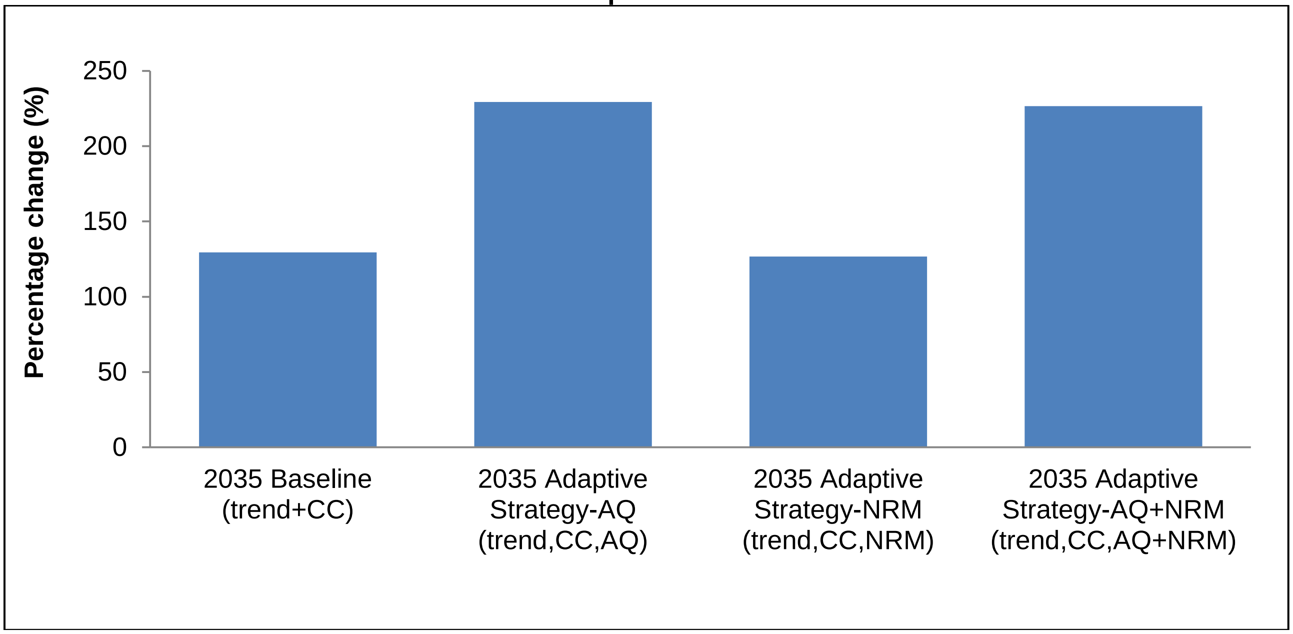
Figure 6.10
Percentage Change in Production of Coastal Species from Baseline (2006–2009) to 2050 with 3% Annual Growth of Per Capita Real Income in Timor-Leste



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

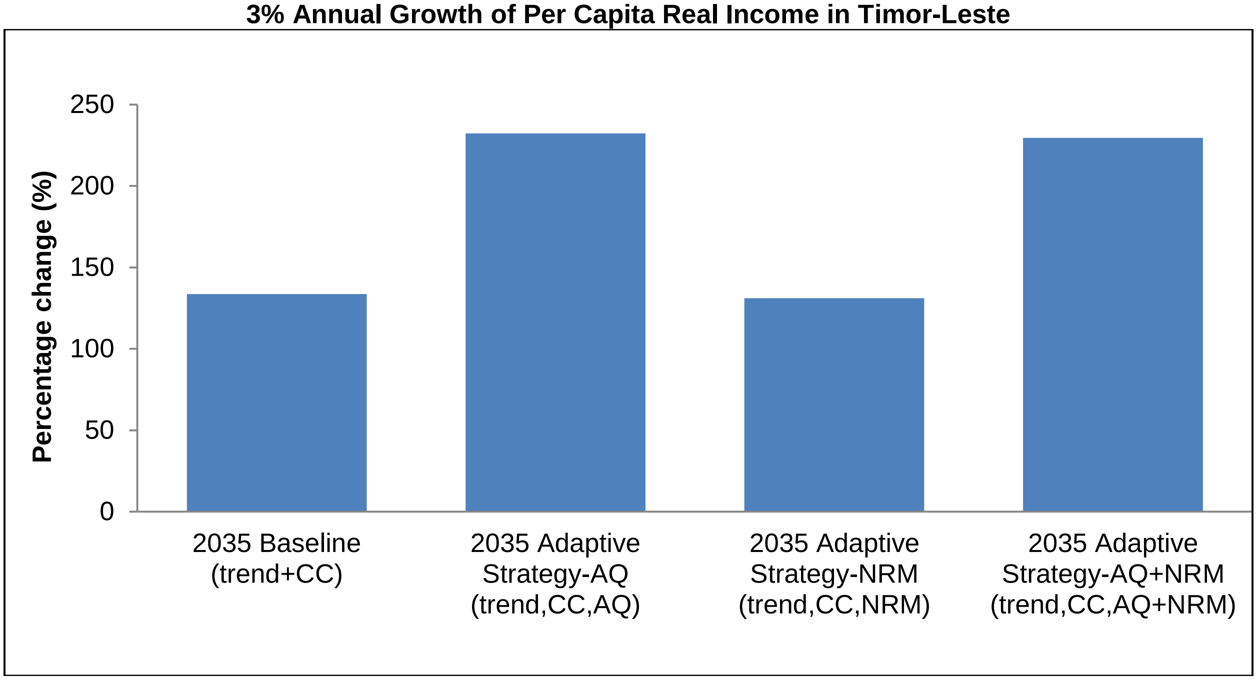
Figures 6.11 to 6.14 show the predicted effects of different climate change adaptation strategies on freshwater fish production in 2035 and 2050. The AQ strategy is expected to increase freshwater fish production substantially, by about 100% in the medium term (2035) and by about 150% in the long term (2050). The NRM strategy is also likely to increase freshwater fish production. But the model predicts that the combined AQ+NRM strategy may not have any added advantage (i.e., additive effects) on freshwater fish supply in Timor-Leste. This is mainly because the NRM strategy is expected to have a positive effect on coastal fish production (Figures 6.7 to 6.10), which may take sway some production resources from the freshwater system. On the other hand, aquaculture growth is projected to increase income, resulting in higher demand for coastal fish and seafood and lower demand for freshwater fish. These effects together may neutralize some positive impacts of the combined AQ+NRM strategy on freshwater production. Given that the freshwater ecosystem supplies fish for domestic consumption only, which was reflected in the close economy model that we choose for this species group, the AQ+NRM strategy may not have any additive effects on freshwater fish consumption (Figures 6.15 to 6.18).

Figure 6.11
Percentage Change in Production of Freshwater Species from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Timor-Leste



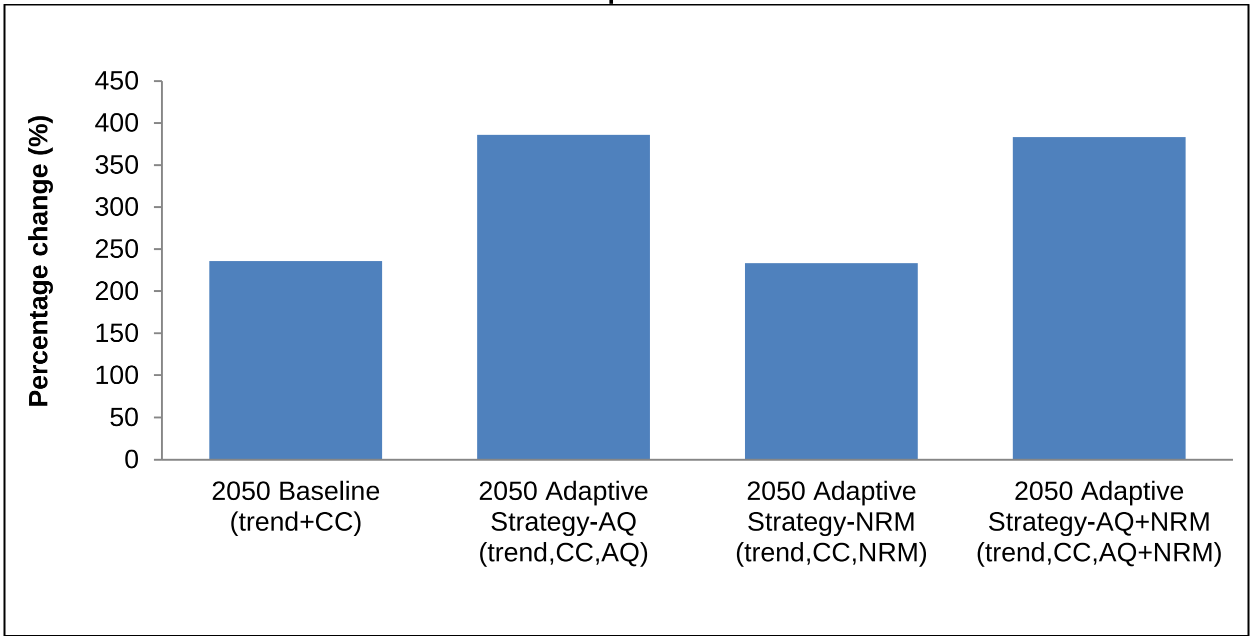
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.12
Percentage Change in Production of Freshwater Species from Baseline (2006–2009) to 2035 with 3% Annual Growth of Per Capita Real Income in Timor-Leste



