Marine Policy 67 (2016) 164–170

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Economic impact of climate change and climate change adaptation strategies for fisheries sector in Fiji

Madan Mohan Dey [a,*], Kamal Gosh [b], Rowena Valmonte-Santos [c], Mark W. Rosegrant [c], Oai Li Chen [a]

[a] Aquaculture/Fisheries Center of Excellence, University of Arkansas at Pine Bluff, United States
[b] School of Fisheries, Aquaculture and Aquatic Sciences, Auburn University, United States
[c] Environment and Production Technology Division, International Food Policy Research Institute, United States

ARTICLE INFO

Article history:
Received 17 December 2015
Accepted 19 December 2015
Available online 20 January 2016

Keywords:
Economic modeling
Aquaculture
Natural resource management
Fish aggregating devices
Fiji

ABSTRACT

Capture fisheries and aquaculture sectors have played major roles in the national economy and food security of Fiji. But climate change may place substantial stress on these sectors within this archipelago. This paper assesses the potential economic impact of two important climate change adaptation strategies in Fiji, natural resource management (NRM) and aquaculture, using a market fish supply–demand model. The model undertakes a comparative analysis of alternative fisheries development scenarios for 2035 and 2050, while taking account of the impact of climate change on the fisheries sector. The modeling and scenario analyses show that promoting aquaculture can help raise aggregate fish production, consumption, and trade. However, the required increases in aquaculture could be massive. While aquaculture development alone is unlikely to meet the growing excess demand for fish in Fiji, it will be an important component in adapting to the negative effects of climate change on capture fisheries. Various NRM strategies, such as marine protected areas (MPAs) and locally managed marine areas (LMMAs), are projected to have positive impacts in Fiji, expanding the stock and catch of fish. But current efforts on various NRM strategies are too small to have any meaningful impact to reverse the declining trends of coastal fisheries catch. Efforts would need to be greatly scaled-up to achieve significant production gains.

1. Introduction

Fiji (officially known as the Republic of Fiji) is an archipelago comprising approximately 844 volcanic and coral islands with a total water area and exclusive economic zone of 1,290,000 square kilometers (km^2) [1,2]. Given its geographic location and environment, the fisheries[1] sector is an important element of Fijian economy. Fisheries enhances food and nutrition security, particularly in the rural coastal areas, and contributes to livelihood and income generation, rural development, environmental preservation, and Fiji's gross domestic product [3–6].

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. Of these six, fish production was found to be highest in Fiji's coastal areas [1,3,4]. Artisanal or small-scale commercial and subsistence fishers are heavily dependent on coastal areas as sources of fish for food, nutrition, livelihood, and income.

The management of fisheries resources in Fiji is divided among national ministries, provincial governments, and indigenous Fijian institutions[2]. At the national level, the Department of Fisheries (DOF) is the main agency responsible for fisheries resources management. DOF regulates fishing (catch limits and entry) mainly through the issuance of permits and licenses. However, effective implementation of fisheries regulations is often hampered by various administrative and budgetary constraints,

* Corresponding author. Present/Permanent address: Aquaculture/Fisheries Center of Excellence, Mail Slot 4912, University of Arkansas at Pine Bluff, 1200 N University Dr, Pine Bluff, AR 71601, United States.
E-mail address: deym@uapb.edu (M.M. Dey).

[1] In this paper, unless otherwise specified, the term “fisheries” is used broadly to include capture fisheries and aquaculture, and the term “fish” is also broadly defined to include finfish, mollusks and crustaceans.

[2] Another paper of this special section of Marine Policy [7] discusses existing fisheries policies in four Pacific countries, including Fiji.

http://dx.doi.org/10.1016/j.marpol.2015.12.023
0308-597X/

including split jurisdiction of different agencies [8]. Subsistence fishing and non-commercial fishing gear types are not subject to permit requirements [8].

