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Economic impacts of climate change and climate change adaptation strategies in Vanuatu and Timor-Leste

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ABSTRACT

The fisheries sectors in Vanuatu and Timor-Leste are important sources of food and income. Similar to other developing countries and those in the Pacific, they are vulnerable to the impacts of climate change more so because of their geographic location, socioeconomic conditions and political instability. Nonetheless, there are approaches to alleviate the damaging effects of climate change in the region's fisheries sector. Using economic modeling, this paper estimates the economic costs of potential climate change adaptation strategies for the fisheries sector in Vanuatu and Timor-Leste through assessment of alternative future scenarios. Strategies include aquaculture development, natural resource management through establishment and/or expansion of marine protected areas, and deployment of low-cost inshore fish aggregating devices. Modeling results demonstrate that the above innovations will enable the two countries to significantly improve coastal and freshwater fish production in the medium-term (2035) and long-term (2050). Fish consumption is projected to grow due to population and income improvements; yet considerable increases in production will augment demand. Furthermore, national-level gains are projected from these adaptation strategies through fish exports. Improved production under climate change will require significant investments from the national governments of Vanuatu and Timor-Leste and/or private sectors.

1. Introduction

Throughout the tropical Pacific where the majority of rural people still live and depend on subsistence agriculture, the fisheries sector (including aquaculture) is vital to economic development, livelihood, and food and nutrition security. Vanuatu has a long tradition tied to inshore and offshore fisheries; the sector supplies the main source of income and protein for many island inhabitants and makes up the country's biggest export. On the other hand, Timor-Leste has historically depended on the rural interior for the bulk of its calories and national revenue, despite its sea surroundings. Since gaining sovereignty over a decade ago, efforts to stimulate sustainable fisheries development in Timor are increasingly in the spotlight. Like other maritime islands and nations in the region, Vanuatu and Timor-Leste are particularly susceptible to climate change because of their geographical location, socioeconomic status, and political instability. Nonetheless, adaptive strategies are available to alleviate vulnerability in the region's fisheries sector to the damaging effects of climate change. Using economic modeling, this paper estimates the potential impact of climate change and climate adaptation strategies for the fisheries sector in Vanuatu and Timor-Leste.

Among the Melanesian countries, Vanuatu has the smallest total water area and exclusive economic zone (EEZ) of 680,000 square kilometers (km^2) [1]. Fisheries is fundamentally important to the nation's economy and food security, and generates income for many of its inhabitants; approximately 72% of the country's rural households are involved in some form of fishing [2]. Vanuatu's fisheries resources can be categorized into six groups: coastal commercial fisheries, coastal subsistence fisheries, offshore foreign-based fisheries, offshore locally based or domestic fisheries, freshwater fisheries, and aquaculture [3]. Unlike Fiji and Solomon Islands, coastal subsistence fisheries produce the highest value of fish harvest in Vanuatu. The four major commercial species of tuna (bigeye, yellowfin, skipjack, and albacore) dominate fish exports within Vanuatu's EEZ [2].

In contrast to Vanuatu, Solomon Islands and Fiji, which have numerous islands, Timor-Leste has only two: the 144-km^2 Atauro Island and the 8-km^2 Jaco Island [4]. Fisheries supplements income and protein for many of Timor-Leste's coastal and inland

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communities, though at smaller scale than Vanuatu. An estimated 7600 of its inhabitants were employed in the fisheries sector in 2008 [5]. Since the country only gained independence in 2002, historical information on the fisheries sector is scant and effective data systems (and policies) have been slow to develop. Timor-Leste currently lacks a domestic commercial fishing fleet and motorized vessels were largely destroyed during the struggle for independence. This limited offshore fishing and concentrated the industry to mostly small-scale fisheries near the coast. In the mid-2000s the government signed bilateral agreements allowing foreign fishing vessels limited access to the country's deep-sea fishing grounds, under conditions that fish landings and shipment be channeled through Timor's ports [5]. However, some of these agreements have expired and others have suffered from non-compliance. Freshwater fishing in Vanuatu is mostly subsistence and restricted during monsoon season. The government has identified aquaculture as a means to improve food and nutrition security and generate income for both inland and coastal communities, although little progress has been made since aquaculture is costly and requires a heavy governmental hand and infrastructure. Despite current status, the fisheries sector in Timor-Leste is at a pivotal time as the government grapples with new policies, infrastructure and strategies that aim to sustainably develop the sector for improved food security and welfare. In 2012, for example, the National Coral Triangle Initiative Coordinating Committee of Timor-Leste reported the preparation of an integrated fisheries policy: *The Future of Fisheries: A Policy and Strategy for the Responsible Development and Management of Fisheries in Timor-Leste*. This policy encompasses optimal use and management of living resources, habitat conservation and development of fishing and aquaculture industries and fisheries institutions [6].