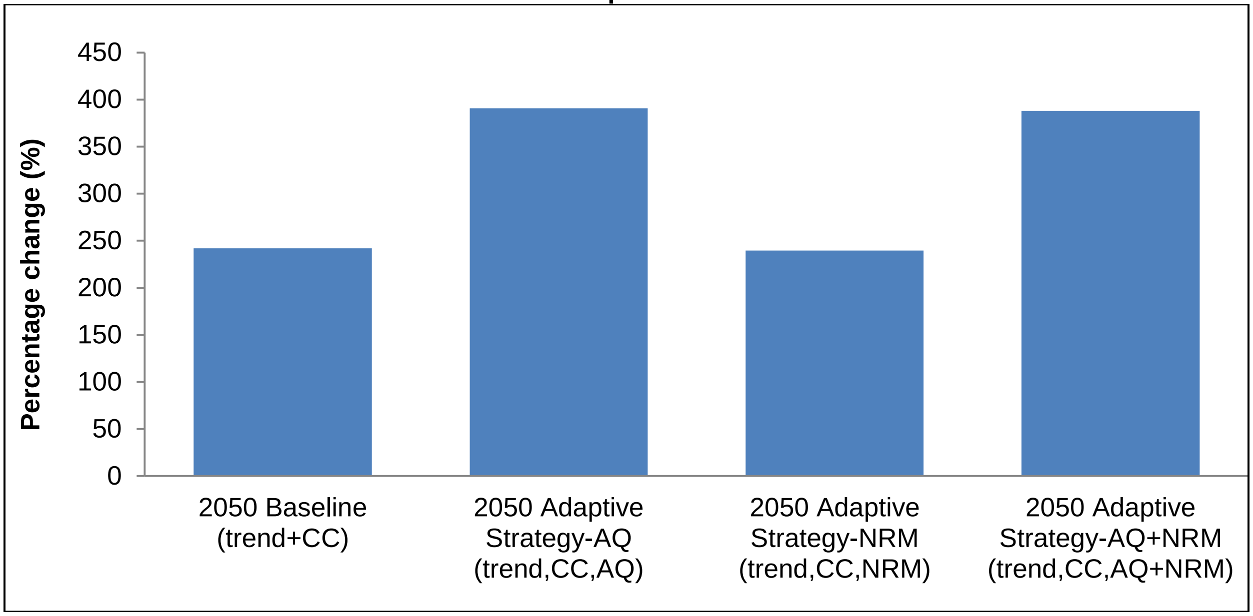
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.13
Percentage Change in Production of Freshwater Species from Baseline (2006–2009) to 2050 with 2% Annual Growth of Per Capita Real Income in Timor-Leste



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.14
Percentage Change in Production of Freshwater Species from Baseline (2006-2009) to 2050 with 3% Annual Growth of Per Capita Real Income in Timor-Leste

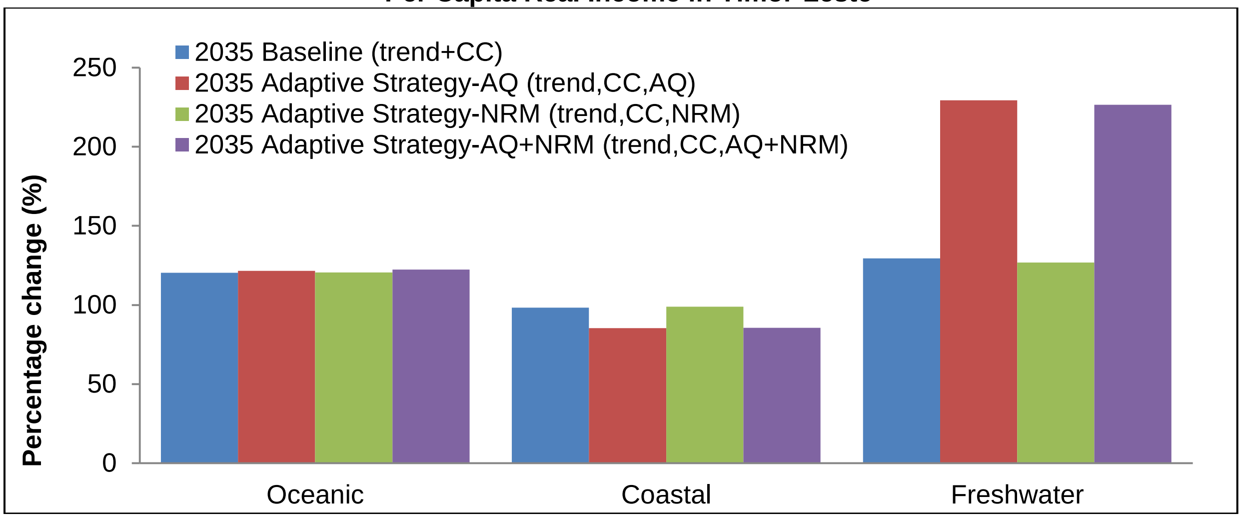


AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

2.3. Changes in fish consumption

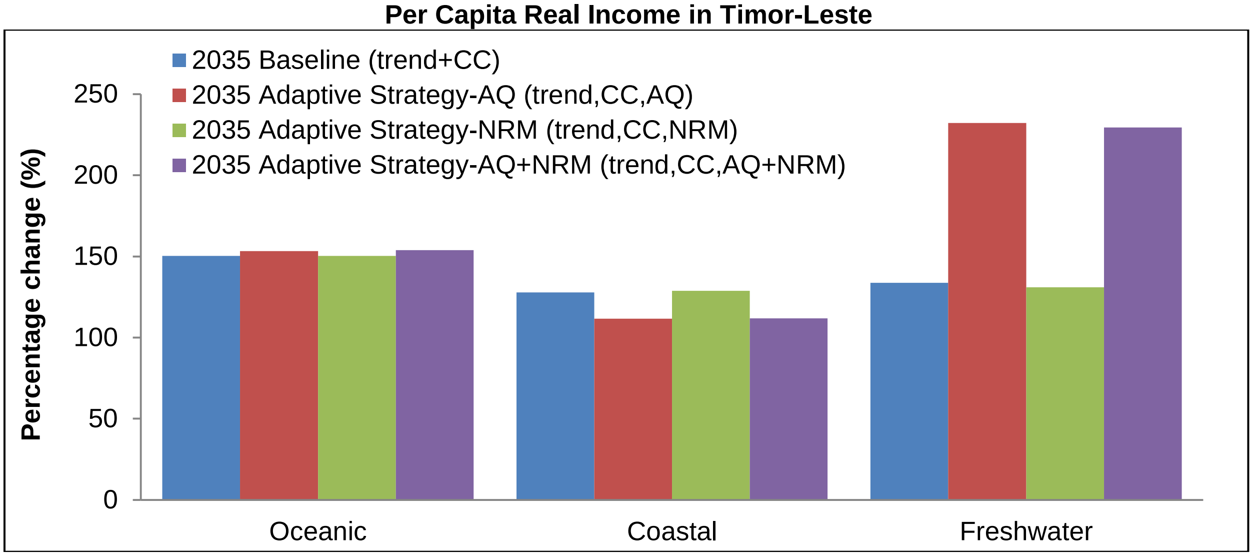
Figures 6.15 to 6.18 show the likely effects of various climate change adaptation strategies on demand for various categories of fish in Timor-Leste in the medium term (2035) and long term (2050). The model predicts that only aquaculture development will have any significant and positive impact on fish consumption in Timor-Leste, mainly through increased consumption of freshwater fish. Continuation of the aquaculture development strategy is expected to have a larger positive impact over time. The likely increases in fish consumption from current levels under the baseline scenario and under the NRM strategy are predicted to be very close (Figures 6.15 to 6.18). This result implies that the NRM strategy is not expected to have any impact on fish consumption in the country.

Figure 6.15
Percentage Change in Consumption from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Timor-Leste



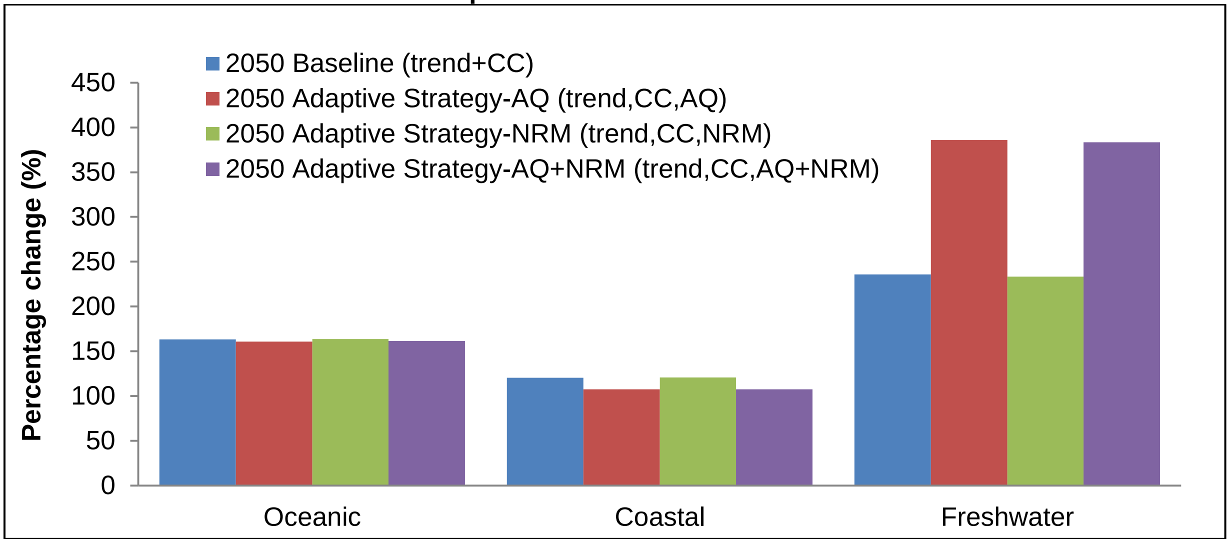
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.16
Percentage Change in Consumption from Baseline (2006–2009) to 2035 with 3% Annual Growth of Per Capita Real Income in Timor-Leste



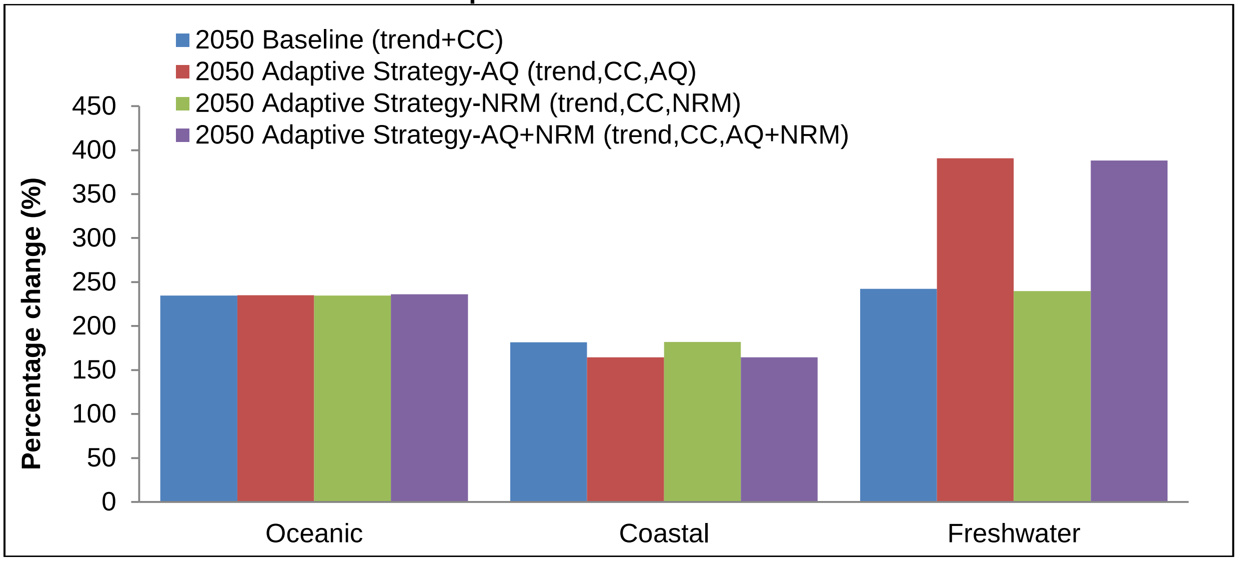
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.17
Percentage Change in Consumption from Baseline (2006–2009) to 2050 with 2% Annual Growth of Per Capita Real Income in Timor-Leste