Climate change is expected to place substantial stress on the capture fisheries and aquaculture sector of Fiji [9] and result in reduction of coastal subsistence fisheries [10] under business-as-usual scenarios. Similar to other Pacific and developing countries, the Government of the Republic of Fiji has begun preparing a National Adaptation Programme of Action and in 2012 developed a *National Climate Change Adaptation Strategy for Land-Based Resources* 2012–2021 [11]. 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* [12]. These documents recognize Fiji's vulnerability to climate change and offer disaster risk-reduction approaches to combat the impacts of extreme weather events.

Numerous studies have profiled Fiji's fisheries (see, for example, [1–4,10]), and some include analyses of climate change impact, related adaptation strategies and their agro-ecological impacts in Fiji (see, for example [13–19]). However, there are no in-depth studies that tackle the economic impact of Fiji's climate change adaptation strategies. In an effort to address this knowledge gap, this paper examines the potential economic impacts of climate change adaptation strategies on the fisheries sector in Fiji.

2. Climate change and related adoption strategies for the fisheries sector

Climate change adaptation strategies in Fiji include various natural resource management (NRM) practices, including marine protected areas (MPAs), locally managed marine areas (LMMAs) and the ridge-to-reef concept; alternative livelihood developments; enforcement of Department of Fisheries (DOF) regulations and compliance with the fisheries regulations and ordinances; inshore low-cost fish aggregating devices (FADs); aquaculture; finance literacy; and post-harvest—improving the quality of products and reducing waste. Among these, NRM strategies and aquaculture are featured most prominently in the government and commonly reported as important climate change adaptation strategies.

"[MPAs] are 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 (Govan et al. [20])". MPAs are covered under the 2007 *National Biodiversity Strategy and Action Plan* and the Fisheries Act in Fiji. In contrast, "LMMAs are 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 (Govan et al. [20])". The main difference between LMMAs and MPAs is that the former emphasize management by local communities and do not necessarily ban all extractive activities such as inherent in MPAs.

Fish aggregating devices (FADs) have been used in Fiji since 1970 to collect all sizes of fish from nearby reefs. Piles of vegetation such as tree logs, branches, bamboo, and coconut leaves are used to attract fish. Two types of FADs are typically constructed in Fiji: inshore (near-shore) and offshore. Near-shore FADs can be used as part of LLMAs.

Finally, fish farming or aquaculture was first initiated in 1976 by DOF with the introduction of Nile tilapia [21] and now include freshwater prawn, grass carps, and silver carps, to name a few. Culture of milkfish, seaweed, and pearls is also under development[3]. The importance of aquaculture has been increasing in Fiji in recent decades with national consumer preferences geared towards tilapia and prawn.

3. Methodology and data

This study uses a fish market supply–demand model that represents climate change in terms of supply shocks. 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. The details of the model are presented in another paper in this special section of Marine Policy [22].

Evaluation of the impact of a climate change adaptation strategy requires a baseline scenario of no adaptation (i.e., a benchmark of "no action"). For each time period (2035 and 2050), two baseline (most plausible with no climate change adaptation strategy) scenarios[4] have been implemented. These scenarios represent two annual growth rates of real per capita income: medium (1% per year) and high (2% per year) growth of real per capita income. During 2008 to 2012, annual percentage growth rate of real per capita income in Fiji ranged from −2.3% to +1.4% [23]. Populations of 977,586 in 2035 and 1,060,706 in 2050 [1] has been assumed for Fiji.

The data needed to run the model were collected from both primary and secondary sources. Primary data sources include expert opinion survey (EOS) and focus group discussion (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 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 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 as comments from other experts (e.g., participants of the North American Association of Fisheries Economists 2013 meeting), minor revision to the model was made and this was implemented in 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 Table A.1 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

[3] 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 [21].

[4] Given the uncertainty of establishing future income growth, two alternative baseline scenarios with different growth rates of real per capita income were presented.

Table 1
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 1% annual growth per capital real income, baseline and climate change adaptation strategies, Fiji, from current (2006–2009) to 2035.
Source: Model projections by authors.

