NATIONAL MARINE ECOSYSTEM SERVICE VALUATION

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MACBIO

MARINE ECOSYSTEM SERVICE VALUATION

The living resources of the Pacific Ocean are part of the region's rich natural capital. Marine and coastal ecosystems provide benefits for all people in and beyond the region. These benefits are called ecosystem services and include a broad range of values linking the environment with development and human well-being.

Yet, the natural capital of the ocean often remains invisible. Truly recognizing the value of such resources can help to highlight their importance and prevent their unnecessary loss. The MACBIO project provides technical support to the governments of Fiji, Kiribati, Solomon Islands, Tonga and Vanuatu in identifying and highlighting the values of marine and coastal resources and their ecosystem services. Once values are more visible, governments and stakeholders can plan and manage resources more sustainably, and maintain economic and social benefits of marine and coastal biodiversity in the medium and long term.

The MACBIO Project has undertaken economic assessments of Tonga's marine and coastal ecosystem services, and supports the integration of results into national policies and development planning. For a copy of all report and communication material please visit **www.macbio.pacific.info**.

macbio.pacific.info

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Marine and Coastal Biodiversity Management in Pacific Island Countries

NATIONAL MARINE ECOSYSTEM
SERVICE VALUATION

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MACBIO
Marine and Coastal Biodiversity Management in Pacific Island Countries

SPREP
Secretariat of the Pacific Regional Environment Programme

IUCN

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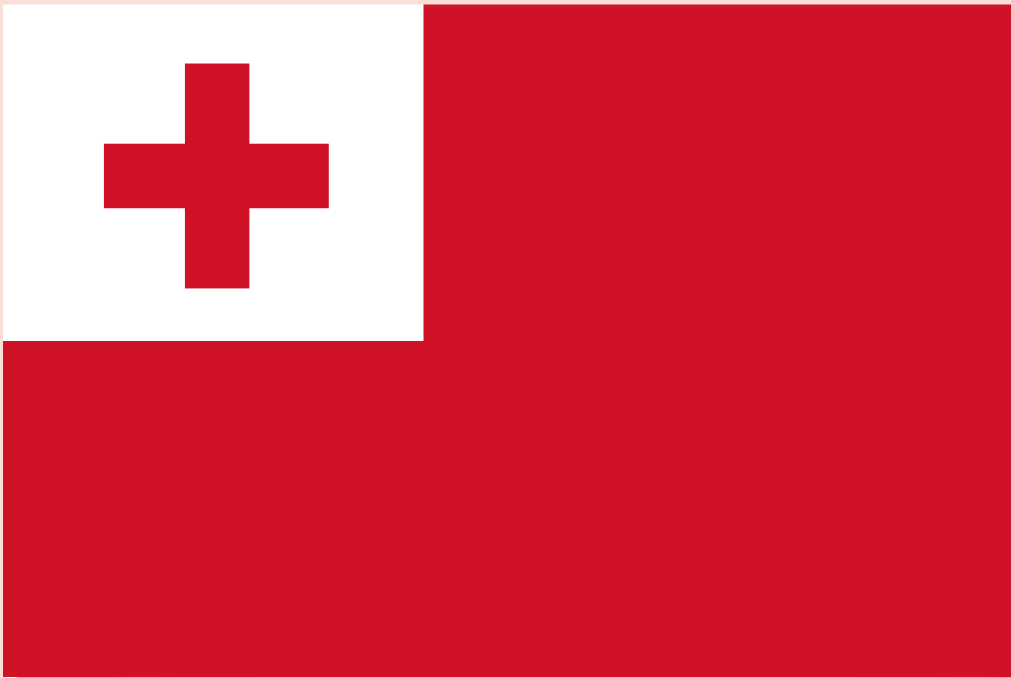

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ACRONYMS

ADB	Asian Development Bank
BIORAP	Rapid Biodiversity Assessment
BMUB	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CBA	Cost-benefit analysis
CBD	Convention on Biological Diversity
CITES	Convention on International Trade of Endangered Species
CPI	Consumer Price Index
CPUE	Catch per unit effort
CSFT	Civil Society Forum of Tonga
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DSM	Deep-sea mineral
DTSF Tonga	Community Development Trust
DWFN	Distant water fishing nation
ECF	Ecosystem contribution factor
EEZ	Exclusive economic zone
EIA	Environmental Impact Assessment
FAO	Food and Agriculture Organization
FFA	Pacific Islands Forum Fisheries Agency
FOB	Free-on-board
GDP	Gross Domestic Product
GEF	Global Environment Fund
GIS	Geographic Information Systems
GIZ	German Agency for International Cooperation
GNI	Gross National Income
HDI	Human Development Index
HIES	Household Income and Expenditure Survey
IMF	International Monetary Fund
IUCN	International Union for Conservation of Nature
MACBIO	Marine and Coastal Biodiversity Management in Pacific Island Countries
MAFFF	Ministry of Agriculture, Food, Forestry and Fisheries
MCTL	Ministry of Commerce, Tourism and Labour
MEIDECC	Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communication
MESCAL	Mangrove Ecosystems for Climate Change Adaptation and Livelihoods
MESP	Marine Ecosystem Services Partnership
MEY	Maximum economic yield
MFNP	Ministry of Finance and National Planning
MPA	Marine protected area
MSY	Maximum sustainable yield
NBSAP	National Biodiversity Strategic Action Plan
NGO	Non-government organisation
PCRAFI	Pacific Catastrophe Risk Assessment and Financing Initiative
PIFS	Pacific Islands Forum Secretariat
RESCCUE	Restoration of Ecosystems Services against Climate Change Unfavourable Effects
SCC	Social cost of carbon
SEEA	System of Environmental-Economic Accounting
SMA	Special Management Area
SMS	Seafloor massive sulphides
SOPAC	South Pacific Applied Geoscience Commission
SPC	Secretariat of the Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
TAC	Total allowable catch
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total economic value
TMDP	Tuna Fishery Management and Development Plan
UNDP	United Nations Development Program
USP	University of the South Pacific
VEPA	Vava'u Environmental Protection Association
WCPFC	Western and Central Pacific Fisheries Commission
WTA	Willingness-to-accept
WTP	Willingness-to-pay

EXECUTIVE SUMMARY

The exclusive economic zone of Tonga, nearly 700,000 km^2 of ocean, is 1000 times larger than the country's land area. Coastal and marine resources provide the Government of Tonga, businesses and households many real and measurable benefits. Without a doubt, the country's largest stock of natural wealth lies within the sea.

The role that natural ecosystems, especially marine ecosystems, play in human wellbeing is often overlooked or taken for granted. The benefits humans receive from ecosystems, called *ecosystem services*[1], are often hidden because markets do not directly reveal their value — nature provides these benefits for free. Failure to recognise the role that marine ecosystems play in supporting livelihoods, *economic activity*, and human wellbeing has, in many instances, led to inequitable and unsustainable marine resource management decisions.

This report describes, quantifies and, where possible, calculates the *economic value* of Tonga's marine and coastal resources. Seven key marine ecosystem services are evaluated in detail: subsistence and commercial fishing; minerals and aggregate mining; tourism; coastal protection; carbon sequestration; and research, management and education. Others services are explored as well, including cultural and traditional values associated with the sea, potential future industries and other human benefits that have not yet been analysed or exploited. The scarcity of data about many of these ecosystem services prevents calculation of the *total economic value*, so the values below should be regarded as minimum estimates. Data gaps are described in detail in this report.

Small-scale nearshore fishing for home consumption (subsistence) and sale at local markets supports the food and income security of most Tongan households. The subsistence and inshore commercial fisheries depend equally on the health and productivity of inshore habitats. The minimum estimate of the annual value of Tonga's inshore subsistence and domestic commercial fisheries is T$ 10 million, made up of approximately T$ 5.46 million in subsistence and T$ 4.2 million in commercial inshore fisheries. This value is derived from an annual subsistence and domestic commercial harvest of between 400 and 1,100 kg/km^2 of inshore habitat.

The deep-sea demersal offshore commercial fishery and the inshore aquarium trade are relatively small but consistent ecosystem services that provide some local employment and export *revenue*. The gross annual *revenue* from the deep-sea demersal fishery is about T$ 1.1 million. Costs are high for both sectors so net benefits are much lower than these estimates. Comprehensive management plans for these two fishery sectors have been improved over the past 20 years; if enforced these plans should ensure sustainability. The commercial *bêche-de-mer* fishery has been through several cycles of boom and bust. Although this sector has provided occasional spurts of export *revenue* and employment for Tongan fishers, sustainable management of the fishery has not been established. Although much of the harvest is done by Tongan households and offers an important source of cash income, much of the value of the resource is captured by the export companies who dry and sell *bêche-de-mer* to Asian markets. Some efforts are being made to encourage fishers to dry the products to receive a greater share of the benefits, and one Tongan exporter is now operating (the four others are Chinese).

The commercial tuna fishery in Tonga is notably smaller than most other Pacific Island countries, mostly due to Tonga's location — further south and east of the largest Pacific tuna stocks. Albacore is the dominant commercial tuna species in Tonga, making up 25–50% of the annual catch. Scientists report that yellowfin stocks show signs of overfishing and bigeye stocks are becoming dangerously low (both are caught within Tonga albeit in lower numbers than albacore), but albacore stocks remain healthy. The albacore fishery is likely to remain sustainable as long as costs-to-returns ratios remain high enough to limit fishing effort; subsidised foreign fleets could threaten sustainability. Although the longline fishing method is relatively sustainable for albacore fishing, bycatch of sharks and other pelagic species such as moonfish and marlin is substantial.

Tuna is the leading generator of income to the government from the fisheries sector and is the dominant fisheries export product. Government *revenues* of about T$ 1.3 million per year are generated from access fees through licensing since Tonga started selling licences to distant water fishing nation boats in 2012. The net benefits to the industry (*gross revenue* minus costs) are about T$ 0.9–2.2 million per year, although much of this benefit goes to foreign vessels. The industry provides some employment on locally-based fishing vessels, at landing sites and processing facilities. Locally-

1 Throughout the report, terms in italics are explained in the glossary (Appendix I: Glossary).

based tuna fishing provides benefits to consumers because locally-based boats sell tuna and tuna bycatch within Tonga. No canneries or sophisticated processing facilities exist in Tonga, so Tonga does not capture much *value-added* benefit. Foreign-based boats only benefit the Government of Tonga through licence fees.

Dredging of sand and aggregate provides benefits to the construction industry and consumers who benefit from concrete roads and buildings, but the negative impacts of dredging could not be assessed in this study. Probable impacts include destruction and siltation of reef and lagoon habitat which may harm Tonga's largest domestic marine ecosystem service, inshore fisheries. Lagoon dredging offers modest benefits to the Ports Authority. Beach mining for domestic purposes contributes a small amount of *net revenue* to the Natural Resources Division of the Ministry of Lands and Natural Resources; benefits to Tongan households could not be quantified without a robust survey. The impacts of beach sand mining and lagoon dredging to inshore fisheries and tourism are potentially significant and warrant further assessment.

Exploration for deep-sea mining is already providing significant benefits to the Government of Tonga, but no real benefits to Tongan households or the general economy. A comprehensive Deep-Sea Mining Act paves the way for oversight and benefit-sharing if mining operations occur in the future. The magnitude of threats to whale migration and tuna and deep-sea demersal habitat cannot yet be quantified, but must be considered. Tourism, tuna and deep-sea snapper industries provide substantial sustainable benefits to Tonga and may be impacted by deep-sea mining.

Tourism is a growing industry in Tonga that depends largely on healthy marine and coastal ecosystems. These ecosystems contribute T$ 9–22.5 million in annual *economic activity* in Tonga; a minimum estimate of the *net value* of expenditure (25%) would be T$ 2.2–5.5million each year. The net benefits from tourism are second only to coastal protection. Tourism benefits a variety of businesses and their employees and provides government tax *revenue*. Tourism can be a sustainable ecosystem service if managed and regulated. Fishing, particularly destructive types of inshore fishing, and nearshore sand and aggregate mining could negatively impact tourism benefits.

Fringing reef, mangroves and seagrasses protect Tonga's coasts from erosion and flooding. The *avoided damage cost method* is used to analyse their value. Because many of the commercial and residential properties in Tonga are near the coast, protection from flood and erosion damage from healthy coral reefs could be significant, from T$ 11.7 million to T$ 19.5 million annually in Tongatapu. Tonga's mangroves also provide carbon sequestration benefits to the world, worth about T$ 1.4 million per year. If protected, areas of mangroves at risk for destruction could be marketed and sold as carbon offsets, but the costs of verifying and managing the protected areas would need to be assessed on a case-by-case basis.

Marine and coastal areas attract foreign aid and research that benefits the Government of Tonga, bringing in T$ 540,000 to the Fisheries Division alone in 2015. Investment in marine and coastal biodiversity also includes many projects run through the Department of Environment, so the total benefit from aid and research is much greater. Money spent by individuals and institutions that research marine and coastal ecosystems or advocate for their protection mostly benefits government, although aid expenditure trickles through many sectors of the economy much like tourism expenditure.

Other marine and coastal ecosystem services include mariculture, handicrafts, bioremediation, cultural identity and aesthetic beauty. These services have not been quantified by this study because of a lack of data and human and financial resources, but they indeed provide benefits to Tongan citizens and the rest of the world.

MACBIO's formal link with the Government of Tonga is through the Department of Environment, but from the onset the project has made an effort to support and assist all departments relevant to marine and coastal resource use and management. The Fisheries Division, in particular, is responsible for oversight of many key marine ecosystem services, and was instrumental in the development of this report. Throughout the development of this report, the authors endeavoured to share information about the *economic value* of marine ecosystems with all the departments that have a role in marine resource use and management. These discussions indicated awareness and understanding that economic valuation information could inform development policy, legislation, and regulation of marine activities.

This study is a step towards a national process of recognising the human benefits of natural ecosystems which will lead to more equitable and sustainable management of Tonga's marine assets. This report serves as an inventory of current information about the *economic value* of Tonga's marine and coastal assets and as a starting point for more in-depth valuations of each of the marine and coastal ecosystem services. More generally, Tonga should consider taking steps towards accounting for natural capital to ensure the sustainable prosperity of the Kingdom.