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.18
Percentage Change in Consumption from Baseline (2006–2009) to 2050 with 3% Annual Growth of Per Capita Real Income in Timor-Leste

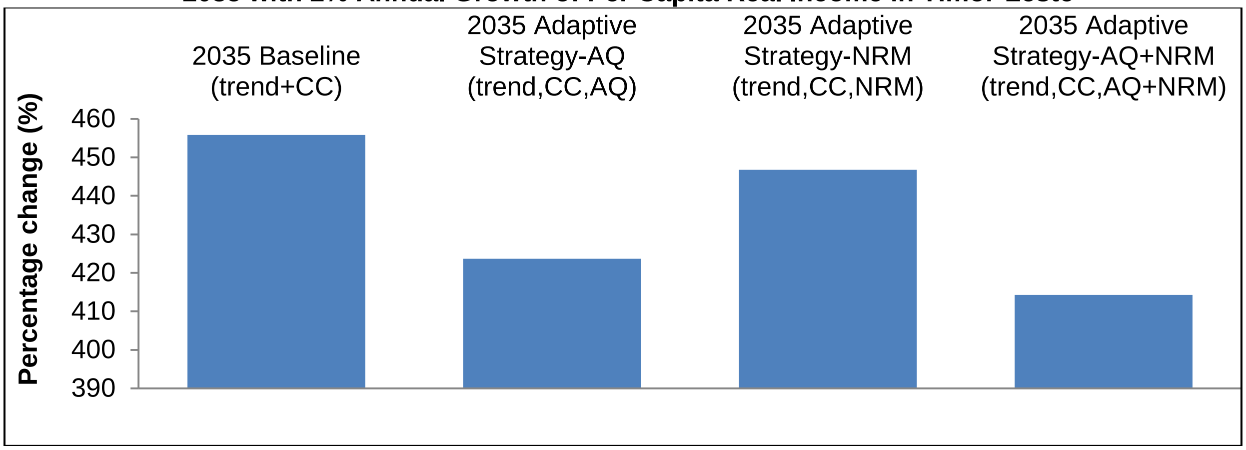


AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

2.4. Changes in net trade

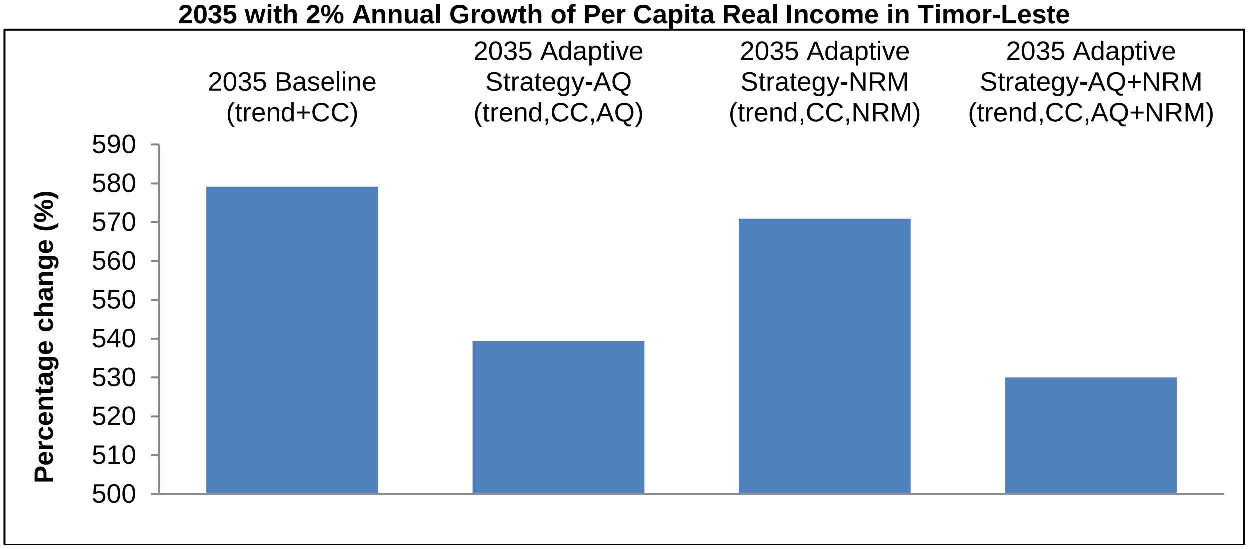
Unlike the other countries studied in this project, Timor-Leste is a net importer of fish and seafood. The model predicts that Timor-Leste will remain a net importer of fish in the long run under the baseline and various climate change adaptation scenarios. Figures 6.19 to 6.22 show the projected effects of different climate change adaptation strategies on net imports of fish in Timor-Leste in the medium term (2035) and long term (2050). Results indicate that both the aquaculture and the NRM strategies will reduce net imports of fish in the country. But, given that the Government of Timor-Leste has placed more emphasis on aquaculture development, which was reflected in the way we conducted the modeling exercise, aquaculture development will have a stronger effect on import reduction. Increased investment in NRM activities is likely to have similar effects.

Figure 6.19
Percentage Change in Net Trade (Import Minus Export) of Fish Trade from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Timor-Leste



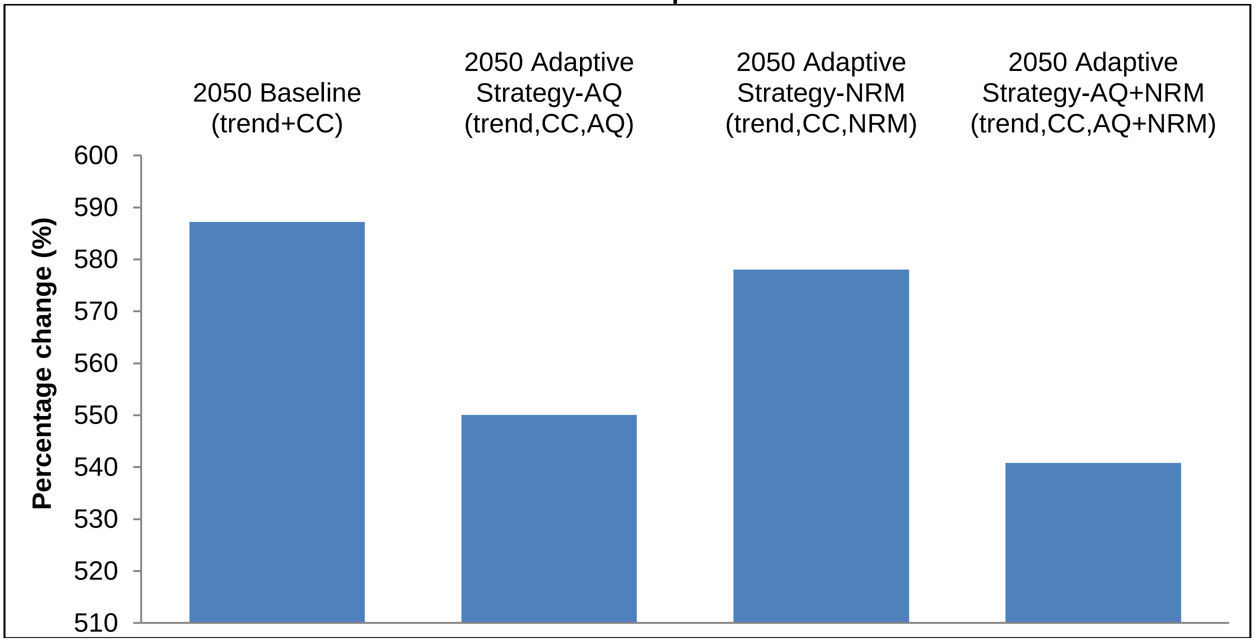
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.20
Percentage Change in Net Trade (Import Minus Export) of Fish Trade from Baseline (2006–2009) to 2035 with 2% Annual Growth of Per Capita Real Income in Timor-Leste



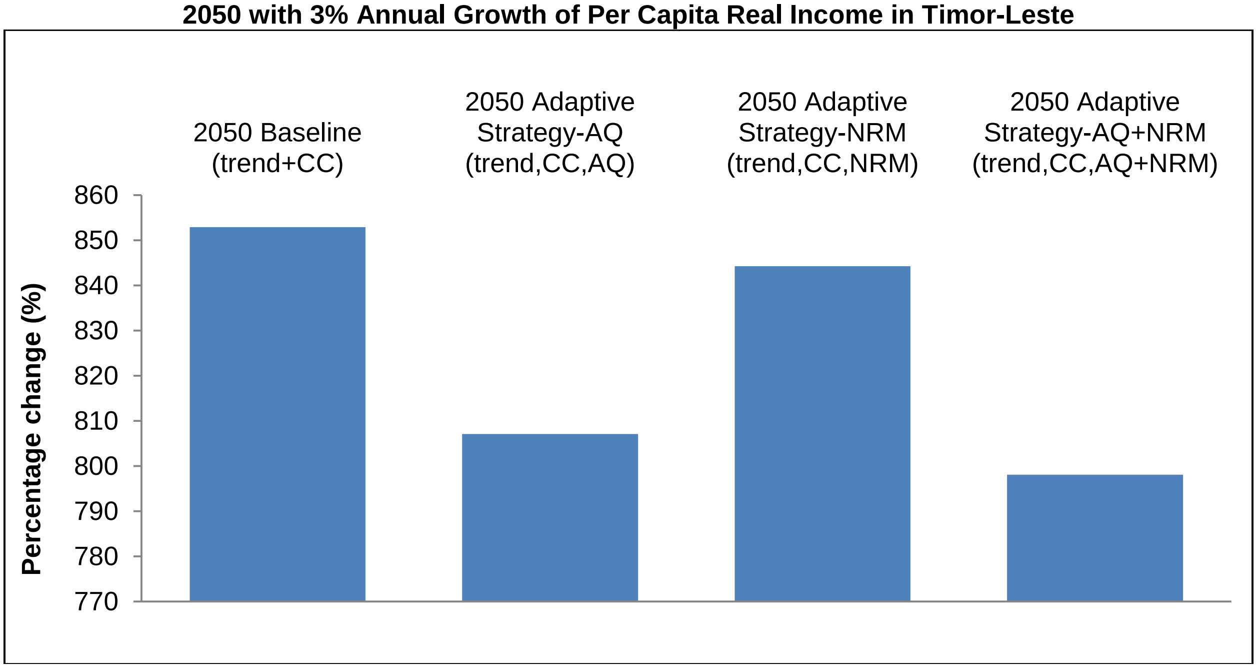
AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.21
Percentage Change in Net Trade (Import Minus Export) of Fish Trade from Baseline (2006–2009) to 2050 with 2% Annual Growth of Per Capita Real Income in Timor-Leste



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

Figure 6.22
Percentage Change in Net Trade (Import Minus Export) of Fish Trade from Baseline (2006–2009) to 2050 with 3% Annual Growth of Per Capita Real Income in Timor-Leste



AQ = aquaculture development; CC = climate change; NRM = natural resource management.
Source: Rosegrant et al. 2016.