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	10.13	48.30	(0.49)	42.83
Other oceanic finfish	(1.69)	(14.89)	1.21	(10.72)
Coastal finfish	3.98	2.48	5.37	1.59
Coastal invertebrates	0.34	1.73	0.02	1.33
Freshwater finfish	(5.01)	(36.19)	0.77	(25.63)
Freshwater invertebrates	(1.08)	(2.59)	(0.77)	(2.74)
PRODUCTION				
Oceanic	23.81	30.15	41.01	53.36
Coastal	(12.27)	(18.53)	(6.34)	(15.09)
Freshwater	39.19	109.77	24.98	77.54
CONSUMPTION				
Oceanic	64.72	60.28	76.41	56.63
Coastal	44.47	58.71	38.89	65.60
Freshwater	39.19	109.77	24.98	77.54

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

Table 2
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 1% annual growth per capital real income, baseline and climate change adaptation strategies, Fiji, from current (2006-2009) to 2050.
Source: Model projections by authors.

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	45.39	57.68	39.36	59.20
Other oceanic finfish	(13.73)	(20.28)	(9.90)	(18.08)
Coastal finfish	3.82	5.26	3.29	3.63
Coastal invertebrates	1.57	2.20	1.23	2.03
Freshwater finfish	(35.89)	(58.74)	(25.06)	(49.82)
Freshwater invertebrates	(2.79)	(3.15)	(2.77)	(3.75)
PRODUCTION				
Oceanic	30.78	24.89	52.06	49.22
Coastal	(28.61)	(29.30)	(19.76)	(21.47)
Freshwater	123.50	243.12	89.81	187.54
CONSUMPTION				
Oceanic	87.97	103.03	85.60	98.50
Coastal	72.04	65.51	77.52	79.37
Freshwater	123.50	243.12	89.81	187.54

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

fish products with other sources of animal protein in the country. Alternative sets of elasticities to test the sensitivity of the modeling results were applied, although detailed results are not presented for brevity's sake. Results indicated that minor variations in supply and demand elasticities (e.g., using 0.5 instead of 0.6 as own price elasticity of tuna supply elasticities) do not change results. Even substantial variations in demand elasticities (e.g., a near doubling of 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) increase the demand for tuna in 2035 under a baseline scenario from 10,953 t to 11,232 t (a mere 2.5% increase).

Three climate change adaptation scenarios were considered: aquaculture development (AQ), NRM, and a combination of AQ+NRM. Scenario 1 (AQ) involves improvements in the productivity of freshwater aquaculture (both finfish and invertebrate). 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, LMMAs, and FADs. Fiji's national climate change policy was approved only in 2012 and the country is in the early stages of implementing climate change adaptation strategies [11,12]. Given that there is tremendous uncertainty about the future, these three adaptation scenarios can be considered as examples of future development[5].

The overall shifts in the supply curve due to climate change (i.e., effect of climate change on fish production) in 2035 and 2050 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 (i.e., shift in supply curve) were taken from [24–28]. Bell et al. [24] and other references cited above focus on 2035 and 2100, but do not have climate change scenarios for 2050. Data for 2050 has been generated 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 [26] and negative effects on coastal fish production [28] in Fiji. The projection of the Spatial Ecosystem and Population Dynamics Model (SEAPODYM) [29] for the likely effects of climate change on tuna catch under relatively low and high emission scenarios were applied. The likely direct effects of various climate change adaptation strategies on shift in fish supply curve were calculated based on secondary literature [14–19,30–32] and primary data collected through the EOS and FGD, reported in columns 3, 4, 5, 7, 8, and 9 of Appendix Table A.4. The positive (or negative) values of shifts 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, and FAD) are likely to reduce 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; this indicates increases in catch with the same cost of fishing and/or decrease in cost of fishing per unit of catch.