TABLE 1 • Annual economic value of marine and coastal ecosystem services in Tonga (2013)

Sector	Ecosystem service 2013	Beneficiaries	Net annual value* (2013 adjusted) m = million	Sustainability**
Fisheries	**Subsistence fishery**	Tongan households, particularly rural and low income	T$ 5.46m (US$ 3.05m)	Sufficient inshore habitat for sustainable subsistence harvests, but localized overfishing has reduced productivity, threatening sustainability
	Domestic commercial inshore fishery	Tongan fishers, Tongan consumers, some restaurants and businesses (only value to fishers is estimated)	T$ 4.2–7.3m (US$2.3–4.1m)	Sufficient inshore habitat for sustainable harvests (for local demand), but localized overfishing has reduced productivity, threatening sustainability
	Bêche-de-mer	Mostly export companies and foreign consumers, some small-scale fishers/divers, some government revenue (value includes exporters, fishers, and government)	T$ 0.45m (US$ 0.25m)	Over-harvesting has led to periodic closures; export of some species competes with subsistence food security
	Aquarium trade	Mostly foreign export companies, some government benefits (not included in value)	T$ 0.25m (US$ 0.14m)	Sustainable management plan, if enforced. Damage to habitat threatens inshore commercial and subsistence
	Offshore tuna	Locally-based and foreign fishing boats, government, some local consumers and workers (value includes local and foreign boats and government revenue)	T$ 2.3–3.5m[7] (US$ 1.3–2m)	Albacore long-line fishing sustainable, yellowfin threatened and bigeye overfished. By-catch threatens sharks and some pelagic fish
	Deep-slope demersal	Tongan fishers, domestic consumers, export companies and foreign consumers, modest government benefits (not included)	T$ 0.23m (US$ 0.13m)	Sustainable management plan, if enforced. Threatened by deep-sea mining
Mining	**Sand and aggregate**	Data only for modest government benefits. No data for benefits to households, construction companies, and everyone who uses concrete structures and roads	Insufficient data	Beach mining for construction is unsustainable; lagoon dredging needs monitored to prevent diminishing fishing and tourism ecosystem services
	Deep-sea minerals	International mining companies; government and local economic benefits depends upon taxes, royalties, and business operations	Insufficient data	Potential destruction of deep-sea demersal habitat. Risks to tourism (whales), pelagic fisheries are unknown
Tourism	**International tourism and recreation**	Tongan businesses and government; benefits to international tourists not included	T$ 3.5–8.8m (US$ 2–4.9m)	Sustainable, if pollution and damage from tourism development and tourist activities are monitored
	Domestic recreation and tourism	Tongan citizens	Insufficient data	Sustainable, if pollution and damage from recreation activities are controlled
Regulating Services	**Coastal protection**	Citizens and visitors, in particular owners of coastal property (measures avoided repair costs)	T$ 11.7–19.5m (US$ 6.5–10.9m)	Sustainable if reef and mangroves are healthy
	Carbon sequestration	Global benefit from mangroves only (lack of data on seagrass and algae). Potential benefit to communities from carbon credits (not included in value)	T$ 1.4m (US$ 0.77m) Gross export value	Sustainable, if mangroves are protected
Foreign Investment	**Research, education, and management**	Mostly government, but some aid money trickles through economy	>T$ 0.54m (>US$ 0.3m) Gross export value	Depends on international relations and agreements related to nature conservation

* Different beneficiaries (local, foreign, producer, consumer, government) are included in the net value estimates. Read beneficiaries column for explanation.

** *Sustainability* refers to whether the values presented can be expected to decrease (unsustainable), increase, or stay the same (sustainable) with current human behaviours.

1. INTRODUCTION

1.1 MARINE AND COASTAL BIODIVERSITY MANAGEMENT IN PACIFIC ISLAND COUNTRIES (MACBIO) PROJECT

Funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) for a period of five years through the International Climate Initiative (IKI), the Marine and Coastal Biodiversity Management in Pacific Island Countries (MACBIO) project aims to strengthen the sustainable management of marine and coastal biodiversity by supporting economic ecosystem assessments, marine spatial planning and consultations in regard to marine protected areas (MPAs). The economic valuations of marine ecosystems will contribute to national development plans. The project also aims to assist governments to extend and/or redesign marine protected area networks using seascape-level planning. The project will, in addition, demonstrate effective approaches for site management, including payment for ecosystem services and other conservation finance tools. Tried and tested concepts and instruments will be shared with governments and stakeholders throughout the Pacific community and disseminated internationally.

MACBIO is being implemented in five Pacific Island countries with the support of German Agency for International Cooperation (GIZ) in close collaboration with the Secretariat of the Pacific Regional Environment Programme (SPREP) and with technical support from the International Union for Conservation of Nature (IUCN).

These efforts to support improved management of marine and coastal biodiversity on the volcanic islands of Fiji, Solomon Islands and Vanuatu and the atolls of Kiribati and Tonga will help countries to meet their commitments under the Convention on Biological Diversity (CBD) Strategic Plan 2011–2020 and the relevant Aichi targets, including the Programme of Work on Protected Areas and the Programme of Work on Island Biodiversity.

All five countries are working towards achieving the quantitative Aichi Target 11: 10% of the coastal and marine environment in protected areas by 2020[2]. As of 2014, the MACBIO countries had protected the following percentages of their marine and coastal environment: Fiji = 2%; Kiribati = 11%; Solomon Islands = > 5%; Tonga = 2%; Vanuatu = > 1%. With the exception of Kiribati, the countries remain a long way from achieving this Aichi target. Most of the existing MPAs are not ecologically representative and countries lack the means to ensure the conservation and sustainable use of resources. Most countries are facing severe challenges in regard to human resources and funding, inadequate law enforcement and lack of access to the information needed for marine biodiversity management.

Under the MACBIO project, IUCN Oceania is primarily responsible for conducting national-scale economic assessments of marine and coastal ecosystem services in all five MACBIO countries, including conducting a data gap analysis. National reports on the value of marine and coastal ecosystem services will be provided to countries to inform marine spatial planning and marine resource management in general. This is one of those reports.

2 Aichi Target 11: By 2020, at least 17% of terrestrial and inland water, and 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

1.2 PROBLEM STATEMENT

Although the people and economies of the Pacific Island countries depend to a large extent on marine and coastal ecosystems, marine resource management should receive more attention in national plans and strategies (e.g. strategies relating to national development planning, tourism, food security, livelihoods, disaster mitigation and climate change adaptation) (MSWG 2005; PIFS 2007; Pratt and Govan 2011). This is due partly to a lack of understanding of the full *economic value* of marine and coastal ecosystem services (TEEB 2012).

The *economic contribution* of biodiversity and ecosystem services to the wellbeing of Pacific Islanders is understated for a variety of reasons including:

- Substantial resource-based *economic activity* exists outside of formal markets (subsistence)
- Customary resource tenure arrangements that poorly reflect individual economic decisions and pricing in markets
- Government agencies in the region typically have relatively low capacity in environmental economics and *green national accounting*
- Many countries of the region are relatively young and/or have lacked continuity in governance which has contributed to a lack of long-term data and analysis of ecosystem service stocks and flows at the national level
- Many countries of the region have a history of a two-tiered economy; one export and expatriate-led and the other traditional village-based and subsistence-oriented. Both tiers, however, are largely dependent on the same resource base. Planning and policy has generally struggled to address the interest of both dimensions of resource-based economic development at the national scale.

Identifying the *economic value* of marine and coastal ecosystems and taking these findings into account in national planning processes can help create incentives for more effective protection and sustainable use of marine species diversity. This, in turn, will help to sustain the benefits that people derive from those marine and coastal ecosystems.

1.3 PURPOSE AND OBJECTIVES

The MACBIO project has undertaken national-level economic assessments of marine and coastal ecosystems in the five project countries in a manner compatible with the global The Economics of Ecosystems and Biodiversity (TEEB) initiative. The work aims to contribute to national development plans and marine resource management policies and decision-making.

The principal objective of the economic component of MACBIO is to help countries to identify, quantify and, as far as possible, value in monetary units the most relevant marine and coastal ecosystem services in each MACBIO country. This should result in a national assessment of the human benefits of marine and coastal ecosystems. A comprehensive survey of the current state of knowledge and priority knowledge gaps is the first step towards accounting for marine natural capital and a *baseline* on which more detailed valuation studies could be built. The information provided within the reports can be used to guide, design and develop marine resources management plans, policies, assessments, legislation and tools, such as MPAs and EIA.

This economic valuation is intended to enhance ecosystem-based marine and coastal resource management to lead to more resilient coastal and marine ecosystems, more effective conservation of marine biodiversity, and to contribute to climate change adaptation and mitigation, as well as to securing and strengthening local livelihoods and food security.

1.4 DESCRIPTION OF THE GEO-POLITICAL BOUNDARIES OF ANALYSIS (SCOPE)

With an area of 180 million km^2 the Pacific represents around 50% of the global sea surface and a third of the Earth's surface. The 22 Pacific Island States and Territories comprise more than 200 mountainous volcanic islands and some 2,500 flat islands and atolls. The Exclusive Economic Zones (EEZs) of the five project countries cover about 7,560,000 km^2, an area the size of Australia. The project region includes one of the world's centres of marine biodiversity, with an unusually large number of endemic species. Despite the outstanding importance of this biodiversity for people's food and livelihoods, comprehensive species and habitat inventories are often lacking, as well as adequate valuation of the ecosystem services they provide to people.

MACBIO adopts a national-scale assessment of the economics of ecosystem services and biodiversity as a direct result of the factors that contribute to a lack of appropriate information to manage the natural wealth of Pacific Island nations.

In Tonga, we chose to conduct a national assessment in part because it would have the largest and broadest potential relevance to policy and decision-makers. Furthermore, the human resources and funding required to conduct valuations specific to each policy or initiative related to the marine environment are unlikely to be available in small Pacific Island countries. An overview of the national-level values of marine and coastal ecosystem services can be used in a variety of ways, in a manner that policy-specific analyses cannot. Consider, for example:

- Although subsistence marine and coastal resource use and management primarily takes place at the village or community level, it does so within an economic and policy context at a national scale.
- Commercial fishing is often managed at the national scale (if not the regional (international) scale).
- Infrastructure investment decisions to mitigate disaster risk in coastal zones are often best managed through national planning processes in this region.
- Most Pacific Island nations have only one international airport, one main deep-water port and one primary commercial centre, so any economic development policy relying on these (e.g. to do with marine tourism) becomes an issue of national policy.
- Many Pacific Island nations have committed to national-level planning and policy efforts under one or more UN Conventions. National capacity-building, data collection, storage and analysis helps to reduce redundancy and perhaps create synergies with other parallel efforts and country-scale commitments in the region.
- Many of the compensatory and regulatory policy tools available and being used to promote behaviour in line with both natural wealth management and sustainable economic development objectives are most often national-level tools. These might include payment for ecosystem services approaches, entry and/or exit fees, hotel taxes, taboo seasons, catch limits, use of coral for construction materials, clearing of mangroves, water, sewage and solid waste disposal, among other issues and concerns.

1.5 REPORT INTRODUCTION

The Kingdom of Tonga is a Pacific Island country, with very small land area but immense marine resource wealth. Tonga's EEZ, nearly 700,000 km^2 of ocean, is 1000 times larger than the country's land area. The country's largest stock of natural wealth lies within the sea, providing numerous real and tangible benefits to Tongan citizens and foreign businesses and consumers.

This report provides details of the country-specific context within which the economic evaluation was conducted and explains the methodological framework for the analysis. The specific methods applied in the report are discussed briefly; see Salcone et al. (2015) for detailed methods. This report depends primarily on existing data and reports, synthesising this information and drawing conclusions where possible. In the process important knowledge gaps and future high priority steps are revealed. The report describes and quantifies Tonga's marine and coastal resources, and where possible, calculates their *economic value*. Seven key marine ecosystem services are evaluated in detail: subsistence and commercial fishing; minerals and aggregate mining; tourism; coastal protection; carbon sequestration; and research, management and education. Additional services explored include cultural and traditional values associated with the sea, non-market *existence values*, and potential industries and other human benefits yet unexplored.

Tonga's unique institutions, in particular the monarchy and the open-access nature of fishing territory, are described in Section 2.1, followed by an analysis of national policies, objectives, and initiatives that could use information about the human benefits of marine ecosystems. The TEEB initiative and global framework for ecosystem service valuation are presented in Chapter 3. Chapter 4 provides an overview of economic valuation literature relevant to Pacific Island States and Territories; technical methods are explained in Chapter 5.

The core of this report is Chapter 6 — the results of an economic assessment of marine and coastal ecosystem services. The first component of each subsection of the results, **Identify**, is a clear identification of how each natural marine and coastal ecosystem provides benefits to humans. That is, how *ecosystem functions* become *ecosystem services*. The second component, **Quantify**, is a review of data that quantitatively describe the magnitude of each ecosystem service. Early in the project it was established that a lack of comprehensive and reliable data would substantially limit the depth and breadth of economic valuation of ecosystem services. In response to this obstacle, an analysis of data gaps is a core focus of this national report. The third component, **Value**, presents the *economic value* of the ecosystem service as much as the data available allow.

Tonga experiences great annual variability in the magnitude of benefits from marine and coastal ecosystems, particularly with regard to commercial fisheries. In some instances, due to variations in harvests and changes to the health of the ecosystem, an annual value of the ecosystem service is hardly relevant. These and methodological and data issues are discussed in the **Uncertainty** section. In the **Sustainability** section, the report indicates whether current resource uses are sustainable, that is whether the natural benefits can be expected to continue, to increase, or to decrease with current practices. The benefits of different *ecosystem functions* may accrue to few or many, nationals or foreigners, businesses or consumers. In order to understand the incentives that motivate different resource use patterns, it is important to consider who receives the benefits from the various marine and coastal ecosystems in Tonga. The **Distribution** section for each ecosystem service describes the distribution and considers equity of existing ecosystem benefits.

The results for each ecosystem service are synthesised in Chapter 7. Recommendations and suggestions for how this information could be used are presented in Chapter 8. Since economic information is commonly plagued by misinterpretation, an explanation of the caveats and limitations of this research as well as disclaimers about how this information should not be used are presented in Chapter 9. Chapter 10 suggests areas for further research.