2.5. National-level net economic gains

Table 6.1 shows the estimated national-level net economic gains to both consumers and producers resulting from various climate change adaptation strategies in Timor-Leste. Aquaculture is the country's main adaptation strategy. Timor-Leste is currently implementing several ongoing initiatives with WorldFish and other regional/international agencies for aquaculture development. Compared with other case study countries, the potential increase in net income from the NRM strategy is less in Timor-Leste. The country is in the early stage of developing a comprehensive strategy for coastal and marine environments.

Table 6.1
National-Level Economic Gain (equivalent variation) Resulting from Climate Change Adaptation Strategies in Timor-Leste)

Climate Change Adaptation Strategy	Economic Gain per Year (US$ in 2009 prices) 2035	2050
Aquaculture	651,915	1,216,366
Natural resource management (NRM)	417,922	399,910
Aquaculture + NRM	1,057,817	1,605,182

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Source: Rosegrant et al. 2016.

E. Summary

The review and analysis of available literature; the discussions at the national, provincial, and community levels through the FGD; and the modeling results and assessment carried out for this study generated key messages for Timor-Leste.

1. The baseline scenario predicted the following likely situations:
    - Total fish production will increase only marginally in 2035 and 2050. Aggregate fish demand is expected to rise substantially over time due to growth in population and real per capita income. This implies that the country will have to import more fish to fill this increasing deficit in the domestic fish supply.
    - Fish supplies from oceanic and coastal ecosystems are likely to decrease during 2010–2050. Only the freshwater ecosystem will be able to supply more fish in the future. Given that oceanic and coastal fisheries supply about 94% of current fish consumption in Timor-Leste, this projected fish supply scenario has serious food security implications for the country.

2. With adoption of climate change adaptation strategies, likely modeling outcome are:
    - The real price of most categories of fish will increase only marginally over 2009–2050, because increased imports of fish are likely to keep real fish prices under check. The real price of freshwater fish is expected to decrease over time, mainly because of higher supply within the sector.
    - Among various climate change adaptation strategies analyzed, aquaculture development is expected to reduce the real price of freshwater fish. Aquaculture is likely to raise the real price of other fish categories, mainly because of the higher incomes associated with aquaculture development.
    - Adoption of the NRM strategy is likely to affect production of coastal fish, while aquaculture development is expected to affect freshwater production in Timor-Leste. The

model projects that these strategies will not have any significant effects on oceanic fish production in Timor-Leste.

- The AQ development strategy is expected to increase freshwater fish production substantially, by about 100% in 2035 and by about 150% in 2050.
- The NRM strategy is also likely to increase freshwater fish production.
- The model predicts that combined AQ and NRM strategies may not produce any added advantage (i.e., additive effects) for freshwater fish supply in Timor-Leste. The NRM strategy is expected to have a positive effect on coastal fish production, which may take away some production resources from freshwater system.
- Aquaculture growth increases income, resulting in higher demand for coastal fish and seafood and lower demand for freshwater fish. These effects together may neutralize some positive impacts of the combined AQ+NRM strategy on freshwater production. Given that the freshwater ecosystem supplies fish for domestic consumption only, which was reflected in the close economy model that we choose for this species group, the AQ+NRM strategy may not have any additive effect on freshwater fish consumption.
- Only aquaculture development will have any significant and positive impact on fish consumption in Timor-Leste, mainly through increased consumption of freshwater fish. Continuation of the aquaculture development strategy is expected to have a larger positive impact over time. The likely increases in fish consumption from current levels under the baseline scenario and the NRM strategy are predicted to be very similar. This result implies that the NRM strategy is not expected to have a significant impact on fish consumption in the country, but rather will reduce fish imports.
- Estimated national-level annual economic gain resulting from the adoption of climate change adaptation strategies range from $0.65 million for aquaculture, to $0.4 million for NRM, and to $1 million for combined aquaculture+NRM (US$ in 2009 constant prices) in 2035. Interestingly, economic gain from NRM remained the same at $0.4 million (US$ in 2009 constant prices) in 2050, whereas the annual benefits from aquaculture expansion increased $1.2 million in 2050 and the annual benefits aquaculture+NRM increased to $1.6 million in 2050.

Unlike the other countries studied in this project, Timor-Leste is a net importer of fish and seafood. Timor-Leste will remain a net importer of fish in the long run under baseline and various climate change adaptation scenarios. Both the aquaculture and the NRM strategies will reduce net imports of fish in the country. However, given that the Government of Timor-Leste has placed more emphasis on aquaculture development, which was reflected in the way we conducted the modeling exercise, aquaculture development will have a stronger effect on import reduction. Increased investment in NRM activities is likely to have similar effects.

7. CLIMATE CHANGE ADAPTATION STRATEGIES AND POLICIES IN THE FISHERIES SECTOR: IMPLICATIONS FOR FOOD SECURITY IN THE PACIFIC CORAL TRIANGLE COUNTRIES

A. Overview

The United Nations Framework Convention on Climate Change (UNFCCC), UN Convention on Biological Diversity, UN Convention to Combat Desertification, Kyoto Protocol, and other agreements extend assistance to developing countries in coping with the adverse effects of climate change. Methods of assistance include development and deployment of appropriate technologies to build climate resilience, as well as the establishment of adaptation funds for financial support of adaptation projects and programs in developing countries that are Parties to the Kyoto Protocol. The conventions acknowledge the vulnerability of developing countries to the negative effects of climate change, particularly the low-lying coastal areas and areas prone to desertification and drought, and thus promise to present extensive support through investment, insurance, and technology transfer. The Pacific Island Coral Triangle (PICT) project countries—Fiji, Solomon Islands, Vanuatu, and Timor-Leste—have ratified the UNFCCC and are members of the UNFCCC Parties. However, Timor-Leste is considered by the UN to be a least-developed country; hence, it has received special attention due to its limited capacity to respond and adapt to the harmful effects of climate change.

The high vulnerability of the Pacific Island countries to the harsh environmental, socioeconomic, and cultural consequences of climate change has induced them to pursue a range of climate adaptation strategies (Davetanivalu 2013; Kauhiona and Vavekaramui 2013; Williams 2013; SPREP/APAN 2013). As noted in Sections 3–6 of this report, much of the focus has been on first mainstreaming climate change policies into national planning, and then mainstreaming adaptation to climate change into the national climate change policies, national adaptation plans of action, and other key programs at the national level. These strategies emphasize longer-term climate change risks in development and resource management planning, and efforts to improve adaptive the capacities and enhance the livelihoods of the Pacific Island countries (Davetanivalu 2013; Kauhiona and Vavekaramui 2013; Williams 2013).

As presented in Section 2, modeling exercises were carried out in this research project to assess the impacts of three adaptation strategies namely, marine protected areas, low-cost inshore fish aggregating devices and aquaculture under climate change, and discussed in Sections 3–6 of this report (Fiji, Solomon Islands, Vanuatu, and Timor-Leste). In order to place the modeling analysis within a broader context, we summarized the evidence in the (relatively limited) literature (presented in Section 1) relevant to our analysis regarding the benefits and costs (whenever possible). In this section, we attempt to summarize the insights from the focus group discussions that bear directly on perceptions of climate change impact and climate change adaptation to improve quality of life in coastal communities, and then review the evidence on and implementation approaches of these strategies, as well as national government policies and support extended to these strategies. Finally, we summarize the key findings and policy conclusions.

B. Impacts of climate change adaptation strategies on quality of life

The harsh effects of changing climate conditions have dramatic effects, not only on the local economies, but more so on income, food security, and eventually quality of life, particularly in rural poor communities in developing countries. Severe weather events prevent coastal villagers from performing their daily economic activities, like fishing and planting in backyard gardens. With the unpredictable activities of gathering food and marketing of produce as sources of family income, there is high risk of jeopardizing the quality of life of these coastal communities. Hence, there is a compelling need to build the resilience of rural communities in developing countries to climate change.

The following subsections qualitatively discuss the current impacts of changes in fish harvests brought about by climate change, among other effects on the quality of life of the coastal communities of Fiji, Solomon Islands, Timor-Leste, and Vanuatu. Consequently, current and/or perceived impacts on the quality of life if climate change adaptation strategies are adopted were likewise described based on FGD responses from the four Pacific countries. Participants of the FGDs were considered as “experts” in their respective livelihood activities, daily experiences, and how they modify these activities according to the current climate conditions. These climate change adaptation strategies include aquaculture development, deployment of low-cost inshore FADs, and establishment of MPAs.

1. *Without climate change adaptation strategies*

In Atauro Island, Timor-Leste, responses from FGDs reveal the decrease if not absence of income during periods of cyclones, since fishers could not fish in rough seas. With less income, families have to prioritize their spending behavior. Most often than not, purchasing food is a high priority, while education and synthetic medicines are among the lowest priorities. Similar responses were observed in coastal communities of Isabel Province, Solomon Islands, as well as in Sanma Province, Santo Island, Vanuatu.