4. Results and discussion

4.1. Changes in fish prices

Tables 1–4 show the effects of different climate change adaptation strategies on real fish prices in 2035 and 2050. Overall, the real prices of most fish categories are likely to remain unchanged under baseline scenarios. This is mainly because increased demand for various fish types is expected to be met through increased fish importation. However, the real price of tuna in Fiji is likely to rise, particularly in the long term (2050). Fiji is a net

[5] Some sensitivity analysis had been undertaken and found that the main conclusions on these adaptation scenarios did not change. Results of the sensitivity analyses were not reported due to space limitations.

Table 3
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 2% annual growth per capital real income, baseline and climate change adaptation strategies, Fiji, from current (2006–2009) to 2035.
Source: Model projections by authors.

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	5.11	42.07	(5.32)	37.19
Other oceanic finfish	0.12	(13.62)	2.40	(9.66)
Coastal finfish	6.29	4.99	8.57	4.00
Coastal invertebrates	0.19	1.59	(0.12)	1.22
Freshwater finfish	(2.15)	(33.99)	3.11	(24.02)
Freshwater invertebrates	(1.24)	(2.39)	(0.61)	(2.58)
PRODUCTION				
Oceanic	19.76	26.35	35.82	49.09
Coastal	(11.15)	(17.61)	(4.81)	(14.07)
Freshwater	49.05	123.76	35.17	91.93
CONSUMPTION				
Oceanic	105.10	99.30	123.62	93.97
Coastal	59.51	71.38	52.03	78.34
Freshwater	49.05	123.76	35.17	91.93

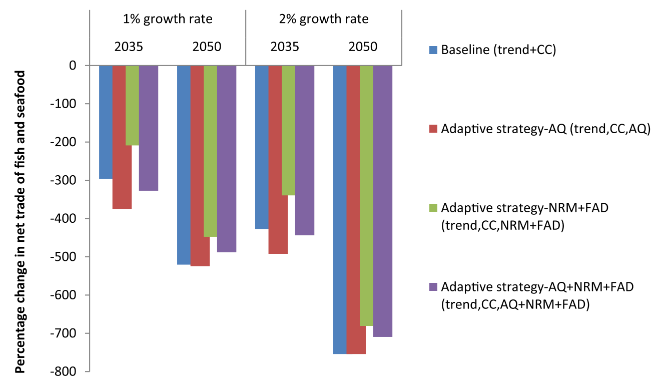
Notes: AQ=aquaculture development; CC=climate change; FAD=fish aggregating device; NRM=natural resource management; numbers in parenthesis=negative.

Table 4
Percentage change (%) in projected price, production and consumption of key fisheries categories and aquatic ecosystems at 2% annual growth per capital real income, baseline and climate change adaptation strategies, Fiji, from current (2006–2009) to 2050.
Source: Model projections by authors.

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	35.44	47.03	30.03	48.24
Other oceanic finfish	(11.42)	(18.35)	(7.76)	(16.28)
Coastal finfish	8.02	9.88	7.35	8.19
Coastal invertebrates	1.34	1.96	1.03	1.81
Freshwater finfish	(31.19)	(54.36)	(21.26)	(46.33)
Freshwater invertebrates	(2.50)	(2.65)	(2.56)	(3.17)
PRODUCTION				
Oceanic	24.55	19.46	44.87	42.31
Coastal	(27.38)	(28.28)	(18.22)	(20.09)
Freshwater	146.68	266.26	113.78	215.39
CONSUMPTION				
Oceanic	166.51	188.73	161.86	180.23
Coastal	97.18	88.35	102.87	101.08
Freshwater	146.68	266.26	113.78	215.39

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

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, however. 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.



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% and 2% from current (2006–2009) to 2035 and 2050, Fiji.

Table 5
National-level economic gain (equivalent variation) resulting from climate change adaptation strategies in Fiji, 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	802,701	2,638,290
NRM+FAD	11,560,219	14,496,463
Aquaculture+NRM+FAD	11,813,084	16,208,939

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

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.