Though several studies have analyzed the vulnerability of Asia-Pacific fisheries (including aquaculture) to climate change and adaptation scenarios (see, for example [7–10]), this is the first study to evaluate economic impact of climate change adaptation strategies in the region. Through modeling applications, trends in fish production, consumption, and trade for medium-term (2035) and long-term (2050) can be projected with and without adaptation strategies. These scenarios provide important information in developing and supporting national strategies and policies to ensure food security, nutrition, assured income and improve economic conditions, particularly for the coastal communities of Vanuatu and Timor-Leste. While the climate adaptation strategies analyzed represent only a few of the potential alternatives for an inherently uncertain future, the developed model and the analyses presented in this paper are robust for the scenarios implemented. Sensitivity analyses of a range of demand and supply elasticities around best estimates show that orders of magnitude in the results are stable with respect to the range of plausible elasticity estimates. A companion article in this special section [6] discusses the study's methodologies in greater detail including data collection, assumptions and modeling. The rest of the paper is divided into modeling scenarios, results and discussion of country case studies, and summary of conclusions.

2. Data, methodology and modeling scenarios

2.1. Vanuatu

Vanuatu has adopted four main climate change adaptation strategies: (1) aquaculture (coastal and freshwater [AQ]); (2) regulations concerning habitat protection in marine protected areas (MPAs), with 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; and (3) low-cost fish aggregating devices (FADs).

AQ was introduced to Pacific Island countries as early as the 1920s, specifically in Vanuatu with the introduction of Pacific oysters [11]. 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.

MPAs in Vanuatu have an estimated size of 58 km^2 [12]. Marine conservation activities implemented by the communities have been ongoing for several years, starting with the assistance of the Vanuatu Department of Fisheries (VDOF) in the 1990s [13]. 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 non-government organizations (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 locally marine managed area (LMMA) network, and is currently in the initial phase of establishing it countrywide [14]. Pascal, Seidi and Tiwok [15] analyzed the economic benefit of MPAs in Vanuatu and demonstrated their positive effects on marine resource productivity, coastal environment, as well as income growth through tourism revenue.

Previous studies suggest climate change is likely beneficial for tuna and oceanic fish production [16] but detrimental for coastal fish production [17] in Vanuatu. Furthermore, the likely impact of various climate change adaptation strategies on fish production indicate favorable responses: use of FADs is expected to increase tuna and other oceanic fish catch in coastal waters; and various natural resource management (NRM) strategies (such as MPAs and LLMAs) are likely to mitigate some of climate change's negative effects on coastal fisheries. Therefore, NRM and FAD strategies are anticipated to expand supply of all four capture fisheries groups (tuna, other oceanic species, coastal finfish and coastal invertebrates).

Given that many of these strategies are still in the formative stage, three climate change adaptation scenarios were modeled. *Scenario 1* (AQ development involves improvements in the productivity of freshwater (both finfish and invertebrate) aquaculture. *Scenario 2* (NRM+FAD) addresses 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. Estimated assumptions about the production impact of these strategies are described in Dey et al. [6] and given in Appendix Tables A.1 and A.2.

Over the period 2009–2013, real per capita income in Vanuatu essentially stagnated. A modest recovery in income growth over the longer run was assumed. For both medium- (2035) and long-term (2050), two baseline (most plausible) scenarios were implemented representing two annual growth rates of real per capita income: medium (1.5% per year) and high (2.5% per year). Populations were assumed at 424,122 in 2035 and 538,707 in 2050 [18].

Validated baseline data (production, consumption, trade, and price) used in the Vanuatu model are presented in Appendix Table A.1. Supply quantities reported in Table A.1 do not include catch by foreign fleets, which is small in Vanuatu. Supply volumes reported in Table A.1 and used in the analysis include catch by national fleets in both national and international waters. Appendix Table A.2 reports the coefficients of supply shifters used in the Vanuatu model to represent climate change and climate change adaptation strategies. The coefficients for climate change, as reported in

Table 1
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 1.5% annual growth per capita real income, baseline and climate change adaptation strategies, Vanuatu, from current (2006–2009) to 2035.

Key Fisheries Categories/Aquatic Ecosystems	Baseline (trend+CC)	Climate Change Adaptation Strategies		
		AQ (trend, CC, AQ)	NRM+FAD (trend, CC, NRM+FAD)	AQ+NRM+FAD (trend, CC, AQ+NRM+FAD)
PRICE				
Tuna	11.04	12.51	7.19	10.10
Other oceanic finfish	−27.60	−43.88	−15.90	−35.34
Coastal finfish	19.62	27.31	14.65	24.46
Coastal invertebrates	4.59	6.77	3.18	6.00
Freshwater finfish	31.64	66.24	19.49	52.62
Freshwater invertebrates	−5.46	−8.61	−4.12	−6.34
PRODUCTION				
Oceanic	9.94	−0.32	15.40	4.60
Coastal	−20.43	117.45	−11.69	141.97
Freshwater	139.59	2,044.88	29.23	1,964.37
CONSUMPTION				
Oceanic	289.06	454.88	201.75	347.63
Coastal	68.34	36.76	79.30	47.99
Freshwater	230.21	107.39	147.66	64.65

Notes: AQ=aquaculture development; CC=climate change; FAD=fish aggregating device; NRM=natural resource management.

Table 2
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 1.5% annual growth per capita real income, baseline and climate change adaptation strategies, Vanuatu, from current (2006–2009) to 2050.