Furthermore, FGD respondents discussed that rising sea temperature, coral bleaching, and destruction of coral reefs, among other effects, impede fish production. With the number of fishers from the immediate communities competing for the same resource, the challenge to catch enough fish from the coastal areas to meet family needs will be considerable. Reflecting this reality, FGD responses from the coastal communities of the four Pacific countries indicate the difficulty of catching the scarce fish resources from the coastal areas. The respondents in Ra province (Fiji); Isabel Province (Solomon Islands); Port Olry and Napauk villages, Sanma Province (Vanuatu); and Liquica district and Atauro Island, Dili district (Timor-Leste) stated that, despite longer hours spent fishing, fish catch has been reduced. This increased time working also results to less quality time spent with the family. In addition, because of less sophisticated or traditional fishing gears and inadequate fishing boat capacity, fishers are unable to go beyond the coastal areas to access other fish resources in the deep sea.

Without any climate change adaptation strategies in place in the coastal areas of the four PICT countries, subsistence or even artisanal and small-scale fishing will have difficulty catching enough fish for food and income. Key findings reported by participants from at least two of the FGD in the four provinces include the following: (1) less food is available as vegetable gardens are destroyed by cyclones, flooding, or rising sea level (Ra Province, Fiji; Isabel Province, Solomon Islands; Atauro Island, Timor-Leste; Sanma Province, Vanuatu); (2) if food is available, accessibility is difficult because floods, impassable roads, or lack of transportation (Isabel Province, Solomon Islands; Atauro Island, Timor-Leste; Sanma Province, Vanuatu); (3) food is limited, particularly fish caught from coastal areas, and/or money is limited (because of decreased incomes from fishing) to purchase enough food (Atauro Island, Timor-Leste; Sanma Province, Vanuatu); (4) the health of family members is poor as a result of insufficient food, imbalanced diets, and deteriorating hygiene (Atauro Island, Timor-Leste; Sanma Province, Vanuatu); (5) spending money to send children to schools or for education is of the least priority compared with food nutrition and security (Atauro Island, Timor-Leste; Sanma Province, Vanuatu); and (6) dependence on traditional medication is increasing, as money is spent on food, rather than synthetic medicines (Ra Province, Fiji; Isabel Province, Solomon Islands; Atauro Island, Timor-Leste; Sanma Province, Vanuatu). Education expenses include tuition fees, transportation costs, books and other school requirements (paper, pencils, pens, etc.). Overall, with worsening climate conditions, the socioeconomic activities of rural coastal communities were seriously impeded, while the future the next generation is at stake, leading to a lower or poor quality of life.

2. With climate change adaptation strategies

Aquaculture has been established at various scales in different areas of the four PICT countries. In Fiji, respondents positively predicted better food availability, regardless of extreme weather events, in areas where tilapia, local prawn, and seaweed farming has been developed and is still in operation. It is anticipated that marketing fish surplus for the farm owners will considerably improve the income of their families. Likewise, creation of jobs as farm laborers will augment the family income of coastal villagers.

Similarly, respondents are encouraged that low-cost inshore FADs will increase tuna harvests in Timor-Leste, Vanuatu, and other countries where they are applied. Inshore FADs are also seen to lower the risks to the fishers' lives, as they do not need to go farther into the open ocean or deep sea to catch fish. Establishment of MPAs is expected to enhance fish growth and recover fish population in Fiji, Solomon Islands, and other Pacific countries. It is anticipated that outside the boundaries of MPAs, there will be an increase in fish populations and thus will improve the catch of coastal fishers.

Respondents from Ra Province (Fiji), Isabel Province (Solomon Islands), Atauro Island (Timor-Leste), and Sanma Province (Vanuatu) articulated that with higher volumes of fish caught in coastal seas due to FADs and/or MPAs or harvested from fish farms, the quantity of food available for consumption to meet the needs of families is greater. In addition, the respondents from the four PICT countries discussed that better diets and nutrition from available food significantly reduce family health problems. Moreover, marketing excess fish harvest will enhance family incomes and remove the barriers to children's education as payment of school fees becomes possible (Atauro Island, Timor-Leste; Sanma Province, Vanuatu).

MPAs have long been established in the Pacific countries through the LMMA Network. To date, the three Pacific countries, Fiji, Solomon Islands, and Vanuatu have corroborated FLMMA, SILMMA, and VLMMA, respectively. A number of studies have been conducted in these areas, and detailed descriptions have been provided throughout this report.

Results from the economic analysis of the case studies in Fiji and Vanuatu show that establishment of MPAs is a sound adaptation strategy that enhances coastal protection against flooding that can occur during extreme weather events. These results support the findings of the current study regarding the positive impacts of MPAs in halting the decline in coastal fisheries and improving fishing productivity in the coastal areas that will favorably affect subsistence fishers in Vanuatu and Fiji. Aside from fishing productivity, reef-associated tourism produces revenues in these two countries. Creation of jobs from tourism businesses increases the incomes of community members, which in turn enhances food and nutrition security, as well as the quality of life in these coastal communities.

On the other hand, inshore FADs are still in the infancy stage for most of the PICT countries. The most common issue reported regarding FGDs is the loss of deployed FADs, probably caused by high waves, cyclones, theft, or unintentional destruction. The respondents assume that the national governments will provide construction materials will take the lead in deploying and maintaining the FADs. Open dialogues among the village leaders/chiefs, coastal communities, and the local and national governments will need to be regularly held to resolve any current or potential issues, such as encroachment on the boundaries of MPAs versus the areas where FADs will be deployed; rules and regulations, including tuna catch inside the FADs; and awareness building regarding FADs, climate change, and other issues.

In summary, the national governments have strong responsibilities and a crucial lead role in the implementation, adoption, and maintenance of climate change adaptation strategies discussed above. Similarly, the actions and cooperation of all stakeholders, particularly the rural communities in the coastal villages, are of vital importance in the success of these climate change adaptation strategies.

C. Management Plans and National Policies Supporting Adaptation Strategies

The possibility and success of developing and executing any adaptation strategy, particularly for catastrophic events, such as the effects of climate change, depend on the creation and implementation of management plans and policies, as supported more significantly by the national governments, and with technical assistance from NGOs as needed. The important documents that are currently supporting the adaptation strategies presented in the preceding sections and in the modeling analysis are discussed below.

1. Fiji

The project reviewed various published reports and other development plans, including the *National Biodiversity Action Plan*, the *National Climate Change Policy*, the *Integrated Coastal Management Plan,* the *Environment Management Plan*, and the Fisheries Act and Marine Species Act. These reports are listed in Table 7.1 and are summarized below.

Table 7.1
National Development Plans and Policies Benefiting Coastal Communities of Fiji

National Development Policies and Plans	Source
20-Year Development Plan (2001–2020)	Ministry of Finance, Planning and Sugar Industry 2007
National Strategic Development Plan (2007–2011)	Ministry of Finance and National Planning 2006
Sustainable Economic Empowerment Development Strategy (2008–2010)	Ministry of Finance, Planning and Sugar Industry 2007
Environment - *National Environment Strategy 1993* - *Endangered and Protected Species Act 2002* - *Endangered and Protected Species Regulations 2003* - *Environmental Management Act 2005* - *National Biodiversity Strategy and Action Plan 2007* - *Ecosystem Based Management Plan 2009 (EBMP)* - *National Biodiversity Strategy and Action Plan Implementation Framework 2010–2014*	Department of Environment, various years; Wildlife Conservation Society (for EBMP)
Climate Change Policy: - *Fiji's First National Communication Under the*	Government of the Republic of Fiji 2012; Department of Environment

National Development Policies and Plans	Source
Framework Convention on Climate Change 2005 - *Clean Development Mechanism Policy Guideline 2010* - *National Climate Change Policy 2012*	
Coastal Development Policies: - *Environment Management Act 2005* - *Integrated Coastal Management (ICM) framework 2010*	Department of Environment, Fiji 2011
Coastal/Capture Fisheries Policies: - *Fisheries Act (Cap 158)* - *Marine Spaces Act (Cap 158A)*	Ministry of Fisheries and Forestry (MFF)
Aquaculture Policies: - *Fiji Islands Freshwater Aquaculture Strategic Plan 2005–2009*	MFF
Management Plans - *Fiji Tuna Development and Management Plan 2002*	Anon 2002
Marine Protected Areas and Biodiversity - *Fiji National Biodiversity Strategy and Action Plan (2007–2011)* - *Implementation Framework 2010–2014*	Department of Environment; Techera and Troniak 2009

Source: Valmonte-Santos, Rosegrant and Dey 2016.

Fiji is currently undergoing policy and institutional reforms to update and develop its legislation. By ensuring sustainable socioeconomic development, the country hopes to improve the livelihoods of its diverse communities. Fisheries is considered one of the major areas of development by the Fisheries Act (Cap 158), Marine Spaces Act (Cap 158A), and Fiji Tuna Development and Management Plan. Moreover, Fiji has developed the *Freshwater Aquaculture Strategic Plan 2005–2009* to support subsistence, semi-commercial, and industrial farms. These initiatives are intended to fulfill the goals of the *National Strategic Development Plan (2007–2011)*, the *Sustainable Economic and Empowerment Development Strategy (2008–2010),* and the *20-Year Development Plan (2001–2020),* which aim to develop and implement the best possible political, social, and economic policies. These initiatives match Fiji's *National Climate Change Policy 2009–2014* in recognizing the vulnerability of—and importance of adaptation strategies for—the Fiji fisheries sector. However, the feasibility of implementing and integrating the *National Climate Change Policy* in coastal fisheries communities remains a challenge. The Fisheries Act (Cap 158) has placed a less than necessary emphasis on coastal subsistence fisheries, which are a vital factor for the food security and livelihood assurance of the coastal communities. There is a need for greater emphasis on fisheries management strategies in climate change policy. Understanding and measuring the potential effects of adaptation strategies (policy- and/or technology-based) remains pertinent to the development of various segments of Fiji, particularly for coastal communities.

2. Solomon Islands

The project reviewed literature, published reports, and other related information on national development strategies, food security, utilization of natural resources, and climate change in Solomon Islands. These reports are listed in Table 7.2 and are summarized in this section. We have also reviewed some of the Asian Development Bank knowledge products, such as Gillett (2009) and the *State of the Coral Triangle Report for Solomon Island* (Sulu et al. 2012).