4.2. *Changes in fish production*

The likely effects of different climate change adaptation strategies on fish production in 2035 and 2050 are also shown in Tables 1–4. 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 [26,28]. Given that the coastal subsistence fisheries sector contributes the highest portion (42%) of total fisheries production in Fiji [10], 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 and LMMAs) 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 resulting higher price and market demand for tuna and other oceanic fish. The projected rate of increase in national tuna production due to increased investment in FADs is well within the sustainable tuna catch (see, for example, [26,33]).

4.3. Changes in fish consumption

Baseline projections indicate that demand for all fish types will increase over time, and the level of increase will be higher, with faster growth in per capita real income (Tables 1–4). 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 demand for tuna and other oceanic species will increase at a faster rate with higher income growth.

The model predicts that adaptation 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).

4.4. Changes in net trade (export minus import)

Fig. 1 shows 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 model predicts that net imports of fish and seafood will increase under all 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.

4.5. National-level economic gains resulting 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 5. 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).

The estimated net economic gains resulting from NRM and aquaculture are significantly higher compared to 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[6]. 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.

[6] For detailed discussion on the cost of MPAs/LLMAs, the readers are referred to [34].

5. Conclusion

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 in this paper generated key messages for Fiji with and without climate change adaptation strategies.

Under baseline scenario (i.e., without any climate change adaptation strategies), total fish production in Fiji is projected to grow at a negligible rate and coastal production is projected to decline over time. But domestic demand for fish, including coastal fish, is projected to rise over the medium (2035) and long term (2050). As expected, higher income growth will be accompanied by higher rise in demand for fish, resulting in falling fish exports and rising fish imports; therefore, net trade (export minus import) is projected to decline over time.

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.

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

Adoption of various NRM strategies (such as MPAs and LMMAs) is expected to halt production declines in coastal fisheries, and further expand production of oceanic fisheries. 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.

The results indicate that aquaculture development will directly increase production from freshwater aquaculture, and will indirectly increase tuna catch as a result of increased income from aquaculture. This will likely result in higher prices and market demand for tuna and other oceanic fish. Through continuation of aquaculture development in Fiji, the rate of increase in freshwater species consumption is expected to speed up in the long run (2050). Between the two real-income growth scenarios, the model predicts that demand for tuna and other oceanic species will increase at a faster rate with higher income growth.

In addition, the annual national economic gains due to the adoption of NRM (MPAs/LMMAs) and aquaculture for the two projection periods were estimated to be $11.5 million (2035) and $14.5 million (2050) for the former, and $800,000 (2035) and $2.6 million (2050) for the latter. Annual investment costs were estimated at $100,000 for about 20 fully functional MPAs/LMMAs and $50,000 for aquaculture in Fiji (2035).

With these results in mind, this paper recommends strategic and supportive policy from the government of the Republic of Fiji that fully implements, at a minimum, the following three climate change adaptation strategies for coastal communities: expansion and recognition of MPAs and LMMAs; construction and deployment of low-cost inshore FADs; and further development and expansion of aquaculture. Policy should deal with the review and mobilization of existing national development plans related to climate change to ensure benefits are targeting coastal communities and vulnerable populations, as well as facilitate the approval of any pending associated development plans.

Acknowledgement

This work was funded by the Asian Development Bank (ADB) Technical Assistance 7753 on “Strengthening Coastal and Marine

Resources Management in the Coral Triangle of the Pacific (Phase 2)" and by the United States Agency for International Development (USAID). Advice from Dr. Carole Engle and Dr. Robert Pomeroy are gratefully acknowledged.

Appendix A

See Tables A.1, A.2, A.3 and A.4.

Table A.1
Aggregate fish balance sheet for Fiji-Fish Model, 2006–2009. Sources: EOS, Suva, Fiji, July 2012; FGD, Ra Province, Fiji, July 2012; FAO [35].

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	–

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

Table A.2
Validated supply elasticity estimates for various fish groups used in Fiji-Fish Model. Sources: Dey et al. [36]; EOS, Suva, Fiji, July 2012; FGD, Ra Province, Fiji, July 2012; post-survey validation meeting, Suva, Fiji June 2013.