Key Fisheries Categories/Aquatic Ecosystems	Baseline (trend+CC)	Climate Change Adaptation Strategies		
		AQ (trend, CC, AQ)	NRM+FAD (trend, CC, NRM+FAD)	AQ+NRM+FAD (trend, CC, AQ+NRM+FAD)
PRICE				
Tuna	12.50	9.51	14.93	14.79
Other oceanic finfish	−37.38	−52.64	−38.73	−48.10
Coastal finfish	23.13	34.90	23.70	27.06
Coastal invertebrates	5.54	7.69	5.56	6.81
Freshwater finfish	49.02	91.37	46.34	76.13
Freshwater invertebrates	−9.51	−11.60	−9.81	−12.52
PRODUCTION				
Oceanic	5.96	−4.72	19.42	9.82
Coastal	35.84	150.56	−11.95	108.98
Freshwater	809.66	3,127.48	256.51	2,202.12
CONSUMPTION				
Oceanic	475.11	693.70	520.82	666.02
Coastal	84.35	23.05	89.80	64.79
Freshwater	81.10	91.11	203.61	60.64

Notes: AQ=aquaculture development; CC=climate change; FAD=fish aggregating device; NRM=natural resource management.

column 2 and column 6 of Appendix Table A.2, were taken or modified from Bell et al. [19], Gehrke et al. [20], Lehodey et al. [16], Pickering et al. [21], and Prachett et al. [17] [2]. The likely effects of various climate change adaptation strategies on fish production, as reported in columns 3, 4, 5, 7, 8, and 9 of Appendix Table A.2, were collected through expert opinion survey (EOS) and focus group discussion (FGD).

2.2. Timor-Leste

As in the Vanuatu model, secondary data and FGDs were utilized to develop the parameters for the Timor-Leste model. For each time period (2035 and 2050), two baseline (most plausible) scenarios were implemented representing two annual growth rates of real per capita income: medium (2% per year) and high (3% per year). Populations of 1,724,683 in 2035 and 2,040,271 in 2050 were assumed for Timor-Leste [18].

Similar to Vanuatu, three climate change adaptation scenarios namely, AQ, NRM, and a combination of AQ+NRM were considered for Timor-Leste. MPA in Timor-Leste has an estimated area of 7 km^2 in 2010 [22]. 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 [14].

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. *Scenario 3* combines AQ and NRM.

Baseline data (production, consumption, trade and price) used in the fish sector model for Timor-Leste are given in Appendix Table A.3. Similar to other countries under study in this special section of Marine Policy, supply volumes reported in Appendix Table A.3 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. The overall shifts in the supply curve resulting from climate change and various climate change adaptation strategies used in Timor-Leste model are reported in Appendix Table A.4. The Spatial Ecosystem and Population Dynamics Model (SEAPODYM) [23] was used for the projection of the likely effects of climate change on tuna catch, which show tuna stock likely shifting to the eastern Pacific Ocean, with increased production due to climate change. Unlike for the other country case studies, the assumption was made that that tuna stock and catch will not increase in the more westward 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 resulting from climate change on coastal fisheries and shift supply curves for coastal species to the right. Likely effects of climate change adaptation strategies on fish production are reported in columns 3, 4, 5, 7, 8, and 9 of Appendix Table A.4.

3. Results of country case studies

3.1. Vanuatu

3.1.1. Changes in fish prices

Tables 1–4 present the projected real prices of several fish types in 2035 and 2050 under different scenarios, that is 1.5% annual growth per capita real income to 2035 and 2050 (Tables 1 and 2 respectively),

[2] Bell et al. [19], Gehrke et al. [20], Lehodey et al. [16], Pickering et al. [21], and Prachett et al. [17] focus on 2035 and 2100, but do not have climate change scenarios for 2050. The data for 2050 were generated from the data ranges for 2035 and 2100, based on the opinions of the experts in Vanuatu and the Pacific region.

and 2.5% annual growth per capita real income to 2035 and 2050 (Tables 3 and 4, respectively). The model predicts real price of most fish species (including coastal finfish, which contribute about 54% of current fish consumption) will increase in 2035 and 2050 under baseline scenarios. 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; the former is widely consumed by poorer households. Demand growth considerably outpaces production growth under the baseline scenario with climate change. Despite the disparity in growth, Vanuatu is projected to remain a net exporter of fish in the long-term, although the level of exports will decline (Fig. 1 below). The scenarios also show the FAD+NRM adaptation strategy is likely to have positive impact on poorer consumers. Furthermore, adoption of the FAD+NRM strategy will have the highest positive impact on oceanic fish supply. This strategy is expected to increase supply by about 14% from the present (2006–2009) level in 2035 and by about 19–20% in 2050. This indicates the potential of Vanuatu to be exporter of fish and seafood in the region. 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).

3.1.2. Changes in fish production

Among the adaptation strategies examined, adoption of FAD+NRM strategy is projected to have the highest positive impact on oceanic fish supply (Tables 1–4). Modeling results reveal that this strategy is expected to improve current supply of oceanic fish by about 14% in 2035 and about 19–20% in 2050. Projected rate of expansion in national tuna production due to rising investment in FADs is well within the sustainable tuna catch [16, 24].