2. CONTEXT

2.1 DEMOGRAPHIC AND ECONOMIC COUNTRY PROFILE

The Kingdom of Tonga is a small island nation in the southern Pacific Ocean surrounded by Fiji to the west, Samoa to the north, Niue to the east and open to the high seas and territories of New Zealand to the south (Figure 1). Tonga's EEZ is about 700,000 km^2, smaller than the EEZ of Vanuatu but larger than that of Italy and South Korea. The exact borders of the EEZ, particularly with regard to Fiji to the west, remain under negotiation at the time of writing. Regardless, land (707 km^2) comprises only about 1% of Tongan territory.

Tonga's 176 islands lie between 15° and 23.5° S. It is within the tropics but further south than most other Pacific Island countries, giving Tonga more distinct seasonal temperature variation and slightly different marine resources. Despite the small land territory, Tonga has a varied topography. Tongatapu is the main island of the Kingdom of Tonga where the capital (Nuku'alofa) and the only international airport are located. It is characterised by flat, fertile plains. The Ha'apai island group is comprised mostly of small coral atolls and extensive lagoons but is also home to one dormant and one active volcano; the Vava'u islands are surrounded by high limestone cliffs and meandering bays; the island of Eua is virtually a limestone mountain rising from the sea. Just east of the Tongan islands lies one of the world's deepest ocean trenches, the Tongan Trench, reaching 10,800 metres below sea level at its lowest point. The Tongan Trench is an active subduction zone where the Pacific Plate is sliding below the Tongan and Indo-Australian Plate at a rate of about 15 cm per year. This makes Tonga susceptible to earthquakes. Tonga's southern latitude places it outside of the Pacific's densest skipjack, bigeye and yellowfin tuna habitats, but squarely within the habitat for albacore ('white meat') tuna. Humpback whales breed and give birth annually in close proximity to Tongan shores, particularly in the Vava'u group.

Approximately 105,500 people lived in Tonga in 2014, a population slightly larger than Micronesia and slightly smaller than Kiribati. More than two-thirds of the population live on Tongatapu Island. About 7,000 people live in the Ha'apai group and about 15,000 in Vava'u. From 2006 to 2011 the population shrank in all areas except Tongatapu, where the population grew about 5% (Tonga Ministry of Finance and National Planning 2014). Tonga is a true nation-state; over 95% of people living in Tonga are of Polynesian Tongan ethnicity. There was a significant immigration of Chinese during the 1980s and 1990s when Tonga was reportedly selling passports, although many Chinese left during pro-democracy riots in 2006. Most Tongans speak Tongan as their first language, but English is also spoken by nearly everyone. English-speaking skills and literacy are especially high among the educated workforce, where English language is a requirement. The Kingdom of Tonga has the proud distinction of being the only Pacific Island country to have never been colonised and has maintained indigenous governance through a monarchy since the 1840s.

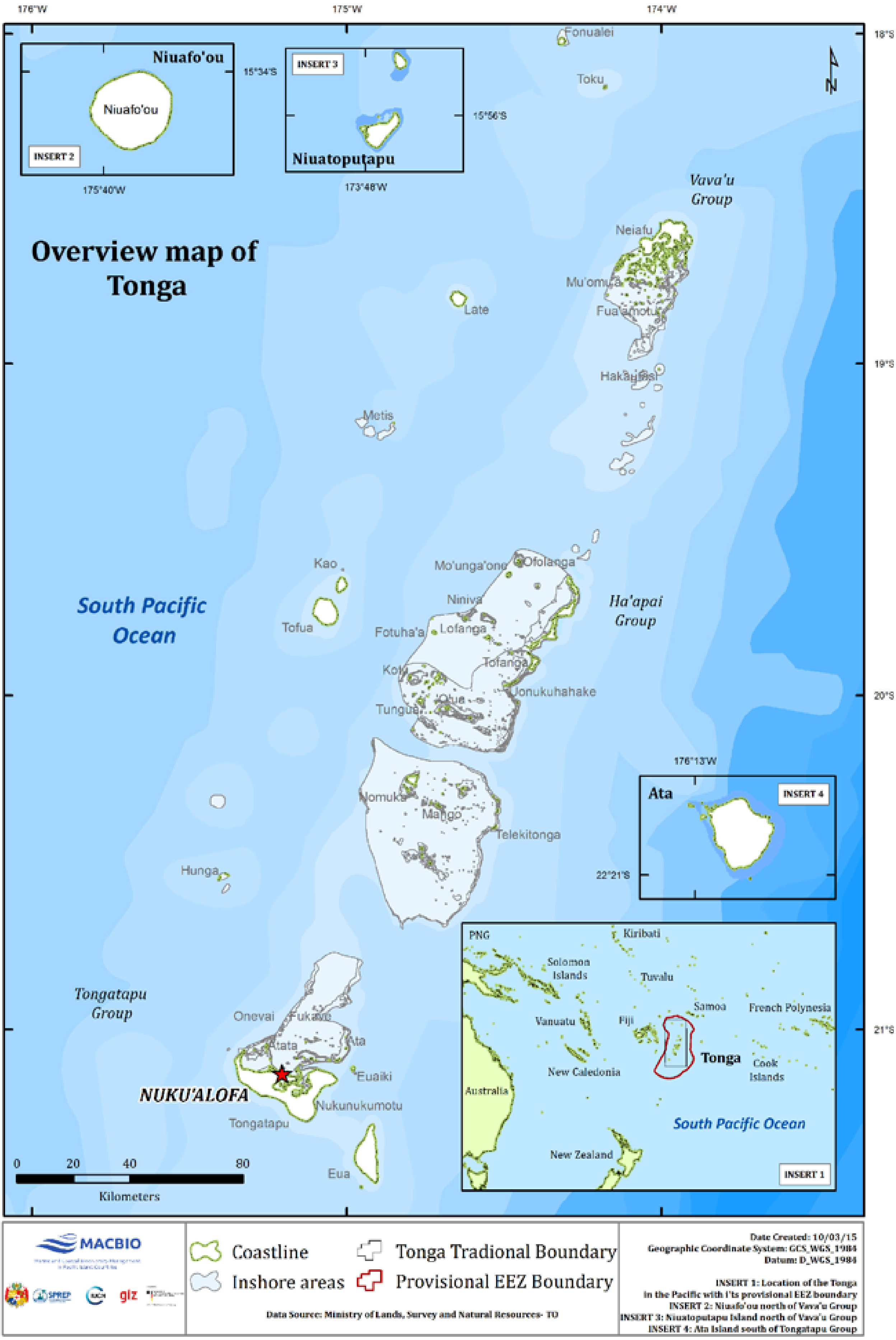

FIGURE 1 • Map of Tonga, including reef and other inshore habitat areas (lightest shade of blue)

Emigration and remittance income is common among Pacific Island countries, but even for a Pacific Island country Tonga's emigration and remittance statistics are exceptional. The number of Tongans living outside of Tonga is significantly greater than the number of Tongans living within Tongan territory. There are 146,322 Tongans living in New Zealand, Australia and the United States of America. The combined Tongan population of those three countries is nearly 40% greater than the population living within Tonga. Although statistics on the magnitude of remittances vary widely by source, it is clear that they are extremely important to the Tongan economy. Between 2000 and 2010, current transfers, remittances and aid were equivalent to between 26% and 31% of annual Gross Domestic Product (GDP), making remittances and aid the largest contributor to foreign exchange.

Tonga's annual GDP is shown in Figure 2. Non-market GDP is an estimate of the value of subsistence activities, mainly growing food, raising animals, fishing and producing artisanal goods for own use or trade. Adding taxes (about T$ 100 million in 2011), total GDP in 2011 was about T$ 800 million. Remittances are not included in market or non-market GDP and therefore are not represented in Figure 2 (Tonga Statistics Department 2012).

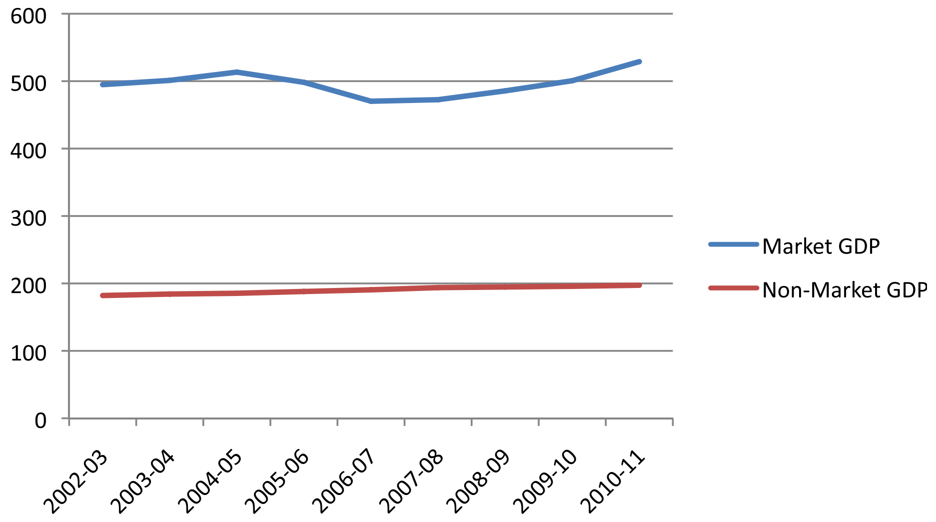

FIGURE 2 • Tonga GDP 2002–2010, in constant 2013 currency (million Pa'anga)

Source: Tonga Statistics Department 2012

Agriculture is the largest official sector of the Tongan economy at 16% of GDP, followed by the public sector (13%), the wholesale/retail industry (10%), and the construction industry (12%) (Tonga Ministry of Finance and National Planning 2014). Manufacturing (which includes food processing and transportation) and communications each make up an additional 7% of annual GDP. The fisheries sector averages around 3% of GDP, though fisheries returns vary widely from year to year. Tourism is difficult to estimate because tourist receipts are spread among many sectors, such as transportation, manufacturing, and hotels and restaurants. The Ministry of Tourism has estimated the contribution of tourism at 7.7% of annual GDP (Tonga Ministry of Commerce, Tourism and Labour 2014). The contribution of each sector to GDP in 2011 is in Figure 3. Note that tourism includes parts of hotels and restaurants, transportation and communications, and many categories in 'other'.

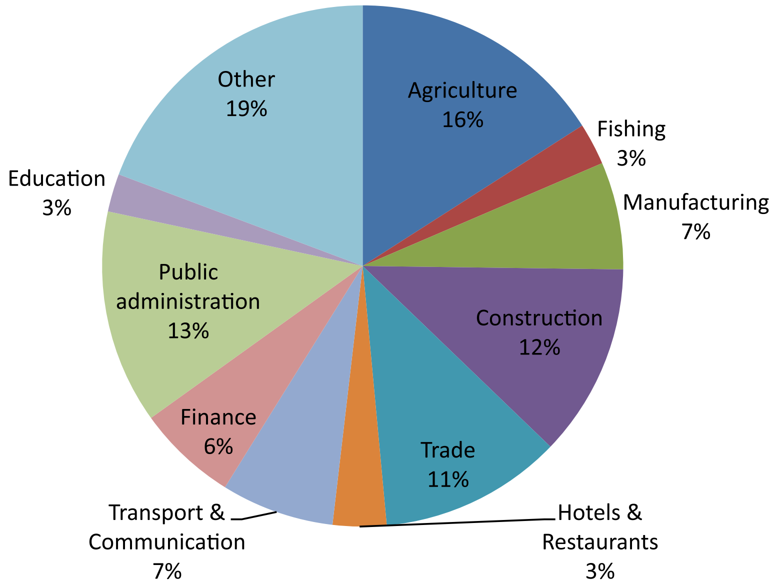

FIGURE 3 • Tonga GDP by economic sector

Source: Tonga Statistics Department 2012

Tonga's largest imports (by value) are fuel, food, and transportation services (flights). Tonga's largest export products are squash, fish, root crops and vanilla. Remittances and tourism bring in much-needed foreign exchange; import spending outpaces export revenue by a ratio of 10:1 (WTO 2014). Aid and remittances help sustain this imbalance. With a total annual GDP averaging less than US$ 500 million (~US$ 850 million *purchasing power parity*), Tonga is the smallest economy with membership to the World Trade Organization (WTO 2014). Thanks largely to remittance transfers, Gross National Income per capita remains moderate at about US$ 4,500 (T$ 8,000) per person, per year.

According to the 2011 Census, there were 64,597 people aged 15 and over in Tonga; 33,795 of these were economically active. Approximately 36% of Tonga's labour force is not formally employed (United Nations 2010). This rate is highest in rural areas where the majority of women and a near majority of men are not formally employed. Many of these individuals participate in household work and subsistence farming and fishing and are recorded as unemployed. To compensate, the Statistics Department reports an adjusted unemployment rate of 6.5% (Tonga Statistics Department 2011).

There are few good sources for statistics about the state of education in Tonga (most reports cite 1990s statistics). However, there is a general sense that education is highly valued by families and that educational attainment is high for an isolated middle-income country. The 2014 Budget Statement of the Ministry of Finance and National Planning reports that Tonga's literacy rate (98.2%) is well above the Asia–Pacific average (94.7%) but comments that the percentage of population aged 15 and older with secondary education is only 74.6%. This is mainly attributed to high drop-out levels, especially for males, and may indicate a relatively low level of reading comprehension by some. The report also states that "*the higher attendance by girls is represented in the active role of women in middle and higher management of government and many private businesses.*" (Tonga Ministry of Finance and National Planning 2014)

Primary education is free and compulsory between ages 6 and 14 in Tonga; enrolment is approximately 93% (United Nations 2010). The literacy rate among children and young adults is close to 99%. Many primary schools and the majority of secondary schools are run by missionaries with connections to foreign churches, but there is also high public sector support for education. There is a government-run scholarship program (funded largely by New Zealand and Australian foreign aid) for families who are inclined to pursue overseas education.

The University of the South Pacific (USP), a regional university owned in part by Tonga, maintains a presence in the form of the 'Atele Campus on Tongatapu. There are small USP outposts for distance-learning students in Ha'apai and Vava'u. Although there is some post-secondary education in Tonga in the fields of agriculture, medicine, nursing and teaching, many young Tongans choose to pursue their studies overseas.