Fish group	Tuna	Other oceanic finfish	Coastal finfish	Coastal inver-tebrates	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

Table A.3
Validated demand elasticity estimates for various fish groups used in Fiji-Fish Model. Sources: Dey et al. [36]; EOS, Suva, Fiji, July 2012; FGD, Ra Province, Fiji, July 2012; post-survey validation meeting, Suva, Fiji June 2013.

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

Table A.4
Shift in supply curve[a] (%) from current (2006–2009) to 2035 and 2050, under alternative climate change adaptation strategies in Fiji. Sources: Authors. Calculated based on secondary literature [24–28], and primary data (EOS, Suva, Fiji, July 2012; FGD, Ra Province, Fiji, July 2012; post-survey validation meeting, Suva, Fiji June 2013).

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

Note: AQ=aquaculture; NRM=natural resource management.

[a] This shift in supply curve has been denoted in Eq. (2) of Dey et al. [22] as (λ_0) for baseline scenarios and as (λ_1) for various climate change adaptation scenarios.

References

[1] M. Ahmed, J. Maclean, R.V. Gerpacio, M. Sombilla, Food Security and Climate Change: Rethinking the Options, Pacific Studies Series, Asian Development Bank, Mandaluyong, Philippines. Available at: ⟨http://www.adb.org/publications/food-security-and-climate-change-pacific-rethinking-options⟩, 2011.

[2] C. Hunt, Fiji's fisheries: their contribution to development and their future, Mar. Policy 23 (6) (1999) 571–585.

[3] T. Hand, D. Davis, R. Gillett, Fisheries Sector Review: Republic of the Fiji Islands, Asian Development Bank, Mandaluyong, Philippines, 2005.

[4] FAO (Food and Agricultural Organization), Fishery and Aquaculture Country Profiles. Republic of Fiji, Country Profile Fact Sheets, in: FAO Fisheries and Aquaculture Department. Available at: ⟨http://www.fao.org/fishery/facp/FJI/en⟩, Updated 1 October 2009.

[5] V. Ram-Bidesi, P.N. Lal, N. Connor, Economics of Coastal Zone Management in the Pacific, An IUCN Report to SPREP, CRISP Programme, Suva, Fiji. Available at: ⟨http://data.iucn.org/dbtw-wpd/edocs/2011-119.pdf⟩, 2011, p. 113.

[6] J.D. Bell, M. Kronen, A. Vunisea, W.J. Nash, G. Keeble, A. Demmkea, S. Pontifex, S. Andrefoue, Planning the use of fish for food security in the Pacific, Mar. Policy 33 (2009) 64–76.

[7] R.A. Valmonte-Santos, M. Rosegrant, M.M. Dey, Fisheries sector under climate change in the coral triangle countries of pacific islands: Current status and policy issues, Marine Policy 67 (2016) 148–155, http://dx.doi.org/10.1016/j.marpol.2015.12.022.

[8] CCIF, Assessment of the Enabling Conditions for Rights-Based Management of Fisheries and Coastal Marine Resources: Fiji Country Report, Conservation and Community Investment Forum, California, USA, 2013.

[9] P.N. Lal, J. Kinch, F. Wickham, Review of economic and livelihood impact assessments of, and adaptation to, climate change in Melanesia, Secretariat of the Pacific Regional Environmental Programme, Apia, Samoa. Available at: ⟨http://www.sprep.org/att/publication/000743_Review_of_economic_and_livelihood.pdf⟩, 2009.

[10] R. Gillett, Fisheries in the Economies of the Pacific Island Countries and Territories. Pacific Studies Series, Asian Development Bank, Mandaluyong, Philippines, 2009.

[11] GOF-NCCAS, Republic of Fiji National Climate Change Adaptation Strategy for Land-Based Resources 2012–2021, GOF-NCCAS, Suva, Fiji, 2012.

[12] SPC (Secretariat of the Pacific Commission), Republic of Fiji National Climate Change Policy, Secretariat of the Pacific Commission, Suva, Fiji, 2012.