Table 7.2

National Development Plans and Policies Benefiting Coastal Communities of Solomon Islands

National Development Policies and Plans	Source
National Development Strategy (NDS, 2011–2021)	Ministry of Development Planning and Aid Coordination 2011
Vision 2020	Solomon Islands Government 2005
National Economic Recovery, Reform and Development Plan (NERRDP) (2003–2006)	Department of National Reform and Planning 2003
Environment - *Environment Act 1988* - *National Environmental Capacity Development Action Plan 2008–2012* - *Wildlife Protection and Management Act 1998* - *National Biodiversity Strategic Action Plan 2009* - *Protected Areas Act 2010* - *Protected Areas Regulation 2012*	Ministry of Environment, Climate Change, Disaster Management and Meteorology (MECDM)
Climate Change Policies - *Solomon Islands National Plan of Action 2010* - *National Plan of Action—Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security 2010* - *Solomon Islands National Climate Change Policy (2012–2017)* - *National Adaptation Programmes of Action (NAPA)*	Wickham et al. 2012; MECDM
Coastal Development Policies - *Environment Act* - *Solomon Island National Strategy for the Management of Inshore Fisheries and Marine Resources 2010–2012*	SPREP 1993; MECDM; Ministry of Fisheries and Marine Resources (MFMR)
Coastal/Capture Fisheries Policies - *Fisheries Act (No. 6 of 1998)* - *Solomon Islands National Fish Aggregation Device Management Plan 2008* - *Fisheries Amendment Act (No. 6 of 2009)* - *Fisheries (USA) (Treaty) Act, Cap 39*	MFMR
Aquaculture Policies - *Solomon Islands Aquaculture Development Plan 2009–2014* - *Solomon Islands Tilapia Aquaculture Action Plan 2010–2015*	MFMR 2009, 2010
Management Plans - *Tuna Management and Development Plan 1999*	MFMR; Aqorau 2001

Source: Valmonte-Santos, Rosegrant and Dey 2016.

Fishery policies in Solomon Islands have made significant attempts to keep up with economic transformation, food security, and livelihood development. It is particularly true for the Fisheries Amendment Act (No. 6 2009), which places special emphasis on tuna resources to maximize their economic and social benefits to the people of Solomon Islands. Duties are imposed on certain Pacific Island countries and on the United States of America under the Fisheries (USA) (Treaty) Act, Cap 39. The *Aquaculture Development Plan (2009–2014)* and the *Tilapia Aquaculture Action Plan (2010–2015)* are currently in place to meet the food and income requirements of Solomon Islanders. These initiatives conform to the *National Development Strategy (2011–2020)*, which recognizes the fisheries sector as a potentially important contributor. The *National Climate Change Policy (2012–2017)* has also proven the importance of this sector by expending much effort in determining the impacts of aquaculture response strategies. However, consistent policy formulation related to the formal designation of MPAs, integrated coastal management (ICM), and subsistence coastal fisheries has so far been largely overlooked. This is also true regarding technological aspects, which are a potential strategy for climate change adaptation in the coastal fisheries communities. Our review suggests that identification of economically viable adaptive strategies (technology- and/or policy-based) tailored to current environmental conditions through an economic model could be beneficial.

3. Vanuatu

Various literature, published reports, government documents, and other related information are available on national development strategies, food security, utilization of natural resources, and climate change in Vanuatu. These documents are summarized in this section and presented in Table 7.3.

Table 7.3
National Development Plans and Policies Benefiting Coastal Communities of Vanuatu

National Development Policies and Plans	Source
National Development Plan 1982–1986; 1987–1991; 1992–1996	
Environment - *Environmental Management and Conservation Act 2002*	Vanuatu Department of Environmental Protection and Conservation (VDEPC)
Coastal Development - *Foreshore Development Act 1975* - *National Integrated Coastal Management Framework*	Ministry of Internal Affairs
Fisheries - *Fisheries Act 1982* - *Fisheries Act (amended) 1989* - *Fisheries Regulations 2004* - *Fisheries Act 2005* - *Decentralization and Local Government Act 1994*	Vanuatu Department of Fisheries (VDOF)
Aquaculture - *Aquaculture Development Plan 2008–2013*	VDOF
Management Plans - *Community Based Management Plans* - *Vanuatu National Marine Aquarium Trade Management Plan 2009a* - *Trochus Management Plan* - *Sea Cucumber Management Plan* - *National Tuna Fishery Management Plan 2000* - *Revised Tuna Management Plan 2009b* - *Vanuatu Management Plan for the Regulation of Fish Aggregating Devices (draft)*	VDOF
Climate Change Policies - *Vanuatu National Adaptation Programme of Action (VNAPA)* - *National Action Plan (NAP)*	Vanuatu Meteorological Services

Source: Valmonte-Santos, Rosegrant and Dey 2016

The Environment and Management Act, encompassing biodiversity strategies and community conservation areas, enabled the development of LMMAs and eventually the MPAs. Other policies supporting these adaptation strategies include an ICM framework and the Fisheries Act and fisheries regulations. The Decentralization and Local Government Act is critically important, as it gives extensive power and authorities to the local government councils and the provincial governments. More important is its extensive powers to pass bylaws affecting marine resource use.

Aside from the MPAs, a FAD management plan, aquaculture policies, and plans, as well as other species-specific management plans will benefit the coastal communities of Vanuatu. These plans provide guidelines regarding conservation, protection, and harvesting strategies of these fisheries resources. The *National Action Plan* and the *Vanuatu National Adaptation Programme of Action* outline proposed actions and adaptation strategies, not only for coastal communities, but also for the entire country. Maintaining government support and providing additional support to feasible strategies in partnerships with the communities, other government agencies, NGOs, donors, and other stakeholders will combat the ill effects of changing climate and worsening environmental and economic conditions of Vanuatu.

4. Timor-Leste

Similar to the other three countries studied, published reports, government documents, and other related information on national development strategies, food security, utilization of natural resources, and climate change were reviewed for Timor-Leste (Table 7.4).

Table 7.4
National Development Plans and Policies Benefiting Coastal Communities of Timor-Leste

National Development Policies and Plans	Source
National Strategic Development Plan (NSDP) 2011–2030, 2011a	
National Development Plan 2002	Ministry of Economy and Development (MED)
Environment - *National Biodiversity Strategic Action Plan (NBSAP), 2011b* - *NAPA to Combat Land Degradation* - Environmental Basic Law (under legislative process) - Policy and Strategic Plan for Environment (for presentation and approval) - Marine Protected Area— Marine Zoning	MED; Democratic Republic of Timor-Leste; Secretary of the State of Environment
Fisheries - Fisheries Sector Plan - *Fish for Sustainability. Our Strategic Plan for Fisheries, 2006–2011* - *The Future of Fisheries: A Policy and Strategy for the Responsible Development and Management of Fisheries in Timor-Leste 2007* - *Fisheries Quarantine 2011*	National Directorate of Fisheries and Aquaculture, Ministry of Agriculture and Fisheries (NDFA-MAF)
Aquaculture - *National Aquaculture Development Strategy 2012–2030*	NDFA-MAF
Management Plans - *Trochus Fishery Management*	Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security; MAF
Climate Change - *National Adaptation Plan of Action (NAPA)*	

National Development Policies and Plans	Source
- *NAPA for Climate Change*	
- *NAPA for Coral Triangle Initiative*	

Source: Valmonte-Santos, Rosegrant and Dey 2016.

The Democratic Republic of Timor-Leste gained its independence a decade ago. Despite being a relatively young country, Timor-Leste has actively positioned itself in several international conventions and agreements to assure the international community—and more so the people of Timor-Leste—of its commitments, particularly regarding adaptation and mitigation measures for alleviating the adverse impacts of climate change.

The responsible government agencies continue to evolve with policies and management plans, including development of strategies and actions when faced with natural disasters. The three main adaptation strategies—namely, MPAs, low-cost inshore FADs and aquaculture—are already incorporated in various environmental and fisheries management plans and policies.

D. Summary and Conclusions: Implications for Food Security and Economies of the Pacific Coral Triangle Countries

We have developed a rigorous analytical tool that is capable of comparatively analyzing alternative development scenarios, even under data-scarce situations. The model is utilized to analyze the potential effects of various climate change adaptation strategies in the four PICT countries studied.

The modeling analysis first illuminates key differences across the four countries, mainly due to the fish trade regimes prevailing in different countries, the relative importance of various sectors in fish production and consumption, and producers' and consumers' behaviors in various countries as reflected through supply and demand elasticities. The key differences in country results include the following:

Net fish trade under baseline conditions. Currently, Fiji, Solomon Islands, and Vanuatu are net exporters of fish and seafood, while Timor-Leste is a net importer of fish. Our baseline projections indicate that Vanuatu will continue to be a net fish exporter and Timor-Leste will remain a net fish importer in the long term. For Solomon Islands, domestic demand for fish is likely to surpass the supply from domestic sources (i.e., the domestic fishing industry and aquaculture farms, but not including the catch of foreign fishing fleets) in the long term (2050). It is likely that, with high population and per capita income growth, Fiji may become a net importer of fish in the long run.

Fish trade by species group under the baseline scenarios. Similar to overall fish trade, all countries under consideration, except Timor-Leste, are currently net exporters of tuna and other oceanic fish. Our model predicts that Fiji and Vanuatu will continue to be net exporters of oceanic fish in the long run. But Solomon Islands is unlikely to be able to meet domestic demand for oceanic fish from its domestic sources.

Supply of oceanic fish species under the baseline scenarios. Our baseline scenarios project that supply of tuna and other oceanic fish from the domestic fishing industry (not considering catch by foreign vessels) will increase over time in Fiji and Vanuatu, but will remain more or less the same in Solomon Islands. Tuna and oceanic fish supply is likely to decrease over time in Timor-Leste. It is important to note that various ecosystem-based tuna models (such as SEAPODYM) show that skipjack tuna is projected to move to the east (Eastern Pacific

Ocean), and the biomass of adult tuna will decrease in the West and Central Pacific Ocean (Lehodey et al. 2011), consistent with our findings.

Effects on fish prices under the baseline scenarios. The real prices of different fish categories are expected to increase over time in Vanuatu under baseline conditions. For other countries, the real prices of various fish categories, except that of tuna in Fiji and of coastal finfish in Timor-Leste, are likely to be held in check due to increased imports. Given the high share of tuna in the total fish consumption of Fiji, the real price of tuna is expected to increase in the country. Our model shows that not all excess demand for tuna in Fiji can be met through trade adjustments. On the other hand, the real price of coastal finfish in Timor-Leste, which is the main source of fish in the country, is expected to increase by about 9% during the 2009–2050 under the high economic growth scenario.

Effects of FADs. Given that quality data on the implementation of FADs were available only for Solomon Islands, we analyzed the economic effects of FADs only for that country. Our simulation analysis shows that adaptation of FADs is likely to increase tuna and oceanic fish supply from domestic sources.

Effects of aquaculture. Modeling analysis in this report illustrated that, if fully developed and supported by the national governments, invested in by the private sector, and implemented at the grassroots level, aquaculture will contribute to food and nutrition security, enhanced livelihoods, and foreign exchange earnings.