Tonga ranks 95th of 132 countries analysed in Transparency International's Corruption Perception Index and 17th of 35 countries in the Asia–Pacific region (Wickberg 2012). This may surprise visitors because corruption is not overtly apparent in Tongan daily affairs. However, the U.S. Department of State has claimed that government contracts have often been awarded to businesses associated with the royal family or government officials (US Department of State 2011). Tonga is not party to any of the international conventions on corruption. Tonga did not enact a Freedom of Information policy until 2012, political financing is poorly regulated, and whistle-blowers are not judicially protected. However, internet access is not monitored and there are no reports of harassment or persecution of journalists. Tonga ranks in the upper half globally in regards to rule of law, a World Bank governance indicator. An anti-corruption commission was established in 2008 but it has never been fully operational. Although political authoritarianism and nepotism may be a historical factor in past power structures in Tonga, transparency has improved substantially with the transition to democracy (Wickberg 2012).

The Human Development Index (HDI) is a combined measure of wellbeing based on life expectancy, education and per capita income measures. According to the HDI index in 2013, Tonga was ranked 100th of 187 countries, above Samoa at 106, but below Fiji at 88 (UNDP 2013a). HDI rankings for Pacific Island countries have been declining over time, meaning that these countries are falling behind the rest of the world in terms of human development indicators (McGillivray and Carpenter 2011). Tonga's HDI index rose from 0.695 in 2005 to 0.705 in 2013, but its rank slipped from 75 in 2005 to 100 in 2013 (UNDP 2013b).

2.2 INSTITUTIONAL CONTEXT

A unique aspect of Tongan institutions is the persistent role of the monarchy. In the 19th century, before the monarchy had exerted control over all Tongan islands, fishing rights belonged to the people living adjacent to the fishing areas, who were under chiefly control (Malm 2001). This changed as chiefly privileges were abolished between 1839 and 1862; the country's first constitution, in 1875, formalised the power of the monarchy. Communities lost exclusive fishing rights and responsibility over marine resources. Since the establishment of the monarchy, the sea and its resources have been common property, owned by the King — people have the right to fish wherever they like and community management controls are limited (Malm 2001). With the exception of relatively new Special Management Areas (SMAs), all Tongan waters are open to fishing and gleaning by any and all citizens.

Although all land and sea was owned by the King, some villages were titled to chiefs, and over time, chiefs have given some land to the residents of the village. Today, land tenure is by inheritance and land may not be sold to foreigners. Many small businesses are owned by Chinese or Chinese Tongans but there is no ethnic Chinese representation in government. Tonga is an active member of the Pacific Islands Forum Secretariat (PIFS), The Secretariat of the Pacific Community (SPC), and the SPREP.

In late 2014, Tonga reorganised its government ministries, grouping Environment, Energy, Climate Change, Disaster Management, Meteorology, Information and Communications under one ministry coined 'the super ministry' because of its enormous acronym (MEECCDMMIC). The new government commencing 2015 renamed the ministry to Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communication. This ministry makes decisions regarding EIAs of larger projects, supports projects to restore mangroves, can implement MPAs and contributes to monitoring of habitats and threatened species including threatened marine species. They have an office in Vava'u.

The Ministry of Agriculture, Food, Forestry and Fisheries is responsible for all aspects of management of commercial and subsistence fisheries including the establishment of SMAs. They are also involved in mangrove restoration. The Fisheries Division maintains offices and staff in several outer islands, including Vava'u, Ha'apai, 'Eua, and Niuatoputapu. One of the major objectives of these outposts is to promote fisheries development. This is carried out through a variety of mechanisms, including market facilitation, advice on fisheries management, deployment of offshore fish aggregation devices, and provision of ice-making equipment (Gillett 2011).

The Ministry of Commerce, Tourism and Labour supports the development and management of marine tourism including whale watching, diving, snorkelling and island resorts including training of tourism sector staff. The Tourism Department also supports waterfront beautification and a 'clean up Tonga' campaign which helps to reduce marine debris.

The Ministry of Lands and Natural Resources oversees land tenure issues including coasts and sand and is also involved in the designation of MPAs. Their responsibility includes exploration and possible future mining of deep-sea minerals, gas and oil. They also hold much of the spatial data and GIS expertise in Tonga. The Marine and Ports Division promotes quality management of safety, security and environmental wellbeing. They also contribute to conservation and management of marine resources and environment. The Ministry of Infrastructure strives to achieve appropriate systems of rules, regulations and enforcement, consistent with Tongan law and international standards to guide the safe and secure operations of maritime services, civil aviation and land transport. They use an appropriate system of rules, regulations and enforcement to guide safe and environmentally sound building and construction in Tonga.

The Ports Authority's mission is to enhance the long-term value of ports business and to ensure its sustainability. For the past 16 years, Ports Authority Tonga has been providing cost efficient, effective and competitive services and facilities for port users and shippers. The authority is moving to work together with other relevant ministries to minimise the impacts from ports development on the marine environment (Lavemai, pers. comm. 2015).

The Tonga Statistics Department provides national statistics on population, household activities and consumption including matters relevant to the marine environment. These statistics are used in planning processes including those of the Department of National Planning. Much of the marine work is funded by projects rather than government appropriations and this creates a challenge in terms of sustainability of government activities.

The Ministry of Internal Affairs consolidates policy and many of the delivery functions related to social and community development including promotion of women's rights and gender issues, promotion and protection of culture, development of youth and sports, management of seasonal work schemes and development of local government capacity and engagement with government as well as the management of District Development Committees. The ministry complements the efforts of other ministries to promote strong inclusive communities by meeting their service needs and ensuring equitable distribution of development benefits.

Non-governmental organisations such as the Civil Society Forum of Tonga (CSFT), Tonga Community Development Trust (DSTF) and the Vava'u Environmental Protection Association (VEPA) are involved in marine conservation activities such as mangrove restoration, environmental conservation, promoting SMAs in communities and awareness programmes in schools. The CSFT also helps to address the needs and coordinate the roles of Civil Society Organisations to better serve their communities. The DTSF works to ensure environmental sustainability, including of marines resources, and disaster risk reduction. VEPA works on conservation projects in a range of environmental habitats including coral reefs, mangroves, and forest areas. They work to protect and restore these natural resources for the benefit of Vava'u and the world and to ensure that Vava'u maintains its unique biological diversity.

From the onset MACBIO has made an effort to support and assist all departments relevant to marine and coastal resource management. The Fisheries Division, in particular, is responsible for oversight of many key marine ecosystem services, and was instrumental in the development of this report.

While there seem to be strong linkages between Environment, Lands and Natural Resources and Fisheries, the connections appear less strong between those departments and some of the other relevant departments. Although the Environment Division is responsible for environmental monitoring and regulation, it is national planning decisions that will largely influence long-term impacts on marine and coastal ecosystems. MACBIO endeavoured to share information about the *economic value* of marine ecosystems with all the departments that have a role in marine resource use and management, in order that this information can inform development policy, legislation, and regulation of marine activities.

2.3 POLICY CONTEXT

The Tongan Constitution makes provision for the sustainable use of all natural resources, including the 99% of Tonga that is ocean. Tonga's fishing grounds stretch from 14.1°S to 25.7°S latitude and 171.1°W to 179.1°W longitude. The extent of Tonga's undeclared EEZ is approximately 700,000 km^2 compared to its land area of 707 km^2. Hence the challenge lies in effectively managing and maximising the sustainable development potential of marine resources.

The Second Strategic Development Framework for Tonga aims to improve cultural awareness, disaster risk management, climate change adaptation and ecologically sustainable use of environmental resources (including marine and coastal resources). The framework aims to integrate these matters into all planning and implementation of programmes by establishing and adhering to appropriate procedures and consultation mechanisms.

The Tongan Department of Environment has recently facilitated the completion of the fifth review of Tonga's National Biodiversity Strategic Action Plan (NBSAP), in accordance with the CBD (Kingdom of Tonga 2014). The NBSAP review is a status report on biodiversity and species abundance and a review of progress towards national biodiversity objectives. This economic valuation is a major step towards achieving objective 7.4: *"To encourage the quantification of benefits derived from the use of biodiversity and other ecosystem services to support the full integration of biodiversity conservation into sustainable development planning and decision-making."* This objective is rated yellow in the fifth review to indicate work in progress. The same category was assigned to progress towards Aichi Target 2[3], citing the IUCN/SPREP economic valuation being conducted in Vava'u (see Section 2.5).

The NBSAP review cites ongoing illegal fishing activities such as poison fishing, dynamite fishing, and hookah diving as major threats to inshore biodiversity, particularly for commercially valuable species such as *bêche-de-mer* and giant clam. While policy measures have been introduced to protect over-exploitation of threatened species, enforcement of these policies is weak or non-existent.

The main policy tools being used to tackle these problems are the establishment and improvement of fisheries management plans and the development of community-managed MPAs known as SMAs. In 2013, there were nine officially designated SMAs in Tonga with ten more in development with funding from UNDP and the Global Environment Fund (GEF) (Kingdom of Tonga 2014).

Tonga has signed up to the Convention on International Trade of Endangered Species (CITES) on 20.10.2016. Shark fins are commonly exported.

There are various policies, plans and legislative acts contributing to conservation and sustaining ocean and marine resources. For example, the *Fisheries Management Act 2002* provides for the conservation and sustainable use and development of fisheries resources in the Kingdom and other relevant matters. The *Aquaculture Management Act 2003* and the National Aquaculture Management and Development Plan (2014–2019) provide for the management and development of aquaculture in the Kingdom. This Act states that the Fisheries Minister is responsible for the control, management and development of aquaculture and any related activity, whether on land or in any aquatic area including marine areas. The *Maritime Zones Act 2009* made provision for the establishment of the maritime zones of the Kingdom and for the exercise of the sovereign rights of the Kingdom and the exploration, exploitation, protection, preservation, conservation and management of those zones and for matters concerned with those purposes. Maritime zones means the archipelagic waters, contiguous zone, EEZ, continental shelf, historic waters, internal waters, maritime cultural zone and territorial sea.

The Tuna Fishery Management and Development Plan has been prepared in line with Tonga's *Fisheries Management Act 2002* and the Tonga Sustainable Development Framework. It is a revised plan and high-level policy document that provides guidance on the management and development of tuna fisheries for the period 2012–2015. It was prepared using an ecosystem approach to fisheries management and through wide consultation with relevant stakeholders. This plan presents the key management, development and compliance strategies and future guidance frameworks and is succeeded by the Tonga National Tuna Fisheries Management and Development Plan (2015–2017).

Tonga National Plan of Action for Sharks 2014–2016 is intended to provide a comprehensive set of policies aimed at guiding the efforts of the Division of Fisheries in the conservation and management of ocean sharks in Tonga's fisheries waters. These efforts are consistent with the Pacific Island Forum Secretariat leaders' direction to promote stock sustainability and ensure maximum *economic benefit* from marine resources.

The Sea Cucumber Fishery Management Plan is the public statement and legal basis for management of Tonga's sea cucumber harvesting, processing and export industry. The harvesting of sea cucumbers refers to fishing activity. To successfully manage the fishery, wider commitment and understanding is required. The plan has been developed under the provisions of the *Fisheries Management Act 2002*. It provides clear objectives and strategic directions for the conservation and management of sea cucumber resources, maximising of the potential economic yield in a sustainable manner through access to the resource, allocation of processing rights and export licences, and environment conservation and sustainability.

The Tonga National Action Plan on Climate Change Adaptation and Disaster Risk Management 2010–2015 aims to address the impacts of climate change and natural disasters on the environment, including the ocean. The Government of Tonga placed high priority on these issues in the national Strategic Planning Framework 2009–2014 because the significant detrimental impacts of climate change and natural disasters are risks to sustainable development of the country.

The Tonga Tourism Sector Roadmap, 2014–2018 supports the delivery of quality tourism that reflects Tonga's unique environmental and cultural heritage. Therefore, one of the specific objectives for the tourism sector is that by 2020 tourism in Tonga will support the formalisation and sustainable management of an additional five marine and land-based protected areas.

Tonga has many important policies, plans and legislative instruments in place to manage ocean and marine resources but enforcement needs strengthening.

3 Aichi target 2: By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.

2.4 STAKEHOLDER INPUT

In July 2014 IUCN conducted a brief training on ecosystem services (attendees listed in Appendix II: Stakeholder consultations and attendee lists) and solicited feedback from Tongan government and civil service representatives on the following three questions:

1. What quantification of ecosystem services or environmental valuation has been done already?
2. What should be done next? What will contribute to previous work or current needs?
3. Who needs to be involved?

Workshop participants identified the following list of activities relevant to environmental valuation:

- The Civil Society Forum of Tonga has collected data on MPAs, fish catch and mangroves. They have a governance structure in place that could support using resource economics, but no analysis has been done.
- The Fisheries Division has data on the value of offshore catches and is currently engaging with communities regarding inshore data. They are running market surveys and designing questionnaires for socioeconomic surveys.
- There will be data from an agriculture and fisheries census at the end of 2014.
- The Ministry of Tourism has data on how many tourists visit and estimates of tourist expenditure. There are some qualitative reports but no ecosystem valuation.
- Environment, Climate Change and Fisheries Divisions have some quantitative studies, such as the MESCAL (Mangrove Ecosystems for Climate Change Adaptation and Livelihoods) and BIORAP (Rapid Biodiversity Assessment) projects. MESCAL evaluated species habitat and carbon storage in mangroves.
- The Forestry Department has some qualitative data on wild forest goods.
- The NBSAP has qualitative and quantitative data from a variety of ministries and Civil Society Organisations.
- Government has done some quantification of ecosystem services in marine parks and reserves.
- Environmental Impact Assessments (EIA) include analysis of expected impact on ecosystem services.
- An analysis was conducted of water quality impacts from landfill.
- There has been some spatial analysis of coastal erosion and coastal protection.