[13] Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change, Secretariat of the Pacific Community, Noumea, 2011 925 pp. ⟨http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/403/Bell_et_al._2011._CC_&_Tropical_Pacific_Fisheries_&_Aquaculture.pdf⟩.

[14] C. Clements, V. Bonito, R. Grober-Dunsmore, M. Sobey, Effects of small, Fijian community-based marine protected areas on exploited reef fishes, Mar. Ecol. Prog. Ser. 449 (2012) 233–243.

[15] J.S. Goetze, T.J. Langlois, D.P. Egli, E.S. Harvey, Evidence of artisanal fishing impacts and depth refuge in assemblages of Fijian reef fish, Coral Reefs 30 (2011) 507–517.

[16] Stacy D. Jupiter, Daniel P. Egli, Ecosystem-based management in Fiji: successes and challenges after five years of implementation, J. Mar. Biol. (2011), (Article ID 940765, 14 pp.) http://dx.doi.org/10.1155/2011/940765.

[17] S.D. Jupiter, R. Weeks, A.P. Jenkins, D.P. Egli, A. Cakacaka, Effects of a single intensive harvest on fish populations inside a customary marine closure, Coral Reefs 31 (2012) 321–334.

[18] A. Tawake, J. Parks, P. Radikedike, B. Aalbersberg, V. Vuki, N. Salafsky, Harvesting clams and data: Involving local communities in moniotirng can lead to conservation success in all sorts of unanticipated ways: a case in Fiji, Conserv. Pract. 2 (2001) 32–35.

[19] F. Waqairagata, R. Simpson, R. Ratuniata, J. Comley, The role of marine protected areas on the protection of herbivorous fish and their ability to control brown macroalgae, in: Proceedings of the Second Fiji Conservation Science Forum, 2011, p. 56.

[20] Govan, H. et al. Status and Potential of Locally Managed Marine Areas in the South Pacific: Meeting Nature Conservation and Sustainable Livelihood Targets through Widespread Implementation of LMMAs. SPREP/WWF/World-Fish-Reefbase/CRISP. Available at: ⟨http://www.sprep.org/att/publication/000646_LMMA_report.pdf⟩, 2009, p. 95.

[21] J. Davetanivalu, Adaptation Strategies Affecting the Coastal Communities in Fiji Islands, Paper presented during the Final Regional Workshop of the Climate Change and Development Strategies for Coastal Communities of the Pacific Coral Triangle Countries, Port Vila, Vanuatu, 18–19 September, 2013.

[22] M.M. Dey, M. Rosegrant, K. Gosh, O.L. Chen, R. Valmonte-Santos, 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, Marine Policy 67 (2016) 156–163, http://dx.doi.org/10.1016/j.marpol.2015.12.011.

[23] World Bank, World Development Indicators, World Bank, Washington DC, 2013, Available at: ⟨http://data.worldbank.org/data-catalog/world-development-indicators⟩..

[24] J.D. Bell, T.J.H. Adams, J.E. Johnson, A.J. Hobday, A. Sen Gupta, Pacific communities, fisheries, aquaculture and climate change: an introduction, in: J.D. Bell, J.E. Johnson, A.J. Hobday (Eds.), Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change, Secretariat of the Pacific Community, Noumea, 2011, p. 925 ⟨http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/403/Bell_et_al._2011._CC_&_Tropical_Pacific_Fisheries_&_Aquaculture.pdf⟩.

[25] P.C. Gehrke, M.J. Sheaves, D. Boseto, B.S. Figa, J. Wani, Vulnerability of freshwater and estuarine fisheries in the tropical Pacific to climate change, in: J. D. Bell, J.E. Johnson, A.J. Hobday (Eds.), Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change, Secretariat of the Pacific Community, Noumea, 2011, p. 925 ⟨http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/403/Bell_et_al._2011._CC_&_Tropical_Pacific_Fisheries_&_Aquaculture.pdf⟩.