Freshwater and marine aquaculture sector is a minor supplier of fish in Vanuatu. The Government of Vanuatu has placed high priority on developing the aquaculture sector (both freshwater and marine), and has taken various initiatives for improvement. To assess the potential for aggressive adaptation policies, highly optimistic productivity growth scenarios for aquaculture were applied 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 improve by about 20 times in the medium-term and about 30 times in the long-term (Tables 1–4). Even with these very high growth rates, the total production of freshwater aquaculture is projected to be 1053 to 1278 mt in 2050, lower than the 3024 to 3243 mt from coastal fisheries in 2050 under two income growth scenarios, because base year production is extremely low.

Modeling results show that aggressive aquaculture development strategy without any accompanying NRM strategies is likely to reduce catch from oceanic resources. This phenomenon is plausible due to reduction in per unit cost of production in aquaculture relative to other fishing sectors (in other words, shift in the supply curve for aquaculture without changes in other fisheries supply curves) and the resulting resource transfer to aquaculture from other sectors. These results highlight the importance of having a balanced approach with multiple climate change adaptation strategies in Vanuatu.

3.1.3. Changes in fish consumption

Modeling estimates show that fish demand will rise over time under baseline (Tables 1–4), and 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 highest increase in demand. With growth in population and income, oceanic fish demand may intensify from current levels (2006–2009) by about 3 times in 2035 and about 5 times in 2050.

Among the adaptation strategies, expanding aquaculture is likely to encourage demand for tuna and other oceanic fish, mainly

Table 3
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 2.5% annual growth per capita real income, baseline and climate change adaptation strategies, Vanuatu, from current (2006–2009) to 2035.

Key Fisheries Categories/Aquatic Ecosystems	Baseline (trend+CC)	Climate Change Adaptation Strategies		
		AQ (trend, CC, AQ)	NRM+FAD (trend, CC, NRM+FAD)	AQ+NRM+FAD (trend, CC, AQ+NRM+FAD)
PRICE				
Tuna	9.54	11.83	7.06	7.71
Other oceanic finfish	−23.34	−43.58	−15.45	−35.23
Coastal finfish	18.15	27.57	15.09	20.86
Coastal invertebrates	4.05	6.73	3.15	6.48
Freshwater finfish	27.81	65.93	19.25	55.95
Freshwater invertebrates	−6.00	−9.20	−4.78	−8.28
PRODUCTION				
Oceanic	10.42	−0.46	15.48	4.12
Coastal	−17.71	117.26	−15.18	141.52
Freshwater	24.63	2,065.20	28.81	2,040.17
CONSUMPTION				
Oceanic	295.06	496.08	232.02	350.50
Coastal	92.10	46.36	96.31	56.01
Freshwater	102.91	141.97	195.17	135.57

Notes: AQ=aquaculture development; CC=climate change; FAD=fish aggregating device; NRM=natural resource management.

Table 4
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 2.5% annual growth per capita real income, baseline and climate change adaptation strategies, Vanuatu, from current (2006–2009) to 2050.

Key Fisheries Categories/Aquatic Ecosystems	Baseline (trend+CC)	Climate Change Adaptation Strategies		
		AQ (trend, CC, AQ)	NRM+FAD (trend, CC, NRM+FAD)	AQ+NRM+FAD (trend, CC, AQ+NRM+FAD)
PRICE				
Tuna	9.60	7.83	14.28	11.53
Other oceanic finfish	−37.46	−49.68	−36.79	−47.53
Coastal finfish	25.59	33.99	21.81	29.49
Coastal invertebrates	5.57	7.35	5.31	6.78
Freshwater finfish	49.35	87.30	44.21	75.90
Freshwater invertebrates	−9.94	−12.20	−11.38	−12.72
PRODUCTION				
Oceanic	4.74	−4.56	20.09	8.67
Coastal	45.64	152.95	−19.19	119.87
Freshwater	1,004.33	3,111.19	150.95	2,386.05
CONSUMPTION				
Oceanic	547.94	755.41	589.61	741.10
Coastal	94.06	49.84	128.21	73.57
Freshwater	179.83	57.11	207.16	99.35

Notes: AQ=aquaculture development; CC=climate change; FAD=fish aggregating device; NRM=natural resource management.