In response to what should be done next and who should be involved, workshop participants responded that funds were needed for “monitoring, otherwise efforts will not be sustainable.” Attendees cited a need to increase awareness about the value of ecosystems at the local level using qualitative and quantitative information, a need to increase awareness of national policies and global initiatives. Workshop participants also suggested a need for:

- Evaluation of the *economic impact* of invasive species
- Visual data (GIS) to assist with decision-making, including mapping of special sites
- Financial support and technical assistance for monitoring and enforcement of the National Environment Act
- Raising awareness in communities about the importance of data on SMAs and assisting communities to collect data
- Collaboration between Customs and Fisheries to evaluate differences in the data they collect
- Socioeconomic *cost-benefit analysis* (CBA) in EIAs for new developments or tourism initiatives
- Comparison of questionnaires for agriculture and fisheries with the survey being used in the Vava’u BIORAP project.

Few of these suggestions refer directly to ecosystem service valuation, perhaps indicating a lack of understanding of the potential uses of ecosystem service valuation. However, valuation could help inform and/or advocate for many of the activities, policies and actions discussed above, for example, with regard to the value of SMAs, providing a *baseline* for CBAs and assessment of *economic impacts* from invasive species or other threats. Valuation may also raise awareness of the importance of data on socioeconomic links with natural ecosystems.

Workshop participants suggested that ecosystem service valuation should, in particular, involve stakeholders who depend on natural ecosystems for their livelihoods or who manage and control natural ecosystem use.

2.5 RELATED PROJECTS AND INITIATIVES

Sustainable use and conservation of marine and coastal biodiversity are priority action areas of the Strategic Plan of the CBD. The Pacific CBD member states (including Tonga) have expressed their commitment to the implementation of the extensive CBD resolutions on the conservation and sustainable use of marine and coastal biodiversity.

In this regard the project responds to the needs of Tonga by:

- Assisting the government in achieving the Aichi targets as a contribution to the CBD Strategic Plan for Biodiversity 2011–2020
- Implementing actions outlined in Tonga's NBSAP
- Contributing directly to the CBD Programme of Work on Protected Areas, especially to attainment of Aichi Target 11
- Assisting with implementation of the CBD Programme of Work on Island Biodiversity in accordance with the CBD COP 11 decision.

Beyond the CBD, Tonga has other commitments, interests and projects that this report can contribute to. For example, it will be:

- Contributing to implementation of the Pacific Regional Environment Programme Strategic Plan 2011–2015
- Implementing some of the principles for regional integration and cooperation for the purpose of conserving marine resources formulated in the Pacific Oceanscape Framework and supported by high-level decision-makers
- Initiating a System of Environmental-Economic Accounts (green national accounting)
- Contributing to other projects, such as Ridge-to-Reef (described below) and RESCCUE (Restoration of Ecosystems Services against Climate Change Unfavourable Effects).

Through its implementation partners the project is a member of the Marine Sector Working Group of the Pacific regional organisations (PIFS, SPREP, SPC and USP) and locally active international environmental NGOs. This allows for project activities to be coordinated with other projects in the target countries and also to serve as an example for other Pacific Island States and Territories.

The transferability of successful approaches is enhanced by involving representatives of other regional institutions and by running workshops at regional events attended by all Pacific Island states, such as the Pacific Climate Change Roundtable and the Pacific Island Roundtable for Nature Conservation.

Dissemination of the knowledge gained from the project and its incorporation into global and regional processes is promoted through continuous dialogue with relevant global institutions (TEEB Global, UNEP World Conservation Monitoring Centre, EU Joint Research Centre, IUCN World Commission on Protected Areas) and cooperation with ongoing BMUB International Climate Initiative projects in the field of marine and coastal biodiversity.

Below are descriptions of a few other projects occurring within Tonga which have related goals, activities, points of leverage and synergies.

Mangrove Ecosystems for Climate Change Adaptation and Livelihoods (MESCAL)

The MESCAL project, also funded by BMUB, concluded just as MACBIO began. MESCAL studied mangrove ecosystems in Fiji, Samoa, Solomon Islands, Tonga and Vanuatu. In Samoa and Vanuatu MESCAL produced economic valuations of mangroves. The valuation results from these countries and the biological data collected in Tonga contribute to this report.

Vava'u Rapid Biodiversity Assessment (BIORAP): assessment of natural resources and livelihoods

Due to limited resources and extensive geographical scope of the project, MACBIO was never intended to collect primary data for ecosystem service valuation. However, MACBIO was intended to support and encourage primary data collection and in-depth economic analysis where possible. The Vava'u BIORAP project offered MACBIO this opportunity. In February 2014, SPREP organised a team of scientists from around the world to conduct a rapid assessment of marine and terrestrial biodiversity in the Vava'u island group. SPREP contracted IUCN to conduct an economic assessment of the area to complement the biodiversity assessment. Jacob Salcone of the IUCN Oceania office developed a household survey and trained a research team to quantify the value of ecosystem services, particularly relating to coastal and shoreline protection, the tourism industry, and commercial and subsistence fishing activities. A local NGO, the VEPA selected and coordinated field teams to conduct 150 two-hour household surveys.

Outputs of this economic assessment will support the development of CBA of climate change adaptation options, coastal and marine spatial plans and incorporation of economic knowledge in discussions on protecting biodiversity, managing fisheries and exploring options for establishing a network of protected areas in Vava'u. The research and other data collected will be fully integrated as an appendix to the rapid biodiversity assessment undertaken by SPREP and the Environment Division in February 2014. This research was conducted under the broader umbrella of the MACBIO project, and data and analysis from the Vava'u economic assessment enhance this national report.

Ridge-to-Reef (R2R)

Ridge-to-Reef is a three-year project focused on conserving the ecosystem services of the Fanga'uta Lagoon and Catchment "through an integrated land, water and coastal management approach thereby protecting livelihoods and food production and enhancing climate resilience" (Ridge-to-Reef 2014). Ridge-to-Reef is funded by the fifth round of funding from the GEF. The project intends to enhance the ecosystem services of the lagoon, improve agricultural practices in areas adjacent to the lagoon, and improve the sustainability of the Fanga'uta Lagoon Marine Reserve. This will be accomplished through updates and enhancements to the integrated ecosystem management plan and a variety of stakeholder engagement and ecosystem rehabilitation activities.

Community governance support

The Civil Society Forum of Tonga (CSFT) is working to improve governance and leadership to support environmental management in Ha'apai, particularly with respect to SMAs. Seven project proposals have been developed to continue this work. Of particular interest, the group is working to promote alternative livelihoods (e.g. weaving, livestock rearing) in villages with SMAs to try to pull labour out of the fishing sector.

System of Environmental-Economic Accounting (SEEA)

The UN Economic and Social Commission for Asia and the Pacific (UN-ESCAP) in Fiji is using UN funding to support countries with natural capital accounting efforts following the SEEA framework. UN-ESCAP has identified Fiji, Vanuatu, Samoa and Palau for assistance, and may choose one or two more Pacific Island countries in 2015. The focus in Fiji and Palau will be on tourism, in Samoa on water provision and Vanuatu is still undecided. The project is intended to support countries with Aichi Target 2, *"By 2020, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems"* (UN CBD 2011). The project will involve approximately 18 months of national accounting statistics and 18 months of national planning. The UN will provide training while the accounting must be conducted by country nationals with UN support. Accounting will include all stocks and flows of natural capital relevant to a chosen sector, even if no monetary values can be calculated.

Tonga's largest stock of natural wealth lies within the sea.

3. CONCEPTUAL FRAMEWORK

The primary purpose of this assessment was to provide decision-makers and policy-makers at all levels with information about the value that people place on their marine and coastal ecosystems. This was with a view to inform the development of those decisions and policies with more concrete information about marine ecosystem values that are otherwise not fully appreciated or considered. For this reason, significant effort was made to conduct the work collaboratively, and with close interaction with key influential government and non-government stakeholders as well as technical staff within Tonga (see Appendix II: Stakeholder consultations and attendee lists).

3.1 DEFINITIONS

Ecosystems

An *ecosystem* is a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. Natural ecosystems have varying attributes (e.g. particular species of plants and animals) and perform various functions (e.g. photosynthesis, chemical and nutrient cycling). Many of these attributes and functions benefit human activities, communities, and industries.

Ecosystem services

Ecosystem services are the benefits humans receive from the natural attributes and functions of ecosystems (cf. Figure 4). These benefits could be material goods such as timber or fish, or biological services such as the treatment of human waste and carbon sequestration.

The value of marine (and other) ecosystem services to people is often not visible in markets, business transactions or in national economic accounts. Their value is often only perceived when the services are diminished or lost. Assigning monetary values to marine ecosystem services to reflect their importance to Tongan people is a powerful tool to make these benefits visible and improve their wise use and management. The process of assigning monetary values to ecosystem services that benefit people is called *economic valuation*.

PROVISIONING	REGULATING	CULTURAL
• Seafoods • Building Materials • Minerals	• Coastal Protection • Carbon Sequestration	• Tourism • Recreation • Cultural Identity
	SUPPORTING	
• Nutrient Cycling	• Photosynthesis	• Habitat

FIGURE 4 • Marine ecosystem services

Economic value

Economic value refers to the quantified net benefit that humans derive from a good or service, whether or not there is a market and monetary transaction for the goods and services. *Economic value* needs to be distinguished from *economic activity* (also known as financial or exchange value), which is a measure of cash flows and is observed in markets[4]. While *economic activity* from market transactions is often used to calculate *economic value*, *economic activity* is not in and of itself a measure of human benefit. *Economic activity*, however, is an interesting measure[5]. The number of formal-sector jobs and the likelihood of capital investment are closely related to *economic activity*, and this is of interest to the

4 Analysis of *economic activity* often focuses on 'multiplier effects', that is, the proportion of cash flows from one industry that spill over in to other industries due to inter-industry linkages.

5 GDP, produced through the System of National Accounts (SNA), is a measure of *economic activity*. The UN Statistics Division has recently published guidance for a System of Environmental-Economic Accounts (SEEA), which provides an accounting framework that is consistent and can be integrated with the structure, classifications, definitions and accounting rules of the SNA, thereby enabling the analysis of changes in natural capital, its contribution to the economy and the impacts of economic activities on it. It should be noted, however, that this system is restrictive in terms of the types of services and values that can be assessed.

public, civil servants and policy-makers. This report focuses on measuring *economic value*. Caution must be taken not to compare *economic activity* to *economic value*. Although both can be represented in dollars per year, they are different measurements of benefits.

In assessing and comparing ecosystem services, sometimes there are trade-offs to be made between different ecosystem services. For example, mining a coral reef for building materials will, likely, diminish its value as a source of food from fishing. Other ecosystem services can be complementary, for example the coastal protection value of coral reefs and their tourism value from diving or snorkelling.

Consumer and producer surplus

In general, the analysis in this report is based on the microeconomic concepts of *consumer* and *producer surplus*. *Consumer* and *producer surplus* are net measures; they measure the difference between the benefits and the costs of a particular good or service. *Producer surplus* is the benefit received by businesses, firms, or individuals who sell a good or service; *consumer surplus* is the benefit received by individuals who purchase or freely enjoy a good or service. For market transactions, *producer surplus* is synonymous with *value-added* or *profit*.

Willingness-to-pay and willingness-to-accept

Benefits are quantified by an individual's *willingness-to-pay* (WTP) or a business's *willingness-to-accept*, or rather, how much money an individual or business would willingly trade for providing or receiving a good or service. The difference between consumers' maximum WTP and what they actually pay is the consumers' benefit from the transaction. Consumer WTP is represented graphically as a demand curve.

Total economic value

The *total economic value* of an ecosystem service includes all of the net benefits humans receive from that ecosystem service. *Total economic value* is a quantification of the full contribution ecosystems make to human wellbeing. *Total economic value* includes market and non-market values (i.e. *direct use value*, *indirect use value*, and *existence*, or *non-use value*) and therefore represents the full benefit humans receive from *ecosystem functions*.

In practice, *total economic value* is nearly impossible to calculate because the data required to do so are rarely available. For example, fisheries resources offer benefits to those who harvest and sell seafood products (producers), as well as those who consume seafood products (consumers). The *total economic value* of the fishery is a sum of the producer and consumer benefits. However, consumer benefits are difficult to estimate and, in the case of export products, they accrue to individuals distant from the natural resource. Producer benefits alone are commonly used to estimate the value of fisheries, as is done in this report. It should be noted, however, that these estimates are a lower-bound value and do not represent *total economic value*.

Further definitions can be found in the Glossary (Appendix I: Glossary).

3.2 THE ECONOMICS OF ECOSYSTEMS AND BIODIVERSITY

As an implementing partner on the MACBIO project, IUCN Oceania is responsible for national assessment of marine and coastal ecosystem services in Fiji, Kiribati, Solomon Islands, Tonga, and Vanuatu. These national reports on marine and coastal ecosystem services follow the approach for assessing ecosystem services developed by the TEEB initiative (The Economics of Ecosystems and Biodiversity; www.teebweb.org). The TEEB approach comprises six steps:

1. Specify and agree on the relevant policy issues with stakeholders
2. Identify the most relevant ecosystem services
3. Define information requirements and select appropriate methods
4. Quantify, then value, ecosystem services
5. Identify and appraise policy options and distributional impacts
6. Review, refine and report.

The MACBIO model for economic assessment of ecosystems was to conduct research in partnership with local organisations and government representatives to improve their capacity to analyse and synthesise ecosystem valuation data. In addition, this collaborative approach contributed to in-county understanding of and belief in the results of the ecosystem service valuations. Capacity development included basic training in resource economics concepts, recommendations for modifying or improving data collection, discussions about how economic service valuations could be used in government and elsewhere and ongoing monitoring and evaluation of ecosystem service values to achieve sustainable development. To this end, the ecosystem service valuation included the participation of government staff and local resource managers at every opportunity to permanently augment the capacity of country nationals to use ecosystem data and economic valuation in development of policies and resource management decision-making.

Stakeholder workshops were held to identify specific applications of the economic valuation in Tonga including which policy issues could be supported by more information about the values of ecosystem services (TEEB Step 1). The policy issues identified by stakeholders covered a wide range of topics. Given the resource constraints in these small countries, it was deemed unlikely that a detailed marine economic service valuation would be conducted for every policy context described. It was decided, therefore, to conduct a more generic marine ecosystem service valuation which could be used in whole or in part to inform a range of different existing and potential policy and decision-making situations in Tonga. These workshops, and individual discussions and existing documentation, helped to identify the most relevant ecosystem services per country (Step 2).