Our results also show important common policy results across the countries. The modeling exercise and scenario analyses led to the following conclusions and policy lessons:

1. **A decrease in per capita consumption of domestically produced fish is expected.** With rising per capita income and population, demand for fish and seafood in various Pacific Island countries is expected to increase substantially for the period up to 2050. As indicated earlier, currently many Pacific Island countries (including Fiji, Solomon Islands, and Vanuatu) are net exporters of fish, excluding foreign tuna catch. Without any appropriate policy and/or technological intervention (as reflected in the baseline scenarios), fish exports from these countries are expected to decrease, fish imports are expected to increase, and net exports (export minus import) are likely to decline over time. This will lead to a decline in per capita consumption of domestically produced fish, which has serious negative food security implications for these countries.

2. **A substantial increase in seafood imports is likely**. In many Pacific Island countries, domestic prices of some fish species are higher than their world market prices. Fish is a highly traded commodity; producers of Pacific Island countries will face competition with more efficient foreign producers of fisheries and aquaculture products. There is a risk that more efficient and cheaper producing countries may take advantage of this situation of higher fish prices and may promote the export of their seafood products in Pacific Island countries. Increased imports of seafood can also strain the foreign exchange reserves of these countries.

3. **Under current policies coastal fish supply will likely decrease.** In contrast to rising fish demand over time, supply of fish from coastal fisheries is expected to decline due to climate change and other adverse environmental effects. Therefore, there is an urgent need to increase the supply of fish in Pacific Island countries from their

domestic sources by reversing the negative trends of coastal fisheries and/or increasing supply from oceanic and freshwater systems.

4. **Aquaculture growth will be an important component of adaptation strategies.** Promoting aquaculture can help raise aggregate fish production, consumption, and trade. However, the required increases in aquaculture could be massive. While it is very unlikely that aquaculture development alone will be able to meet the growing excess demand for fish in these countries, aquaculture will be an important component in adapting to the negative effects of climate change on capture fisheries. As shown in some of our simulation results, it is important to note that aquaculture development also increases income and may trigger higher consumption and imports of other types of fish.

5. **Better access to tuna resources should be created.** Overall tuna abundance is expected to increase due to climate change. However, small-scale fishers are unable to access the rich offshore fishing grounds. Rising fuel prices have made fishing even more costly, particularly for small-scale fishers. In many cases, foreign vessels catch these offshore fish. In some countries, like Solomon Islands, about 90% of tuna is caught by foreign fleets. License fees from foreign vessels are an important source of revenue, but tuna caught by foreign vessels are not available for domestic consumption. There is a need for policies and/or technologies to enable small-scale fishers to access the resources of offshore fisheries. Low-cost FADs offer a mechanism for subsistence and small-scale fishers to access oceanic species. One of our model simulations shows the likely positive effects of low-cost FADs in Solomon Islands. If cost and topographic conditions permit, low-cost FADs are expected to be a good mechanism for augmenting domestic supplies of tuna and similar species.

6. **Better marketing and processing infrastructure are necessary.** In some cases, such as in Vanuatu, fish caught offshore cannot be marketed in the country due to the absence of transport/storage and facilities/marketing chains. Improvement in storage and transportation facilities and onshore processing of oceanic species (such as tuna) will augment the domestic supply of fish.

7. **The positive effects of NRM strategies should be supported and communities encouraged**. Various NRM strategies, such as MPAs, are projected to have positive impacts in the project countries, expanding the stock and catch of fish. However, as shown in our simulations, current efforts on various NRM strategies are too small to have any meaningful impact to reverse the declining trends of coastal fisheries catch.

8. **Returns on investments on climate change adaptation strategies are very high**. The economic (welfare) analysis conducted based on modeling results show that the national-level net economic gains due to climate change adaptation strategies are substantial. In most cases, the yearly net benefit is more than 10- to 20-fold higher than the required yearly investment cost. For example, the estimated yearly net economic gain from investment in an MPA/LLMA in Fiji is about 100-fold of the investment cost. In Solomon Islands, a yearly investment of about $230,000 in FADs is expected to generate a yearly income of more than $6.95 million in 2035 (a more than 30-fold increase in yearly net return). These national-level findings are consistent with the findings of previously conducted location specific studies, which were summarized in this Section.

9. **Better quality of life due to climate change adaptation strategies**: In additional to the tangible economic gain, adaptation of climate change adaptation strategies improves quality of life of rural coastal communities in the Pacific island countries. Results of our FGD show that without any climate change adaption strategies, the socio-economic activities of the rural coastal communities will be seriously impeded while the future of children, the next generation is at stake, leading to lowered or poor quality of life.

10. **Current scales of adaptation strategies are too small.** Our results show that climate change adaptation strategies, such as aquaculture, FADs, and NRM, are likely to have a positive impact on the Pacific Island countries. However, their current scales of implementation are too small to have any substantial and necessary impacts.

11. **Investment in fisheries needs to be increased.** There is a need for an aggressive, but judicious, increase in investment in aquaculture, low-cost FADs, and NRM technologies and management strategies to adapt to climate change and to meet the growing demand for fish.

12. **Adaptation strategies need to be location-specific.** As shown in most of our simulation exercises, aquaculture, FADs, and NRM affect different products and ecosystems differently. Therefore, it is essential to tailor these climate change adaptation strategies and policies to the conditions in each of the countries and locations.

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APPENDIX TABLES

Appendix Table A.1
Aggregated Fish Balance Sheet for Fiji-Fish Model

Fish Group	Production (t)	Consumption (t)	Net Trade (t)	Price ($/t)
Tuna	17,600.25	7,956.96	9,643.29	2,546
Other oceanic finfish	550.50	237.68	312.82	3,076
Coastal finfish	28,467.50	33,126.78	–4,659.28	2,544
Coastal invertebrates	2,625.25	1,157.41	1,467.84	4,408
Freshwater finfish	1,019.26	1,019.26	0.00	2,500
Freshwater invertebrates	985.47	985.42	0.00	7,652
Total	**51,248.17**	**44,483.49**	**6,764.68**	**-**

Net trade positive = net export, and Net trade negative = net import.
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Source: Dey et al. 2016b.

Appendix Table A.2
Validated Supply Elasticity Estimates for Various Fish Groups Used in Fiji-Fish Model

Fish Group	Tuna	Other Oceanic Finfish	Coastal Finfish	Coastal Invertebrates	Freshwater Finfish	Freshwater Invertebrates
Tuna	0.60					
Other oceanic finfish	0.10	0.60				
Coastal finfish	–0.15	–0.20	0.45			
Coastal Invertebrates	–0.15	–0.10	–0.05	0.45		
Freshwater finfish	–0.15	–0.10	–0.05	–0.05	0.75	
Freshwater invertebrates	–0.25	–0.30	0.00	–0.10	-0.40	1.05

Reprinted from "Economic impact of climate change and climate change adaptation strategies for fisheries sector in Fiji" by Dey, M.M., K. Gosh, R.A. Valmonte-Santos, M.W. Rosegrant, and O.L. Chen. *Marine Policy*. Copyright (2016) by Elsevier
Source**:** Dey et al. 2016b.

Appendix Table A.3
Validated Demand Elasticity Estimates for Various Fish Groups Used in Fiji-Fish Model

Fish Group	Tuna	Other Oceanic Finfish	Coastal Finfish	Coastal Invertebrates	Freshwater Finfish	Freshwater Invertebrates
Own-Price Elasticity						
Tuna	–1.00					
Other oceanic finfish	0.20	–1.05				
Coastal finfishes	0.10	0.05	–1.05			
Coastal invertebrates	0.05	0.05	0.05	–1.15		
Freshwater finfish	0.05	0.15	0.20	0.10	–1.00	
Freshwater invertebrates	0.05	0.05	0.05	0.05	0.00	–1.00
Income Elasticity	0.55	0.55	0.60	0.85	0.50	0.80

Reprinted from “Economic impact of climate change and climate change adaptation strategies for fisheries sector in Fiji” by Dey, M.M., K. Gosh, R.A. Valmonte-Santos, M.W. Rosegrant, and O.L. Chen. *Marine Policy*. Copyright (2016) by Elsevier
Source: Dey et al. 2016b.

Appendix Table A.4
Shift in Supply Curve[a] (%) from Baseline (2006–2009) to 2035 and 2050, under Alternative Climate Change Adaptation Strategies in Fiji

Species Group	2035				2050			
	Baseline (trend)	AQ	NRM	AQ+NRM	Baseline (trend)	AQ	NRM	AQ+ NRM
Tuna	15	15	30	30	15	15	30	30
Other oceanic finfish	15	15	30	30	15	15	30	30
Coastal finfish	–5	–5	0	0	–15	–15	–5	–5
Coastal Invertebrates	–5	–5	0	0	–15	–15	–5	–5
Freshwater finfish	25	75	25	75	75	125	75	125
Freshwater invertebrates	25	75	25	75	75	125	75	125

[a] This shift in supply curve has been denoted in equation (2) as (λ_0) for baseline scenarios and as (λ_1) for various climate change adaptation scenarios.
AQ = aquaculture; NRM = natural resource management.
Reprinted from “Economic impact of climate change and climate change adaptation strategies for fisheries sector in Fiji” by Dey, M.M., K. Gosh, R.A. Valmonte-Santos, M.W. Rosegrant, and O.L. Chen. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Dey et al. 2016b.

Appendix Table A.5
Aggregated Fish Balance Sheet for Solomon Islands Fish Model

Fish Group	Production (t)	Consumption (t)	Net Trade (t)	Price ($/t)
Tuna	22,388.75	5,672.75	16,716.00	3,700
Other oceanic finfish	3,624.50	296.50	3,328.00	3,700
Coastal finfish	11,500.00	9,829.00	1,671.00	3,381
Coastal invertebrates	1,910.33	1,683.33	227.00	7,500
Freshwater finfish	30.00	30.00	0	2,560
Freshwater invertebrates	1.0	1.0	0	7,500
Total	39,454.58	17,512.58	21,942.00	-

Net trade positive = net export and Net trade negative = net import.
Reprinted from "Economic impacts of climate change and climate change adaptation strategies for the fisheries sector in Solomon Islands" by Dey, M.M., K. Gosh, R.A. Valmonte-Santos, M.W. Rosegrant, and O.L. Chen. 2016. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Dey et al. 2016c.