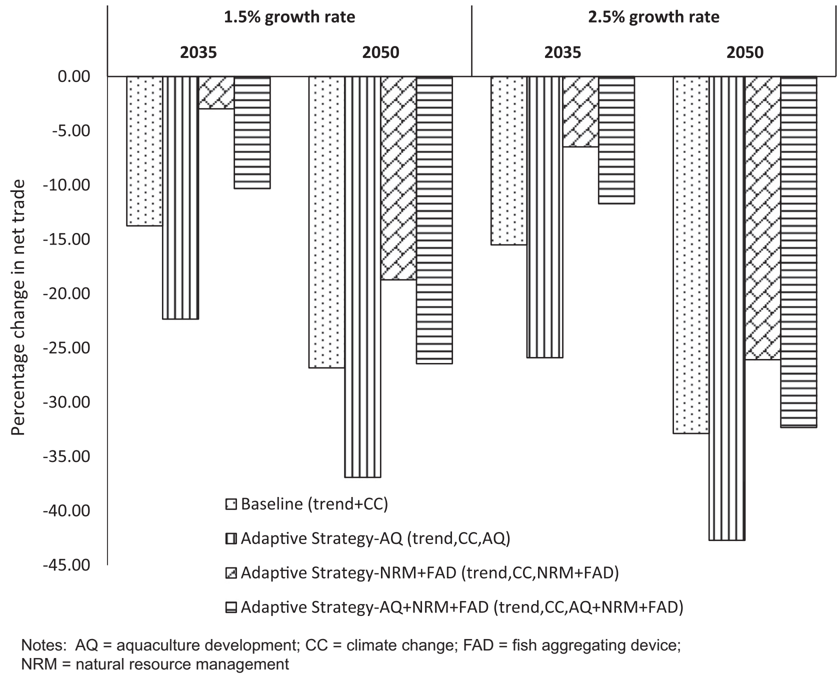

Fig. 1. Percentage change (%) in net trade of baseline and climate change adaptation strategies with annual growth of per capita real income at 1.5% and 2.5% from current (2006–2009) to 2035 and 2050, Vanuatu.

as a result of higher income from aquaculture growth. The model predicts that NRM + FAD strategy will increase fish demand in the long-term and for coastal and freshwater fish in the medium-term. The NRM + FAD strategy is likely to promote consumption through expected reduction in real fish price.

3.1.4. Changes in net trade (export minus import)

Fig. 1 presents the projected effects of different climate change adaptation strategies on fish trade in Vanuatu in 2035 and 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 scenario. Income growth outstrips production growth in the baseline, resulting in a reduction in export volume over time. Thus, the volume of net imports is expected to increase with higher growth in real income. AQ results in further reduction in exports relative to the baseline because the income generated under AQ boosts demand across fish species by an amount greater than the increase in freshwater species. The other strategies increase exports relative to the baseline.

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

Table 5 reports the estimated national-level net economic gains to both consumers and producers from adopting these adaptation strategies in Vanuatu. Projections show that substantial net income gains are likely to be generated where aquaculture and NRM + FAD strategies are expected to generate several million dollars in annual net incomes in 2035 and 2050. Cost of various planned adaptation strategies were collected from secondary literature and validated through expert consultation. 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[3].

[3] See Pascal, Seidl, and Tiwok [15] for details on the cost of MPAs and LLMAs, and Sharp [25] for details on the cost of FADs in the Pacific.

Table 5
National-level economic gain (equivalent variation) resulting from climate change adaptation strategies in Vanuatu, annual value in 2035 and 2050.
Source: Authors, calculated based on model projections.

Climate Change Adaptation Strategies	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

Notes: FAD = fish aggregating device; NRM = natural resource management.

3.2. Timor-Leste

3.2.1. Changes in fish prices

Tables 6–9 show the projected real prices of several fish types in Timor-Leste in 2035 and 2050 under different scenarios. The real price of most fish categories is projected to increase only marginally during 2009–2050 under the baseline scenarios, because high fish imports 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.

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 and lower supply of other species. As reported earlier for Vanuatu, higher productivity in aquaculture without any accompanying technical change in other fisheries sectors is likely to draw resource away from other sectors, and thereby reduce their supply and increase price.

3.2.2. Changes in fish production

Adoption of NRM strategy is likely to have positive impact on

Table 6
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 2% annual growth per capita real income, baseline and climate change adaptation strategies, Timor-Leste, from current (2006–2009) to 2035.

Key Fisheries Categories/Aquatic Ecosystems	Baseline (trend+CC)	Climate Change Adaptation Strategies		
		AQ (trend, CC, AQ)	NRM+FAD (trend, CC, NRM+FAD)	AQ+NRM+FAD (trend, CC, AQ+NRM+FAD)
PRICE				
Tuna	1.56	3.68	1.47	3.61
Other oceanic finfish	2.55	2.13	2.57	2.09
Coastal finfish	5.88	8.54	5.79	8.67
Coastal invertebrates	2.70	9.04	2.46	9.05
Freshwater finfish	−4.39	−34.42	−3.37	−33.83
Freshwater invertebrates	−4.98	−4.93	−5.01	−4.88
PRODUCTION				
Oceanic	−10.08	−13.62	−11.28	−14.59
Coastal	−7.74	−6.95	−1.70	−1.08
Freshwater	129.45	229.34	126.74	226.61
CONSUMPTION				
Oceanic	120.43	121.57	120.57	122.34
Coastal	98.25	85.41	98.81	85.51
Freshwater	129.45	229.34	126.74	226.61

Notes: AQ=aquaculture development; CC=climate change; FAD=fish aggregating device; NRM=natural resource management.

Table 7
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 2% annual growth per capita real income, baseline and climate change adaptation strategies, Timor-Leste, from current (2006–2009) to 2050.

Key Fisheries Categories/Aquatic Ecosystems	Baseline (trend+CC)	Climate Change Adaptation Strategies		
		AQ (trend, CC, AQ)	NRM+FAD (trend, CC, NRM+FAD)	AQ+NRM+FAD (trend, CC, AQ+NRM+FAD)
PRICE				
Tuna	0.85	3.37	0.75	3.32
Other oceanic finfish	2.95	2.55	2.94	2.53
Coastal finfish	5.49	8.84	5.23	8.92
Coastal invertebrates	0.54	7.91	0.22	7.91
Freshwater finfish	4.97	−27.39	6.01	−26.76
Freshwater invertebrates	−6.28	−5.82	−6.39	−5.78
PRODUCTION				
Oceanic	−10.83	−14.30	−12.01	−15.27
Coastal	−8.39	−7.33	−2.41	−1.48
Freshwater	133.68	232.19	131.06	229.49
CONSUMPTION				
Oceanic	150.40	153.25	150.25	153.91
Coastal	127.84	111.69	128.80	111.87
Freshwater	133.68	232.19	131.06	229.49

Notes: AQ=aquaculture development; CC=climate change; FAD=fish aggregating device; NRM=natural resource management.