Steps 2–6 were conducted by IUCN staff with in-country colleagues following the approach of the TEEB initiative. TEEB encourages economic valuation practitioners to engage with stakeholders not just to identify needs and policy applications for the ecosystem service valuation but also to develop methods for valuation that meet those particular needs and to ensure that the data provided are useful and relevant. In addition, in-country colleagues advised about the best way to communicate the results to relevant stakeholders. This report forms the basis for any communication products.

A methodological guidance document (Salcone et al. 2015) was created in consultation with the country-based research teams to ensure as-consistent-as-possible treatment across the five study sites.

It is anticipated this report will provide a platform from which to identify priority actions — in terms of national policy development, national and watershed-scale data collection, regular analysis, planning and outreach — that better incorporate ecosystem service stocks, flows, and values into ongoing national discussions and policy processes (Steps 5 and 6).

3.3 APPLICATIONS OF MARINE ECOSYSTEM SERVICE VALUATION

There are three main categories of applications of ecosystem service valuation: 1) to enable rational decision-making, via cost-benefit analyses or other analyses of the trade-offs in management decisions; 2) as a technical tool to set prices for protecting resources or compensation for ecosystem damage; or 3) as general information, to raise awareness about the human benefits of healthy ecosystems and support policy and governance that manages resources from a social equity perspective (Mermet et al. 2014). The third application can lead to full integration of the benefits of ecosystems into national accounting (natural capital accounting). National-scale ecosystem service valuation is applicable mostly to this third use — general information for planning and advocacy. See also Section 2.4 above.

Humpback Whales in Vava'u.

4. LITERATURE REVIEW

This section briefly reviews ecosystem service valuation studies that have been conducted in Tonga and the Pacific Islands region, drawing mainly on a survey of literature through the library of the Marine Ecosystem Services Partnership (MESP) at Duke University (Jungwiwattanaporn et al. 2015). The MESP literature survey found that very few valuation studies have been conducted in Tonga. However, the survey focused mainly on academic journal articles and was specific to valuation studies. There have been a number of more general economic analyses of Tonga's natural resource industries, notably the whale-watching industry in the Vava'u island group and national and Pacific-wide assessments of the tuna and deep-water snapper industries.

There have been some regional studies of the value of ecosystems and ecosystem services in the Pacific islands region. A general assessment of the value of Pacific Island ecosystems conducted by economists at IUCN in 2010 estimated that coral reefs had a *total economic value* of US$ 4.11 billion or US$ 79,000/km^2/yr (Seidel and Lal 2010). This value was based on an extrapolation from Pacific case study estimates. *Direct use values* made up US$ 2.22 billion of this estimate, and *indirect* and *non-use values* made up US$ 1.40 billion. *Direct use values* included fisheries, coastal protection and tourism and recreation; indirect values included existence and biodiversity values (Seidel and Lal 2010). The same authors estimated that mangroves contributed a *total economic value* of US$ 4.20 billion or US$ 593,726 per square kilometre per year within the 22 Pacific Island States and Territories. This value included US$ 2.48 billion from *direct use values* (subsistence and artisanal fishing, shoreline protection, fuelwood production) and US$ 1.71 billion from *indirect* and *non-use values* (cultural and social values, *existence values*) (Seidel and Lal 2010).

A report prepared for the Asian Development Bank, the Forum Fisheries Agency and the World Bank, estimated that the combined value of fishery and aquaculture production, including subsistence fisheries, local commercial fisheries, and foreign-based commercial fisheries in nearshore and open ocean habitats, was more than US$ 2.29 billion per year (Gillett 2009). This value was estimated to contribute as much as 10% of GDP in the region. Pacific Island States and Territories received an additional US$ 89.6 million per year in access fees and other charges to foreign fishing vessels. This amount has increased substantially since the report was published. Of this value, coastal commercial fisheries contributed an estimated US$ 183.1 million annually, and coastal subsistence fisheries contributed an estimated US$ 221.4 million per year. These values were based on fish prices at the dock (Gillett 2009). The same report estimated that the annual value of offshore fishing in all Pacific Island States and Territories in 2007 was more than US$ 1.7 billion, including more than US$ 681 million per year for locally-based fisheries and US$ 1.23 billion per year for foreign-based fisheries. These values were also based on dockside prices (Gillett 2009). Most of the value of inshore fisheries and some of the value of locally-based offshore fisheries accrued within the Pacific Islands States and Territories. Most of the value of the foreign-based fishing accrued to the foreign fleets and foreign countries where the catch was unloaded.

According to a later study for the Western and Central Pacific Fisheries Commission (WCPFC) in 2012, the total estimated annual value of delivered tuna captured in the Western and Central Pacific Ocean, based on prices paid at the processor, was US$ 7.4 billion. This amount included *value-added* through transportation and initial processing. Tuna caught using purse seine nets accounted for 56% of the total value; tuna caught in the longline fishery made up 27%. Skipjack represented 49% of the total value; yellowfin accounted for 30%; bigeye was 15%; and albacore just 6%. In 2012, fishers caught more than 2.6 million tonnes of tuna, the highest volume on record and 59% of the global tuna catch (Williams and Terawasi 2013).

Two authors have studied the contribution of whale watching to the Tongan economy. In 2006, whale watching generated total estimated expenditures of approximately US$ 2.08 million. This value includes US$ 825,786 in direct expenditure, US$ 13,956 in government *revenue*, and US$ 1,244,713 in indirect expenditure. In 2006, Tonga had more than 9,800 whale watchers (O'Connor et al. 2009).

According to a 2009 study, the expenditure associated with whale watching in Tonga grew from US$ 711,000 per year in 1999 to US$ 5.52 million per year in 2009 (converted to 2013 prices) (Orams 2010). This study estimated that the direct expenditure on whale-based tours in Vava'u was US$ 663,024 in 2009, and the total expenditure was US$ 5,155,062 (Orams 2010). This figure included spending on accommodation, transport, souvenirs and food by whale-watching tourists as well as expenditure of whale-watching operators. Employees of whale-watching businesses received

US$ 289,520, of which an estimated 80% was re-spent in the Vava'u area, which, in turn, generated an estimated additional ('induced') *economic activity* of US$ 232,058 in the 2009 season. Questionnaires were used to collect data from 499 tourists travelling by aircraft, 52 tourists travelling by cruising yacht, and ten whale-watching business operators. These questionnaires examined only expenditure and *revenue* and did not attempt to estimate the *existence value* of whales or the *option* or *bequest value* of whale watching (Orams 2013).

This literature review is a sample of studies related to the economics of key Tongan ecosystems and ecosystem services. The collection of studies that have some relation to marine and coastal ecosystems or Pacific Island economies in general is extensive. The literature most frequently cited in this report includes fisheries publications by Robert Gillett (and donors), national statistics from the Tonga Department of Statistics and the Ministry of Finance and National Planning, and reports by the SPC.

The methods that can be used to measure and quantify *economic benefits* are varied, and the resultant values can rarely be compared directly; rather, they should be evaluated on a case-by-case basis. Readers interested in learning more are encouraged to read the Summaries of Marine Ecosystem Service Valuation Studies in the Pacific (Jungwiwattanaporn et al. 2015) and the Pacific Marine Ecosystem Service Valuation Guidebook (Salcone et al. 2015).

5. METHODS

The general methods are presented in Salcone et al. (2015). Specific details of methods applied in this report are presented below or in the relevant sections of the report.

As far as possible, government staff and other relevant parties within Tonga worked with the authors to answer questions, supply information and data and to identify data gaps for this report (TEEB steps 1–4). See Appendix II for the list of people consulted. These colleagues also identified in-country policies, plans, strategies and other marine resource management tools to which this work could contribute (see Section 2.4).

5.1 OVERVIEW

This analysis identified seven key marine and coastal ecosystem services that are described and valued in this report:

1. Subsistence food
2. Commercial food
3. Minerals and aggregate
4. Tourism and recreation
5. Coastal protection
6. Carbon sequestration
7. Research, management and education

Marine and coastal ecosystems provide many more ecosystem services than the seven explored here. These seven were identified as nationally important, potentially quantifiable with existing data and amenable to policy intervention or private action.

The detailed and specific mathematical methods and data requirements for estimating the value of these seven marine and coastal ecosystem services are provided in Salcone et al. (2015). This is a methodological guidance document created in consultation with the country-based research teams and other Pacific resource economists to ensure consistent treatment across the five study sites.

Where sufficient data are available, ecosystem service valuation represents *producer* and/or *consumer surplus* and includes market and non-market values for direct and indirect ecosystem services. Where sufficient data do not exist to implement the most appropriate methods, the next best possible ecological-economic analysis has been conducted. This may include qualitative descriptors of values or references to other locations with data on the identified values. Gaps in data and previous research are partially offset with the authors' judgment based on economic theory.

Introductions to specific methods used to value each of the seven ecosystem services are given in Chapter 6.

Unless otherwise stated, all monetary values have been converted to 2013 US dollars (US$) and Tongan Pa'anga (T$). Currencies are converted using the most appropriate method to facilitate comparison of the magnitude of the benefits or costs. The value of export goods were typically converted to USD and then inflated using a US dollar *inflation* index. Local income and expenditure figures were updated using the World Bank Consumer Price Index (CPI) for Tonga. Where appropriate, international seafood products were inflated using the Food and Agriculture Organization (FAO) Fish Price Index. Throughout the report an exchange rate of US$ 1 = T$ 1.79 is used.

5.2 SECONDARY DATA SOURCES AND QUALITY

MACBIO was not intended to collect primary data. Instead, the objective was to locate existing sources of data that could be used for ecosystem service valuation and to identify data gaps. Data were obtained from government divisions, in particular the Fisheries Division and the Statistics Department. Primary data sources from the Government of Tonga were the 2011 Census, the 2009 Household Income and Expenditure Survey, and the 2014 Budget Statement. The Fisheries Division provided data records for fisheries exports since 2006 and estimates of tuna harvest; additional fisheries data were obtained from reports by the SPC, the Pacific Islands Forum Fisheries Agency (FFA), and particularly from reports prepared for the Asian Development Bank (ADB) and the FAO. Additional data were obtained from academic studies and project reports (such as MESCAL). The validity and accuracy of these secondary data, which vary substantially among sources, is described following the identification, quantification, and valuation of each ecosystem service.

Where no other sources of data are cited, the authors' own knowledge of Tonga was the source of the information presented, mainly drawing on the knowledge and experience of Tongan authors and the economic knowledge of Jacob Salcone (MSc Resource Economics) and Salome Tupou-Taufa (PhD Fisheries Economics).

Some primary data were made available due to collaboration between MACBIO and the BIORAP project undertaken during 2014 in the Vava'u island group. Household and business surveys conducted as part of this project provided additional detail on tourism business activities and artisanal and subsistence fishing.

5.3 DATA GAP ANALYSIS

A major focus of this research effort was identifying gaps and weaknesses in data that prohibited the accurate valuation of marine and coastal ecosystem services. The importance of this exercise should not be understated. This report encourages and supports the use of ecosystem service valuation in national planning and policy-making, but in many instances a true *economic value* of the human benefits of ecosystems could not be estimated because of a shortage of ecological or socioeconomic information. These data gaps are described where ecosystem services are quantified in Chapter 6. A summary of data gaps is presented in Section 6.12.

5.4 DATA SYNTHESIS AND EXTRAPOLATION

Fisheries, tourism, carbon sequestration, aggregate mining, coastal protection and research and management benefits are estimated based on actual Tonga data, in so much as it is available. No extrapolations from results or data from other Pacific countries has been done for this report, although general connections are drawn to other countries in regards to tourism, deep-sea mining, and cultural values.

6. RESULTS

This section includes the identification, quantification, and where possible, valuation of Tonga's most significant marine and coastal ecosystem services. The first subsection for each ecosystem service, **Identify**, describes the ecosystem service and the relation between the ecological or biological processes of that ecosystem (the *ecosystem functions*) and the human benefits (the ecosystem *services*). This subsection also describes the human activities and livelihoods that are related to the ecosystem service. The second subsection, **Quantify**, describes data that illustrate the magnitude of the service either in monetary units or ecological measures and evaluates data gaps. Where sufficient data could be collected, the third subsection, **Value**, presents the *economic value* of the ecosystem service. The value represents a quantification of human benefits in terms of local monetary currency.

The **Sustainability** and **Distribution** of ecosystem service benefits is evaluated following the valuation of each service. It is important to understand whether human benefits can be maintained or if they are expected to decrease because of unsustainable resource use or management practices. It is also important to recognise who receives the benefits from the ecosystem, whether it be poor or wealthy households, government, visitors or foreign nations. The **Uncertainty** of each value estimate is also discussed in this section.

6.1 SUBSISTENCE FISHERIES

Tongan households benefit more from inshore fisheries than from any other marine ecosystem service.

6.1.1 IDENTIFY

Subsistence fishing refers to harvesting of seafood species that are consumed, given, or exchanged by fishers without any monetary transaction. In Pacific Island countries, particularly in rural coastal areas, subsistence fishing contributes significantly to household diets and therefore has substantial *economic value* (Gillett 2009).

By providing appropriate food and habitat conditions, mangrove, seagrass, coral reef, seamount and open sea ecosystems support the growth and reproduction of a range of fish and invertebrate species that become food for humans, including groupers, surgeonfish, parrotfish, clams, crabs, octopus, sea cucumbers (*bêche-de-mer*) and shellfish. These species are important foods for Tongan families (Salcone 2015). Each of these species requires a particular habitat to grow and reproduce. The reproduction and growth of fished species, and thus the potential magnitude of this ecosystem service, depends on the functions provided by marine habitats, including tidal seagrass beds, coastal mangroves, coral reefs, and deep-water seamounts. The functions of each ecosystem depend on natural geographical and biological factors, such as coastal bathymetry and sea currents, as well as human factors such as pollution, habitat destruction and overharvesting. Unlike agricultural systems, which require consistent and often intensive human labour, these marine ecosystems can produce food naturally as long as they are not damaged or over-exploited.