Appendix Table A.6
Validated Supply Elasticity Estimates for Various Fish Groups Used in Solomon Island Fish Model

Fish Group	Tuna	Other Oceanic Finfish	Coastal Finfish	Coastal Invertebrates	Freshwater Finfish	Freshwater Invertebrates
Tuna	0.30					
Other oceanic finfish	0.10	0.30				
Coastal finfish	–0.15	–0.20	0.35			
Coastal invertebrates	–0.15	–0.05	–0.05	0.30		
Freshwater finfish	–0.05	–0.05	–0.05	–0.05	0.25	
Freshwater invertebrates	–0.05	–0.10	0.10	0.00	–0.05	0.10

Reprinted from "Economic impacts of climate change and climate change adaptation strategies for the fisheries sector in Solomon Islands" by Dey, M.M., K. Gosh, R.A. Valmonte-Santos, M.W. Rosegrant, and O.L. Chen. 2016. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Dey et al. 2016c.

Appendix Table A.7
Validated Demand Elasticity Estimates for Various Fish Groups Used in Solomon Islands Fish Model

Fish Group	Tuna	Other Oceanic Finfish	Coastal Finfish	Coastal Invertebrates	Freshwater Finfish	Freshwater Invertebrates
Own-Price Elasticity						
Tuna	–1.05					
Other oceanic finfish	0.20	–1.00				
Coastal finfish	0.20	0.05	–0.95			
Coastal invertebrates	0.10	0.05	0.10	–0.95		
Freshwater finfish	0.10	0.15	0.15	0.00	–1.00	
Freshwater invertebrates	0.00	0.05	0.00	0.00	0.15	–0.90
Income Elasticity	0.45	0.50	0.45	0.70	0.45	0.70

Reprinted from "Economic impacts of climate change and climate change adaptation strategies for the fisheries sector in Solomon Islands" by Dey, M.M., K. Gosh, R.A. Valmonte-Santos, M.W. Rosegrant, and O.L. Chen. 2016. *Marine Policy*. Copyright (2016) by Elsevier.
Sources: Dey et al. 2016c.

Appendix Table A.8
Shift in Supply Curve[a] (%) from Baseline (2006–2009) to 2035 and 2050, under Alternative Climate Change Adaptation Strategies in Solomon Islands

Species Group	2035				2050			
	Baseline (trend)	AQ	FAD	NRM	Baseline (trend)	AQ	FAD	NRM
Tuna	3	3	10	3	3	3	13	3
Other oceanic finfish	3	3	10	3	3	3	13	3
Coastal finfish	-5	-5	-5	0	-10	-10	-10	-5
Coastal Invertebrates	-5	-5	-5	0	-10	-10	-10	-5
Freshwater finfish	12.5	75	12.5	12.5	25	100	25	25
Freshwater invertebrates	25	25	25	25	25	25	25	25

[a] This shift in supply curve has been denoted in equation (2) as (λ_0) for baseline scenarios and as (λ_1) for various climate change adaptation scenarios.
AQ = aquaculture; FAD = fish aggregating device; NRM = natural resource management.
Reprinted from "Economic impacts of climate change and climate change adaptation strategies for the fisheries sector in Solomon Islands" by Dey, M.M., K. Gosh, R.A. Valmonte-Santos, M.W. Rosegrant, and O.L. Chen. 2016. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Dey et al. 2016c.

Appendix Table A.9
Aggregated Fish Balance Sheet for Vanuatu Fish Model

Fish Group	Production (t)	Consumption (t)	Net Trade (t)	Price ($/t)
Tuna	55,000.00	1,896.00	53,104.00	5,500
Other oceanic finfish	3,450.50	1,358.00	2,092.50	5,500
Coastal finfish	1,908.00	4,239.31	–2,331.31	5,000
Coastal invertebrates	318.50	318.50	0.00	12,000
Freshwater finfish	100.00	100.00	0.00	3,320
Freshwater invertebrates	15.76	15.76	0.00	12,000
Total	**60,792.76**	**7,927.57**	**52,865.19**	**-**

Net trade positive = net export, and Net trade negative = net import.
Reprinted from "Economic impacts of climate change and climate change adaptation strategies in Vanuatu and Timor-Leste" by Rosegrant, M.W., M.M. Dey, R.A. Valmonte-Santos, and O.L Chen, 2016. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Rosegrant et al. 2016.

Appendix Table A.10
Validated Supply Elasticity Estimates for Various Fish Groups Used in Vanuatu Fish Model

Fish Group	Tuna	Other Oceanic Finfish	Coastal Finfish	Coastal Invertebrates	Freshwater Finfish	Freshwater Invertebrates
Tuna	0.30					
Other oceanic finfish	0.10	0.30				
Coastal finfish	–0.15	–0.20	0.35			
Coastal invertebrates	–0.15	–0.05	–0.05	0.30		
Freshwater finfish	–0.05	–0.05	–0.05	–0.05	0.25	
Freshwater invertebrates	–0.05	–0.10	0.10	0.00	–0.05	0.10

Sources: Dey et al. 2008; FGD, Sanma Province, Santo Islands, Vanuatu, August 2012; post-survey validation meeting, Port Vila, Vanuatu, June 2013.

Appendix Table A.11
Validated Demand Elasticity Estimates for Various Fish Groups Used in Vanuatu Fish Model

Fish Group	Tuna	Other oceanic Finfish	Coastal Finfish	Coastal Invertebrates	Freshwater Finfish	Freshwater Invertebrates
Own-Price Elasticity						
Tuna	–1.05					
Other oceanic finfish	0.20	–1.00				
Coastal finfish	0.20	0.05	–0.95			
Coastal invertebrates	0.10	0.05	0.10	–0.95		
Freshwater finfish	0.10	0.15	0.15	0.00	–1.00	
Freshwater invertebrates	0.00	0.05	0.00	0.00	0.15	–0.90
Income Elasticity	0.45	0.50	0.45	0.70	0.45	0.70

Sources**:** Dey et al. 2008; FGD, Sanma Province, Santo Islands, Vanuatu, August 2012; post-survey validation meeting, Port Vila, Vanuatu, June 2013.

Appendix Table A.12
Shift in Supply Curve[a] (%) from Baseline (2006–2009) to 2035 and 2050, under Alternative Climate Change Adaptation Strategies in Vanuatu

Species Group	2035				2050			
	Baseline (trend)	AQ	NRM+ FAD	AQ+ NRM+ FAD	Baseline (trend)	AQ	NRM+ FAD	AQ+ NRM+ FAD
Tuna	10	10	15	15	10	10	20	20
Other oceanic finfish	10	10	15	15	10	10	20	20
Coastal finfish	–10	–10	0	0	–15	–15	–10	–10
Coastal invertebrates	–10	–10	0	0	–15	–15	–10	–10
Freshwater finfish	25	75	25	75	50	100	50	100
Freshwater invertebrates	25	75	25	75	50	100	50	100

[a] This shift in supply curve has been denoted in equation (2) as (λ_0) for baseline scenarios and as (λ_1) for various climate change adaptation scenarios.
AQ = aquaculture; NRM = natural resource management; FAD = fish aggregating device.
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Sources: Rosegrant et al. 2016.

Appendix Table A.13
Aggregated Fish Balance Sheet for Timor-Leste

Fish Group	Production (t)	Consumption (t)	Net Trade (t)	Price ($/t)
Tuna	585.98	818.24	-232.26	4,030
Other oceanic finfish	1,022.38	1,112.44	-90.06	3,910
Coastal finfish	2,145.81	2,987.95	–842.14	3,390
Coastal invertebrates	854.19	1,185.99	–331.80	1,690
Freshwater finfish	398.39	398.39	0	2,500
Freshwater invertebrates	1.00	1.000	0	5,000
Total	**5,007.750**	**6,504.01**	**–1,496.26**	–

Net trade positive = net export and Net trade negative = net import.
Reprinted from "Economic impacts of climate change and climate change adaptation strategies in Vanuatu and Timor-Leste" by Rosegrant, M.W., M.M. Dey, R.A. Valmonte-Santos, and O.L Chen, 2016. *Marine Policy*. Copyright (2016) by Elsevier.
Source: Rosegrant et al. 2016.

Appendix Table A.14
Validated Supply Elasticity Estimates for Various Fish Groups Used in Timor-Leste Fish Model

Fish Group	Tuna	Other Oceanic Finfish	Coastal Finfish	Coastal Invertebrates	Freshwater Finfish	Freshwater Invertebrates
Tuna	0.60					
Other oceanic finfish	0.10	0.60				
Coastal finfish	–0.15	–0.20	0.45			
Coastal invertebrates	–0.15	–0.10	–0.05	0.45		
Freshwater finfish	–0.15	–0.10	–0.05	–0.05	0.75	
Freshwater invertebrates	–0.25	–0.30	0.00	–0.10	–0.40	1.05

Sources**:** Dey et al. 2008; expert consultations in the Asia and Pacific regions.

Appendix Table A.85
Validated Demand Elasticity Estimates for Various Fish Groups Used in Timor-Leste Fish Model

Fish Group	Tuna	Other Oceanic Finfish	Coastal Finfish	Coastal Invertebrates	Freshwater Finfish	Freshwater Invertebrates
Own-Price Elasticity						
Tuna	–1.00					
Other oceanic finfish	0.20	–1.05				
Coastal finfish	0.10	0.05	–1.05			
Coastal invertebrates	0.05	0.05	0.05	–1.15		
Freshwater finfish	0.05	0.15	0.20	0.10	–1.00	
Freshwater invertebrates	0.05	0.05	0.05	0.05	0.00	–1.00
Income Elasticity	0.55	0.55	0.60	0.85	0.50	0.80

Source**:** Dey et al. 2008; expert consultations in the Asia and Pacific Region.

Appendix Table A.96
Shift in Supply Curve[a] (%) from Baseline (2006–2009) to 2035 and 2050, under Alternative Climate Change Adaptation Strategies in Timor-Leste

Species Group	2035				2050			
	Baseline (trend)	AQ	NRM	AQ+ NRM	Baseline (trend)	AQ	NRM	AQ+ NRM
Tuna	0	0	0	0	0	0	0	0
Other oceanic finfish	0	0	0	0	0	0	0	0
Coastal finfish	–5	–5	0	0	–10	–10	–5	–5
Coastal Invertebrates	–5	–5	0	0	–10	–10	–5	–5
Freshwater finfish	50	100	50	100	100	175	100	175
Freshwater invertebrates	50	100	50	100	100	175	100	175

[a] This shift in supply curve has been denoted in equation (2) as (λ_0) for baseline scenarios and as (λ_1) for various climate change adaptation scenarios.
AQ = aquaculture; NRM = natural resource management.
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Source: Rosegrant et al. 2016.