Table 8
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 3% annual growth per capita real income, baseline and climate change adaptation strategies, Timor-Leste, from current (2006–2009) to 2035.

Key Fisheries Categories/Aquatic Ecosystems	Baseline (trend+CC)	Climate Change Adaptation Strategies		
		AQ (trend, CC, AQ)	NRM+FAD (trend, CC, NRM+FAD)	AQ+NRM+FAD (trend, CC, AQ+NRM+FAD)
PRICE				
Tuna	0.85	3.37	0.75	3.32
Other oceanic finfish	2.95	2.55	2.94	2.53
Coastal finfish	5.49	8.84	5.23	8.92
Coastal invertebrates	0.54	7.91	0.22	7.91
Freshwater finfish	4.97	−27.39	6.01	−26.76
Freshwater invertebrates	−6.28	−5.82	−6.39	−5.78
PRODUCTION				
Oceanic	−10.83	−14.30	−12.01	−15.27
Coastal	−8.39	−7.33	−2.41	−1.48
Freshwater	133.68	232.19	131.06	229.49
CONSUMPTION				
Oceanic	150.40	153.25	150.25	153.91
Coastal	127.84	111.69	128.80	111.87
Freshwater	133.68	232.19	131.06	229.49

Notes: AQ=aquaculture development; CC=climate change; FAD=fish aggregating device; NRM=natural resource management.

Table 9
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 3% annual growth per capita real income, baseline and climate change adaptation strategies, Timor-Leste, from current (2006–2009) to 2050.

Key Fisheries Categories/Aquatic Ecosystems	Baseline (trend+CC)	Climate Change Adaptation Strategies		
		AQ (trend, CC, AQ)	NRM+FAD (trend, CC, NRM+FAD)	AQ+NRM+FAD (trend, CC, AQ+NRM+FAD)
PRICE				
Tuna	2.62	4.17	2.57	4.13
Other oceanic finfish	3.70	3.10	3.71	3.07
Coastal finfish	9.27	11.46	9.24	11.55
Coastal invertebrates	4.98	10.07	4.86	10.13
Freshwater finfish	−11.12	−39.31	−10.42	−38.92
Freshwater invertebrates	−7.75	−8.11	−7.75	−8.07
PRODUCTION				
Oceanic	−14.98	−17.63	−15.94	−18.36
Coastal	−14.02	−13.17	−8.33	−7.64
Freshwater	242.14	390.77	239.62	388.15
CONSUMPTION				
Oceanic	234.54	235.21	234.82	236.01
Coastal	181.43	164.28	181.92	164.36
Freshwater	242.14	390.77	239.62	388.15

Notes: AQ=aquaculture development; CC=climate change; FAD=fish aggregating device; NRM=natural resource management.

coastal fish production in 2035 and 2050 (Tables 6–9). Aquaculture development is expected to affect freshwater fish production substantially, by about 100% in 2035 and by about 150% in 2050, from a low base level. Even this large percentage increase adds a relatively small increase to total fish production in volume terms.

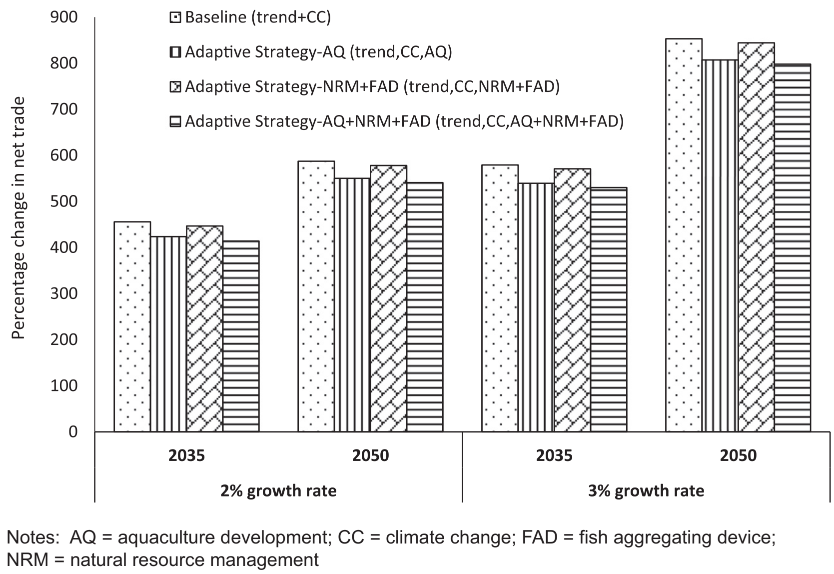

Fig. 2. Percentage increase (%) in net imports of baseline and climate change adaptation strategies with annual growth of per capita real income at 2% and 3% from current (2006–2009) to 2035 and 2050, Timor-Leste.