Tongan waters can be generally characterised as open-access, meaning anyone can fish or glean anywhere at any time and keep what is harvested. Many Tongan households take advantage of this open-access resource as a source of food and cash income. Tongan fishers (both men and women) cannot be strictly separated into subsistence or commercial; many fishers fish for both purposes. Fishers may be better categorised by the type of gear used or fishing technique (spear, net, hand gleaning) (Kronen 2004). Both men and women fish, although women tend to fish for shorter hours, nearer to shore, mainly without canoes or boats (Kronen 2002). In many villages, women more commonly glean from the reef, while men more commonly spearfish and use deep-water handlines, and often fish at night (Kronen 2002).

6.1.2 QUANTIFY

Tonga has approximately 5,870 km^2 of inshore fish and invertebrate habitat that provides for subsistence and artisanal fishing, including reef, mangrove, lagoon and intertidal shoreline (Table 2). This is eight times the total land area of Tonga (707 km^2). Coral reef areas alone total over 3,200 km^2. Healthy island coral reef fisheries have been estimated to support an average sustainable yield of 5 $t/km^2/yr$ (Newton et al. 2007). However, Tonga fisheries have been characterised as over-exploited, so this estimate based on the sustainable yield of healthy reefs may no longer be relevant to Tonga. The sustainability of subsistence fisheries is discussed in more detail in Section 6.1.5.

TABLE 2 • Inshore fishing habitat area, all of Tonga

Inshore habitat	Depth label	Area for Tonga (km^2)
Mangroves*	Intertidal/coastal	12.66
Reefs (reef flat, back reef, fore reef — all reef areas)**	Shallow, variable and deep	3,210.74
Non-reefs (shoreline intertidal seagrass and sandy areas, lagoon and bank and other patchy non-reef habitats)[2]	Shallow, variable and deep	2,615.41
Other non-reef habitat[2] (*This includes mangrove areas)*	Shallow, intertidal	42.87
Total area		**5869.02**

* GIS Unit, Ministry of Lands and Natural Resources
** Millennium Coral Reef Mapping Project (Andréfouët et al. 2005)

The FAO estimated that fish contributed an average 11.5% of protein in Tongan diets in 2011 (15.6% of all animal protein) (FAO 2014). However the FAO balance sheets, based on production, imports and exports, vary substantially from year to year[6]. Between 2007 and 2011 there was between 30 kg and 35 kg of seafood available in Tonga per capita, per annum (FAO 2007–2011). But socioeconomic surveys conducted in 2009, as part of the PROCFish initiative by SPC[7], found rates of seafood consumption in coastal communities in Ha'apai to be as high as 92 kg/person/yr for finfish and 21 kg/person/yr for invertebrates (Friedman et al. 2009). The average fish consumption across four PROCFish research sites was 68.6 kg/person/yr for finfish and 11.6 kg/person/yr for invertebrates. This is likely the best estimate of per capita fish consumption in rural areas of Tongatapu and Ha'apai. The subsistence (non-market) proportion of average fish harvest ranged from 12 kg/person/yr to 87 kg/person/yr among the four villages. Given the large range and small sample size, this data cannot be accurately extrapolated to all of Tonga. The paucity of data regarding subsistence harvest in Tonga is a significant limitation to this study and inshore fisheries management more generally[8].

The Fisheries Division of Tonga does not currently have data for household harvest of fish, although surveys are planned to begin gathering this information in 2015. In 1996, Dalzell et al. estimated the commercial and subsistence production of all Pacific Island countries from a collection of literature 1990–1994. At that time Tonga's annual subsistence production was estimated to be 933 tonnes, compared to a coastal commercial production of 1,429 tonnes (Dalzell et al. 1996). Gillett and Lightfoot (2001) updated these estimates using the 2000 Tonga GDP Statistics Data for non-market seafood. Using a *value-added* ratio of 0.8 and a very low fish price (approximately T$ 2.25/kg), the total annual harvest was calculated as 2,863 tonnes, or about 23 kg per person. This amount is consistent with results from PROCFish, but the representative price of fish is unreasonably low even for 2001.

The Household Income and Expenditure Survey (HIES) conducted by the Statistics Department provides some general information about income and expenditures related to fish. This includes measurement of household seafood production and consumption. Although Tonga is experiencing a gradual transition towards middle/high-income expenditure patterns, food remains the largest segment of household expenditure. On average, one-third of household expenditure

6 For example, fish was 10.2% of protein in 2005, 13.5% in 2007, 14.3% in 2009, and 9.9% in 2010 (FAO 2005, 2007, 2009, 2010). FAO fish supply is calculated as follows: "Total food supply equals production less reduction to meal and other non-food uses, plus imports, less exports and re-exports, plus or less variation in stocks." (FAO 2014).

7 PROCFish is the Pacific Regional Oceanic and Coastal Fisheries Development Programme, an inshore fisheries research initiative of the Secretariat of the Pacific Community.

8 Note that what the Statistics Department calls 'Subsistence Income' from fisheries is, in fact, the ***value-added*** proportion of small-scale domestic fish sales, not the value of household consumption. See Section 6.2.1.

is dedicated to food. In 2009, fish and seafood made up 10.6% of food expenditure, on average (Tonga Statistics Department 2009). This included food that is home produced, which represented approximately 29% of food in rural areas and 11% in urban areas. Fish and seafood made up a larger portion of diets in Ha'apai and Ongo Niua and a smaller proportion in Vava'u. 89% of rural households and 44% of urban households participated in some form of subsistence activity, including gardening, raising animals, catching fish and producing handicrafts. According to the 2009 HIES, about 21% of Tongan households caught seafood for home consumption; roughly 35% purchased fresh or frozen seafood (Tonga Statistics Department 2009).

The PROCFish initiative by SPC analysed inshore finfish and invertebrate fishing at four sites in Tonga (Ha'atafu and Manuka on Tongatapu, and Koulo and Lofanga on Ha'apai). The proportion of finfish consumed at home (versus sold at market) varied among the villages from 15% to 77% of the total annual artisanal catch (Friedman et al. 2009). Although the PROCFish study provides good information about localised fishing activities and impacts on fish stocks, it was not collected in a manner that allows extrapolation to all of Tonga. A recent household survey in Vava'u found that 31% of households fished at least once a month during the previous year, primarily for their own consumption or to share with family and community members (Salcone 2015). Only 13 households (9% of sample, 29% of fishing households) reported selling any of their catch. Many fishing households donated part of their catch to churches or other households.

The Tonga Statistics Department estimates domestic production and consumption as part of the National Accounts estimates. The department estimates 'marketed domestic consumption', 'marketed exports', and 'non-marketed domestic consumption[9].' The average non-marketed domestic consumption for the past ten years was about T$ 5.5 million (US$ 2.8m). This is the only national estimate of the value of subsistence fishing.

The 2011 Census reported that 9,549 people were primarily engaged in 'subsistence work' in Tonga, more than 25% of the economically active labour force of 35,735 individuals aged 15+ years (Tonga Statistics Department 2011). The census found 5,623 individuals aged 15+ were subsistence farmers, fishers, hunters and gatherers. The census recorded 437 adults (393 men) whose main activity was 'fishing for own consumption' (and another 859 for whom 'fishing mainly for sale' was the main activity). In comparison, 5,258 individuals reported 'farming for own consumption' as their main activity in the previous week. It appears farming is a more common main activity than fishing, but many of these subsistence workers probably do some of both. Presumably, many of the 9,549 people for whom 'subsistence work' was the main type of employment were at least somewhat dependent on fishing for food security. A socioeconomic survey in 2005 estimated the number of people engaged in fishing activities to be 12,898: 6,470 in Tongatapu, 2,053 in Ha'apai, 4,375 in Vava'u (Tonga Fisheries Project 2005). This is approximately 13% of the population nation-wide. The survey also found that of the households surveyed, approximately 64% in Tongatapu fished for their own supply of seafood and gifts to others. The corresponding figures for Vava'u and Ha'apai were 80% and 82%, respectively (Gillett 2011). This is much higher than was found in the Vava'u survey (Salcone 2015) or the 2009 HIES.

The price (and value) of inshore fish and other seafood at the local market is collected through an ongoing market survey that is conducted every Saturday morning. Unit prices (and estimated quantities) of all marine products sold are gathered. Since this survey was only started in 2014, data are available for only two quarters; these data are explained in more detail in Section 6.2. The average prices for seafood products (T$ 8.27/kg) can be used to estimate the replacement cost value of subsistence fishing. These data are evaluated in more detail in Section 6.2.1.

The CSFT has collected data on fish catch and mangroves in locally-managed SMAs. They have a governance structure in place that can support resource economics research at the community level, but no analysis has been done. In regards to SMA programs, CSFT comments that there is a need to raise awareness in communities about the importance of data and to establish data collection by communities. Both CSFT and the Fisheries Division work on aspects of community-based fisheries management efforts. The Fisheries Division notes that they are the entity legally responsible for designating SMAs.

Subsistence fishing costs include basic fishing gear, such as line, hooks, nets, spears, goggles and lights as well as boats and boat-related expenses such as fuel and maintenance. These capital and variable costs must be subtracted from the gross value of harvest to determine the true *economic value* of subsistence fishing. Tonga Fisheries Division has not estimated harvest costs for artisanal fishers[10]. A recent household survey in Vava'u found average variable fishing

9 Locally marketed and non-marketed consumption are estimated from the Household Income and Expenditure survey, and then updated using the CPI for fish (M. Masila, Tonga Statistics Department, pers. comm.).

10 Household fishing costs have been studied in Fiji by O'Garra (2007). The cost estimates, converted to 2013 Pa'anga, total T$ 9,127/year/household. This estimate seems excessively high for Tonga subsistence fishers since the per capita gross national income (GNI) is only T$ 8,000/yr.

costs per household were about T$ 1,575/yr and the median was T$ 736[11]. Excluding households that reported fishing costs of less than T$ 100/yr and one outlier who reported T$ 14,400/yr, the average was T$ 815/yr for market and non-market fishers. Capital costs and/or depreciation of capital were not included in this measure. Total costs should include capital and capital depreciation, therefore the total annual subsistence fishing costs would be higher than the figures presented above. However, those fishing primarily for subsistence (not market) may use simpler, cheaper equipment and have somewhat lower annual costs than this average.

Subsistence fishers are not paid a wage but their time has value. Some authors have noted that when an *opportunity cost* of labour (such as the average local wage rate) is subtracted from the value of the fish caught, the value of subsistence fishing is negative (Kronen 2004). In other words, fishers are earning less per hour than the typical wage rate. Subtracting the *opportunity costs* of wage labour may be applicable in some scenarios where wage-earning jobs are available to fishers, but in many instances, particularly in rural villages where there are no other employment opportunities, there are no true *opportunity costs* for subsistence fishers.

6.1.3 VALUE

The value of the subsistence fishery ecosystem service should be estimated from accurate fish and invertebrate harvest data, multiplied by appropriate local food prices, less the costs of subsistence fishing techniques[12], as illustrated by the equation:

$$\text{Value (Benefit)} = \left(\text{Subsistence Harvest}_{kg} \cdot \text{Price Protein Equiv.}_{\frac{\$}{kg}}\right) - \text{Harvest Costs}_{\$}$$

However, data for all these parameters are not available in Tonga. Equivalent food prices could represent common protein equivalents (typically tinned fish or tinned meat in Tonga) or market prices of the species consumed by fishing households. Using market prices for equivalent seafood products would reflect the true replacement cost value, but in reality, households may choose to purchase lower-value products in place of the kinds of seafood they typically catch.

Average local prices for inshore fish and invertebrate species are becoming available from market surveys that have been trialled in 2014. The Fisheries Division has not recently conducted an analysis of artisanal fishing costs, but such an analysis is a relatively simple and straightforward exercise. Measuring subsistence harvest, on the other hand, is not so simple. Subsistence harvest is particularly difficult to measure because it occurs daily and is dispersed widely throughout the country. At best the Fisheries Division could produce extrapolations from isolated studies such as PROCFish. A creel survey will be undertaken by the Fisheries Division in 2015 in an attempt to quantify the production from inshore resources. The survey methods are still being tested and altered (as of February 2015) to produce reliable data on subsistence and commercial harvest and estimate catch per unit effort.

Since PROCFish data cannot be extrapolated nation-wide and because creel survey data are not yet available, national estimates from the Statistics Department are used to calculate the value of subsistence fishing in Tonga. The ‘non-marketed domestic consumption’ of fish and crustaceans provided by the Statistics Department estimates the value of subsistence fisheries in Tonga from data gathered by the HIES, using a *value-added* ratio of 0.9 (i.e. costs equal 10% of gross value) (M. Masila, pers. comm. 2015). This net *economic value*, inflated to 2013 prices would be T$ 5,457,000/yr (US$ 3,050,000/yr).

The net *economic value* can be used to roughly estimate the amount of fish harvested for subsistence. First, the costs of fishing are added to *net value*, then the gross value is divided by the cost per kilogram of inshore seafoods. Using the same 10% costs ratio used by the Statistics Department, the gross value of subsistence fishing would be T$ 6,063,000. Starkhouse (2009) estimated the costs of artisanal fishing in Fiji to be approximately 50% of the gross value, which would equate to a gross value of T$ 10,914,000. From this range of costs, we estimate the gross annual value of subsistence fishing to be between T$ 6,063,000 and T$ 10,914,000 per year (US$ 3,384,000 to US$ 6,091,000/yr). Using the weighted average price[13] per kilogram of seafood purchased via 2014 market surveys, T$ 8.27/kg, this would equate to 733 tonnes to 1320 tonnes of fish products, or about 7–12.5 kg/person/yr for every man, woman, and child in Tonga (population 105,300). This amount would be much higher for fishing families and zero for households that do not fish.

11 Averages may not be very accurate. Just 15 households reported fishing expenses; for those households, annual expenses ranged from T$ 75 to T$ 14,400.

12 Ideally, value would be calculated separately for each different fishing technique (gleaning, spearing, nets, handline) since the harvests and costs vary accordingly.

13 This average price is calculated by weighting respective volumes and average prices of products identified in the market survey.