[26] P. Lehodey, J. Hampton, R.W. Brill, S. Nicol, I. Senina, B. Calmettes, et al., Vulnerability of oceanic fisheries in the tropical Pacific to climate change, in: J. D. Bell, J.E. Johnson, A.J. Hobday (Eds.), Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change, Secretariat of the Pacific Community, Noumea, 2011, p. 925 ⟨http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/403/Bell_et_al._2011._CC_&_Tropical_Pacific_Fisheries_&_Aquaculture.pdf⟩.

[27] T.D. Pickering, B. Ponia, C.A. Hair, P.C. Southgate, E.S. Poloczanska, L.D. Patrona, et al., Vulnerability of aquaculture in the tropical Pacific to climate change, in: J.D. Bell, J.E. Johnson, A.J. Hobday (Eds.), Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change, Secretariat of the Pacific Community, Noumea, 2011, p. 925 ⟨http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/403/Bell_et_al._2011._CC_&_Tropical_Pacific_Fisheries_&_Aquaculture.pdf⟩.

[28] M.S. Pratchett, P.L. Munday, N.A.J. Graham, M. Kronen, S. Pinca, K. Friedman, et al., Vulnerability of coastal fisheries in the tropical Pacific to climate change, in: J.D. Bell, J.E. Johnson, A.J. Hobday (Eds.), Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change, Secretariat of the Pacific Community, Noumea, 2011, p. 925 ⟨http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/403/Bell_et_al._2011._CC_&_Tropical_Pacific_Fisheries_&_Aquaculture.pdf⟩.

[29] P. Lehodey, I. Senina, R. Murtugudde, A spatial ecosystem and populations dynamics model (SEAPODYM) – Modeling of tuna and tuna-like populations, Prog. Ocean. 78 (2008) 304–318 ⟨http://www.sciencedirect.com/science/article/pii/S007966110800116X⟩.

[30] D.B. Rasher, M.E. Hay, Chemically rich seaweeds poison corals when not controlled by herbivores, Proc. Natl. Acad. Sci. 107 (2010) 9683–9688.

[31] D.B. Rasher, E.P. Stout, S. Engel, J. Kubanek, M.E. Hay, Macroalgal terpenes function as allelopathic agents against reef corals, Proc. Natl. Acad. Sci. 108 (2011) 17726–17731.

[32] D.B. Rasher, S. Engel, V. Bonito, G.J. Fraser, J.P. Montoya, M.E. Hay, Effects of herbivory, nutrients, and reef protection on algal proliferation and coral growth on a tropical reef, Oecologia 169 (2012) 187–198.

[33] J.D. Bell, A. Ganachaud, P.C. Gehrke, S.P. Griffiths, A.J. Hobday, O. Hoegh-Guldberg, et al., Mixed responses of tropical Pacific fisheries and aquaculture to climate change, Nat. Clim. Chang. 3 (2013) 591–599 ⟨http://www.nature.com/nclimate/journal/v3/n6/pdf/nclimate1838.pdf⟩.

[34] N. Pascal, A. Seidl, T. Tiwok, Analysis of Economic Benefits of Marine Protected Areas: Case Studies in Vanuatu (9 MPAs) and Fiji (5 MPAs), South Pacific, 2012. (Powerpoint presentation).

[35] FAO (Food and Agricultural Organization) FishStatJ: Fisheries Statistics Database, FAO, Rome, Italy. Available at: ⟨http://www.fao.org/fishery/statistics/software/fishstatj/en⟩, 2012.

[36] M.M. Dey, R.M. Briones, Y.T. Garcia, A. Nissapa, U.P. Rodriguez, R.K. Talukder, A. Senaratne, I.H. Omar, S. Koeshendrajana, et al., Strategies and Options for Increasing and Sustaining Fisheries and Aquaculture Production to Benefit Poorer Households in Asia. WorldFish Center Studies and Reviews No. 1823. The WorldFish Center, Penang, Malaysia, 2008, p. 180.