Table 10
National-level economic gain (equivalent variation) resulting from climate change adaptation strategies in Timor-Leste, 2035 and 2050.
Source: Authors, calculated based on model projections.

Climate Change Adaptation Strategies	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

The model projects that 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 NRM is expected to have positive effect on coastal fish production, which may take away 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 relative to freshwater fish[4]. These effects together may neutralize some positive impacts of the combined AQ+NRM strategy on freshwater production. Given that freshwater ecosystem supplies fish for domestic consumption only, which was reflected in the closed economy model chosen for this species group, the AQ+NRM strategy may not have any additive effects on freshwater fish consumption.

3.2.3. Changes in fish consumption

Aggressive aquaculture development is projected to have a substantial positive impact on consumption of freshwater fish (Tables 6–9), although again, the increased on fish consumption in per capita terms is relatively modest (around 9.6 kg/capita/year) to 2050. Implementation of the aquaculture development strategy is expected to have larger positive impact over time. The likely increases in fish consumption from current levels under the baseline and under NRM strategy are relatively small, implying that NRM strategy is not expected to have any substantial impact on fish consumption in Timor-Leste.

[4] Income elasticity of demand for coastal fishes is higher than that for freshwater fishes.

3.2.4. Changes in net trade

Unlike the other countries studied, Timor-Leste is a net importer of fish and seafood. Total imports are 1496 mt in 2006–2009, and are projected to increase to 10,162 mt in 2035 and 14,259 mt in 2050 with 3% annual growth of real per capita income. Model estimates that the country will remain a net fish importer in the long-run under the baseline and with climate change adaptation scenarios. Fig. 2 show the projected effects of these strategies on net fish imports in Timor-Leste in between 2035 and 2050. Results indicate that both aquaculture and NRM strategies will reduce net fish imports and if Government of Timor-Leste placed more emphasis on aquaculture development, as reflected in the modeling exercise, aquaculture development will have a stronger effect on import reduction. Increased investment in NRM activities is likely to have similar effects. The reductions in imports are relatively small across the scenarios, because the adaptation strategies result in increased income and consumption, partly offsetting the higher production.

3.2.5. National-level net economic gains

Table 10 provides the estimated national-level net economic gains to consumers and producers resulting from various adaptation strategies in Timor-Leste. Aquaculture is the main adaptation strategy where several ongoing initiatives are being implemented with regional/international agencies in the country. Compared with other case study countries, the potential increase in net income from NRM strategy is less since it is in the early stage of developing a comprehensive strategy for coastal and marine environments.

4. Discussion

Vanuatu is currently a net exporter of fish and seafood, with domestic production far exceeding domestic consumption. Under the baseline scenario, projected aggregate fish consumption is expected to rise substantially in 2035 and 2050; yet the country will remain a net fish exporter by 2050 due to production and export of oceanic fish, predominately tuna. Simulations show an increase in production of oceanic fish and a decline in coastal fish during 2010–2050. Though consumption of oceanic fish is anticipated to rise at a faster rate than any other sector, this subsector is projected to remain a net exporter, although at a lower level. However, Vanuatu will most likely have to import coastal fish to meet expanding demand from population and income growth. Given that many of Vanuatu's poorer households rely on coastal fisheries for their consumption needs, this projected scenario has serious food security implications. Cost-effective expansion of coastal fisheries would provide income and calories while reducing imports. It is also projected that freshwater fish consumption will exceed domestic production in 2035 and 2050, and Vanuatu will also need to rely on imports to meet this demand.

The real price of most fish types—including coastal finfish, which contribute about 54% of current fish consumption—will escalate in 2035 and 2050 under baseline scenarios. Adoption of FADs and NRMs will likely reduce prices of coastal finfish, tuna, coastal invertebrates, and freshwater finfish in 2035. Coastal finfish and tuna contribute about 77% of current consumption and because coastal finfish are widely consumed by Vanuatu's poorer households, FAD+NRM is likely to have positive impact on consumers. This strategy will also favorably affect oceanic fish supply; from present (2006–2009) level an increase of about 14% in 2035 and 19–20% in 2050 were anticipated. Fish demand is projected to increase for coastal and freshwater fish in 2035 through expected real price reduction of these fish categories. But with its current pace of implementation, FADs and NRMs will not halt the increase of fish prices in 2050 unless more aggressive investments are put in place. Tuna and other oceanic fish are expected to experience the highest rise in demand, about three-five times in 2035 and 2050, respectively, due to growth in population and projected improvement in income from aquaculture development.

With higher income from the aquaculture development scenario, Vanuatu's net export is predicted to decrease. FAD+NRM strategy is projected to reduce the country's fish imports and increase its net exports. Calculated values of national-level economic gains are US $4 million for aquaculture, US $18 million for NRM+FAD, and US $22 million for AQ+NRM+FAD (in 2009 US$ constant price) in 2035; and US $4.5 million for aquaculture, US $35 million for NRM+FAD, and US $38 million for AQ+NRM+FAD (in 2009 US$ constant price) in 2050.

Unlike Vanuatu, Timor-Leste is a net importer of fish and seafood, and net imports are projected to increase in the long-run under baseline and various climate change adaptation scenarios. Under baseline scenario, total fish production will increase only marginally in 2035 and 2050. Aggregate fish demand is expected to rise substantially due to growth in population and real per capita income, thus increasing fish import to fill this escalating deficit in the domestic fish supply. Fish supplies from oceanic and coastal ecosystems are projected to decrease during 2010–2050 due to climate change (please see Appendix Table A.4 for detailed assumptions). 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.

Based on the modeling outcome, adoption of climate change adaptation strategies will likely result in a marginal increase in real fish price over 2009–2050, because increased fish imports are likely to keep real prices under check. 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, but likely to raise the real price of other fish categories, mainly because of the higher incomes associated with aquaculture development. Aquaculture is also expected to increase freshwater fish production substantially, by about 100% in 2035 and by about 150% in 2050.

Aquaculture development will have 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 as time goes by. The likely increases in fish consumption from current levels under the baseline scenario and the NRM strategy are predicted to be very similar, implying that NRM strategy is not expected to have significant impact on fish consumption in the country, but rather will reduce fish imports.

Combined AQ and NRM strategies may not produce any added advantage (i.e., additive effects) for freshwater fish supply in Timor-Leste based on the modeling results. Aquaculture growth increases income, leading to 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, as reflected in the close economy model chosen for this species group, the AQ+NRM strategy may not have any additive effect on freshwater fish consumption.

Estimated national-level annual economic gain resulting from the adoption of climate change adaptation strategies range from US $0.65 million for aquaculture, to US $0.4 million for NRM, and to US $1 million for combined aquaculture+NRM (US$ in 2009 constant prices) in 2035. Interestingly, economic gain from NRM remained the same at US $0.4 million (US$ in 2009 constant prices) in 2050, whereas the annual benefits from aquaculture expansion increased US $1.2 million in 2050 and the annual benefits aquaculture+NRM increased to US $1.6 million in 2050.

5. Conclusions

Three main adaptation strategies to the effects of climate change are presented and applied in the modeling exercises for the Pacific coral triangle countries, in this case, Vanuatu and Timor-Leste. These strategies are aquaculture development, expansion of NRMs, and establishment of FADs which all indicated favorable effects on the fisheries sector in these two countries. Very importantly, substantial results of the modeling application demonstrate national-level economic gains for the adaptation strategies, with significantly higher estimated economic gains in Vanuatu.

Finally, it is critical to note that the current scales of adaptation strategies in these Pacific countries are relatively too small to have the necessary impacts in the future. 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 meet growing fish demand. These adaptation strategies need to be location-specific. Aquaculture, FADs, and NRM affect diverse 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 A

See Tables A.1–A.4

Table A.1
Aggregated Fish Balance Sheet for Vanuatu Fish Model.Sources: FGD, Sanma Province, Santo Islands, Vanuatu, August 2012; post-survey validation meeting, Port Vila, Vanuatu, June 2013; FAO FishStatJ 2012.

Fish Group	Production (*t*)	Consumption (*t*)	Net Trade (*t*)	Price ($/*t*)
Tuna	55,000.00	1896.00	53,104.00	5500
Other oceanic finfish	3450.50	1358.00	2092.50	5500
Coastal finfish	1908.00	4239.31	−2331.31	5000
Coastal invertebrates	318.50	318.50	0.00	12,000
Freshwater finfish	100.00	100.00	0.00	3320
Freshwater invertebrates	15.76	15.76	0.00	12,000
Total	**60,792.76**	**7927.57**	**52,865.19**	**–**

Note: Net trade positive = net export, and Net trade negative = net import.

Table A.2
Shift in Supply Curve[a] (%) from Current (2006–2009) to 2035 and 2050, under Alternative Climate Change Adaptation Strategies in Vanuatu.Sources: Authors. Calculated based on secondary literature [16,17,18,20,21], and on primary data (FGD, Sanma Province, Santo Islands, Vanuatu, August 2012; post-survey validation meeting, Port Vila, Vanuatu, June 2013).

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

Note:

[a] This shift in supply curve has been denoted in Eq. (2) of [6] 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.

Table A.3
Aggregated Fish Balance Sheet for Timor-Leste.Sources: FAO FishStatJ 2012; National Fisheries Statistics of Timor-Leste (http://www.peskador.org/).

Fish Group	Production (*t*)	Consumption (*t*)	Net Trade (*t*)	Price ($/t)
Tuna	585.98	818.24	−232.26	4030
Other oceanic finfish	1022.38	1112.44	−90.06	3910
Coastal finfish	2145.81	2987.95	−842.14	3390
Coastal invertebrates	854.19	1185.99	−331.80	1690
Freshwater finfish	398.39	398.39	0	2500
Freshwater invertebrates	1.00	1.000	0	5000
Total	5007.750	6504.01	−1496.26	–

Note: Net trade positive = net export and Net trade negative = net import.

Table A.4
Shift in Supply Curve[a] (%) from Current (2006–2009) to 2035 and 2050, under Alternative Climate Change Adaptation Strategies in Timor-Leste.Source: Authors. Calculated based on secondary literature [16,17,19,20,21], and on primary data (expert consultations in the Asia and Pacific regions).

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

Note:

[a] This shift in supply curve has been denoted in Eq. (2) of [6] 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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