The estimate of 7–12.5 kg/person/yr is low relative to the PROCFish data (average total seafood consumption of 80.2 kg/person/yr). The variance in information provided from different sources of data for many of these measures illustrates the difficulty in quantifying this ecosystem service. It is clear that fish is an important element of food security in Tonga, particularly in rural areas, but subsistence fishing and consumption of fresh fish is perhaps not as predominant as one would expect for an island nation. Fresh pork and chicken and canned meat contribute significantly to diets. A transition to meat protein may be associated with over-exploitation of inshore fisheries, population growth, and monetisation of Tongan livelihoods (Gillett 2011; Kronen et al. 2003). Canned fish, an import, is also consumed in many households because it is often cheaper than local fresh fish.

6.1.4 UNCERTAINTY

There is little reliable data for subsistence fisheries in the Pacific. Most estimates are dubious extrapolations from isolated and/or old data sets that have chronically underestimated subsistence harvests (Zeller et al. 2014). Although the PROCFish data are locally reliable, the variability between villages make nation-wide extrapolations uncertain. The FAO consumption estimates are calculated by dividing the total food resources available (production and imports) by the population (FAO 2014). Because there is not yet a reliable way to estimate artisanal fishery production in Tonga, these consumption estimates are unreliable. The HIES data come from an extensive periodic survey with a large sample size (Tonga Statistics Department 2009). However, the value estimates are extrapolations from responses to questions about household food consumption and labour activity and may seriously underestimate subsistence activity (Gillett 2009). The Statistics Department will be updating the estimates with data from an agricultural census planned for 2015.

A range is used to compensate for uncertainty about the costs of subsistence fishing. The average variable costs found during the Vava'u study were T$ 815 per household per year. This would equate to a total of T$ 3,107,399/yr (21% of households fishing multiplied by T$ 815/yr costs) or a cost ratio of 36%, squarely between the estimates of Starkhouse 2009 (50%) and the Tonga Statistics Division (10%) used above.

Lastly, the price estimate used (T$ 8.27/kg) reflects 2014 prices in Tongatapu markets. This is likely higher than the national average, and is more than three times higher than estimates used by Gillett and Lightfoot (2001). Dividing gross values by a high price of fish per kg will underestimate the total harvest. Using a replacement cost of seafood of T$ 5/kg would increase harvest estimates by 40% to 1212–2183 tonnes per year (12–21 kg/person/yr).

The data source (non-market GDP from the Statistics Division) and method used to make the value and harvest estimates above is the same data source and method used by Gillett (2009). The data used for the value estimates provided in this report are all relatively recent (2009 or later). The harvest estimates above are much lower than Gillett in 2009 (2,800 t) because the replacement cost of seafood used in this report is much higher than that used by Gillett.

6.1.5 SUSTAINABILITY

The number of households dependent on subsistence fishing is small relative to the size of Tonga's marine and coastal areas. If Tongan reefs and species populations were healthy, Tongan reef areas alone could produce a sustainable yield of about 16,000 tonnes per year. This is much greater than any of the estimates of subsistence and inshore commercial harvest (Section 6.2.1).

Tonga's extensive fish and invertebrate habitats should be sufficiently productive to maintain a sustainable source of seafood for households that depend on subsistence activities. However, resource pressure seems to be highly localised around villages and there is evidence of localised depletions. PROCFish evaluated catch per unit effort (CPUE) for finfish in four villages. CPUE varied significantly among villages, indicating variable resource pressure. In general, reef fisheries in Tonga are characterised as overfished, from moderately to seriously over-exploited. In particular, the mullet fishery in Tonga has been decimated by overfishing (Friedman et al. 2009).

The open-access nature of Tongan fisheries resources means that commercialisation of some species (such as *bêche-de-mer* and the aquarium trade) can compete with subsistence fishing by depleting stocks or damaging habitat. Commercialisation and particularly export markets can jeopardise the sustainability of the subsistence fishery and threaten food security. Tonga's approach to protect this ecosystem service is to have fishery management plans for all the fisheries and to promote the establishment of SMAs. Under the *Fisheries Management Act* of 2002 coastal communities can establish SMAs to control fishing activities, restore fish stocks in no-fishing areas, and raise awareness of fisheries conservation and resource management.

6.1.6 DISTRIBUTION

The benefits from subsistence fishing accrue entirely to households within Tonga. Subsistence fishing does not generate government *revenue* or foreign exchange, which means that it can be easily neglected in economic planning and policy-making. Despite the uncertainty in subsistence fishing data, the proximity of households to marine resources and the limited income available to most Tongan households to purchase imported and/or processed foods indicate that subsistence fishing is, and will continue to be, important to the wellbeing of Tongan families. This is particularly true for families close to nearshore lagoon, reef, and mangrove habitats that are accessible to fishing with minimal costs.

Table 3 shows a collection of statistics that quantify the magnitude and value of subsistence and artisanal commercial fishing (Section 6.2.1).

TABLE 3 • Summary of data on subsistence and artisanal fishing in Tonga[14]

Statistic	Data	Source	Method
Inshore habitat	Reefs: 3,210 km^2 Other inshore habitat: 2,658 km^2	Millennium Coral Reef Mapping Project (Andréfouët et al. 2005)	GIS
Fish consumption	30–35 kg/person/yr (All Tonga: 3,160–3,690 t/yr)	FAO food balance sheets	Represents total fish (fresh and canned) available per capita in Tonga
	Finfish: 68.57 kg/person/yr Invertebrates: 11.58 kg/person/yr (All Tonga: 8,440 t/yr)	PROCFish (Friedman et al. 2009)	Survey in four villages
Subsistence harvest	933 t/yr	Dazell et al. 1996	Estimated from literature review 1989–1994
	2,863 t/yr	Gillett and Lightfoot 2001	Based on non-market GDP estimates from the Statistics Division
Percent of catch consumed at home (vs. sold)	15–77%	PROCFish (Friedman et al. 2009)	Survey in four villages
Percent of households fishing and selling	31% fish regularly; 29% of those report selling some of their catch (9% of total)	Vava'u Survey 2013	Household survey, Vava'u group
Households consuming own-caught fish or purchasing fish	21% consume home produced 35% purchase fish	HIES 2009	Survey; representative sample from all island groups
Income from artisanal fishing	Total: T$ 8,339,000/yr	HIES 2009	Called 'Subsistence Income' by Tonga Statistics Department
	Urban: T$ 3,085,000/yr		
	Rural: T$ 5,254,000/yr		
Expenditure on fish and seafood	T$ 9,129,000/yr	HIES 2009	Includes local offshore and deep-water, and imports. Does not include canned fish
Inshore commercial harvest	1,429 t/yr	Dazell et al. 1996	Estimated from literature 1989–1994
	3,700 t/yr	Gillett 2009	Update from Gillett and Lightfoot 2001; Includes export products
Employment	9,549 subsistence workers	Tonga Census 2011	Census data; note that many 'subsistence workers' likely fish as part of their subsistence activities
	433 subsistence fishing 'main activity'		
	859 'fishing mainly for sale'		

14 Commercial, inshore artisanal fisheries are described in more detail in Section 6.2.1.

6.2 COMMERCIAL FISHERIES

This section evaluates the harvest of seafood that is sold or exchanged via a monetary transaction. Commercial fishing is a large component of many Pacific Island economies. The EEZs of Pacific Island countries are home to great stocks of seafood that become food for people throughout the world. The Western Pacific skipjack tuna fishery is one of the world's largest natural sources of animal protein and white meat albacore tuna from southern Pacific waters is canned and sold world-wide. Millions of square miles of reef and lagoon habitat support the reproduction of a wide variety of commercially popular seafood, such as lobster, coral trout and sea cucumber (*bêche-de-mer*).

Commercial fishing is divided into inshore fisheries and offshore fisheries. Inshore fisheries occur in any reef, lagoon, mangrove, intertidal zones or other areas that have relatively shallow water and are home to non-migratory fish and invertebrate species. Offshore fisheries occur in deep-water areas that are home to sharks, billfish, tuna and deep-water snapper and jobfish. Five sectors are evaluated below, three inshore: *bêche-de-mer*, reef fish and invertebrates, and the aquarium trade; and two offshore: deep-slope demersal and tuna.

Because countries can exclude others from fishing within their waters, a *resource rent* can be earned from seafood products. A *resource rent* is a margin of *profit* that can be earned because access to the resource is limited. This is the nature of an exclusive economic zone — governments can exclude and/or regulate fishers and companies who wish to harvest seafood in their EEZ. Fishers who are permitted to harvest seafood in the EEZ can capture this rent. When a country charges a licence fee for access to its EEZ, they are taking some of the *resource rent* earned by the fishers. This *resource rent* is a benefit to the country.

The Tonga Statistics Department estimates the total output of fisheries (subsistence and commercial) to be around T$ 18 million (US$ 10m) in recent years (in *constant* 2013 *prices*). Figure 5 shows the gross *value-added* of the Tongan fisheries sector during the 2000s. *Value-added* refers to the total output of the sector minus any *intermediate costs* and is used to measure GDP. The large decline in gross *value-added* of fisheries from 2005 to 2009 is difficult to explain. Part of the decline reflects Tonga national statistics adjustments for *inflation* of fish prices, which apparently occurred at a much higher rate than the prices of other goods (Tonga Statistics Department 2012). This led the Statistics Department to lower their estimate of the total output of the fisheries sector. In *nominal* (yearly) prices, output appears stable, but adjusting for *inflation* shows that the value of fisheries declined during the 2000s.

During the 2000s, aquarium and snapper exports declined slightly, but most fisheries production remained constant for most of the decade. Many locally-based tuna vessels pulled out of the industry in the later part of the decade, causing a large decline in tuna harvests from 2008 to 2011, but this is not reflected in national GDP calculations. The Fisheries Division could not explain this aberration between harvest statistics and national accounting statistics.

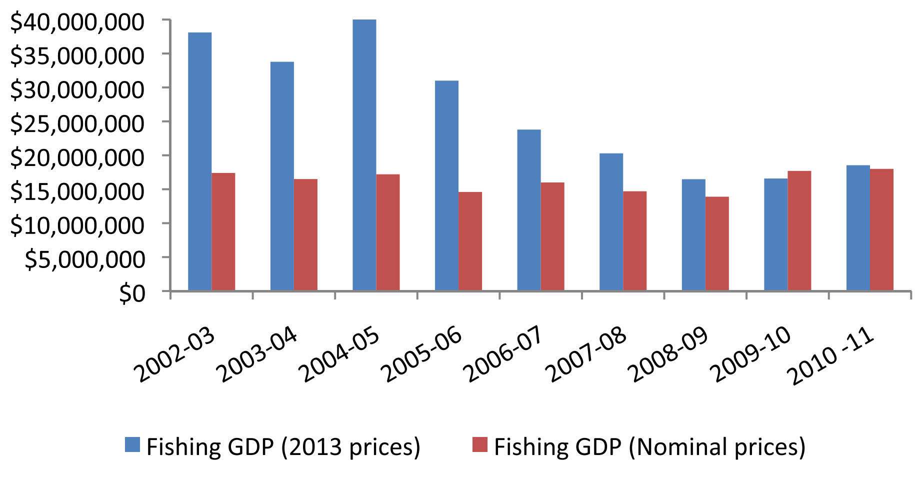

FIGURE 5 • Gross value added of fishing industry, all sectors (T$)

Source: Tonga Statistics Department 2012

In Tonga, the long-run average value of market and non-market fisheries is 3–4% of national GDP (Tonga Ministry of Finance and National Planning 2014). The total value of fisheries exports averages about T$ 6 million per annum (US$ 3.3 million). However, due to international market shifts, crashes in fish stocks, and periodic changes in licensing and other fishing regulations, fisheries exports have varied by as much as 40% from year to year. Fisheries exports do not include harvests by distant water fishing nation (DWFN) vessels that do not process their catch at Tonga ports. The export data in Figure 6 has been adjusted to *constant* 2013 value using the FAO Fish Price Index.

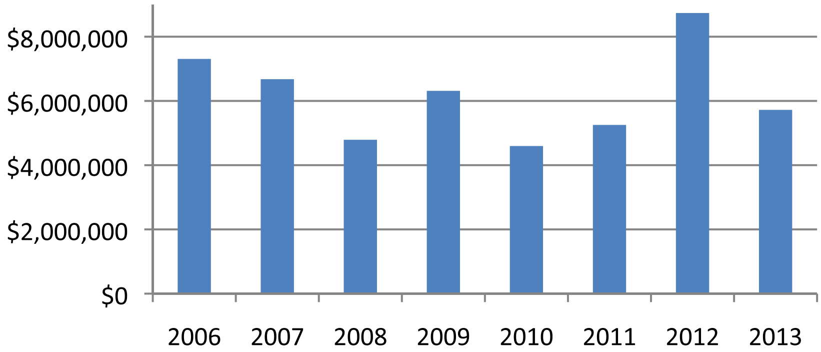

FIGURE 6 • Total fisheries exports from Tonga 2006–2013

Source: Tonga Fisheries Division; FAO Fish Price Index

Apart from a sudden increase in 2012 from a change in policy to allow licensing of foreign fishing vessels (see Section 6.2.4), exports of fishery products (including aquarium trade) has remained between T$ 4.5 million and T$ 7 million since 2006 (US$ 2.5–4 million). The major exports by value shift substantially among fishery sectors from year to year. In 2010, 66% of fishery export value was from *bêche-de-mer*, followed by the aquarium trade (18%) and snapper exports (10%); tuna exports were just 3% of total fisheries exports in 2010. In 2011 tuna exports increased to 13%, then to 52% of fisheries exports in 2012[15]. In 2012 shark meat exports increased to 24.5%; and *bêche-de-mer* fell to just 6.5% (T$ 545,000) of the total value of fisheries exports. In 2013 tuna exports fell to 38% of fisheries exports, but shark meat exports remained high at over T$ 1.4m (26%). The value of shark fin exports averaged about T$ 98,000/yr (1,660 kg) between 2006 and 2013, but shark fin exports have fallen by about 70% since 2006 (4,030 kg).

Despite the fact that fish products are one of Tonga's largest exports, making up more than 25% of the annual value of exports, the country imports over T$ 2.5 million annually (US$ 1.4m) in fish products, mostly tinned tuna and mackerel (Tonga Statistics Department 2013). Domestic commercial sales of locally caught fresh fish are not easily measured, as they occur mainly via informal markets and roadside stalls. Because domestic demand for fish does not change quickly, domestic sales can be expected to be relatively constant from year to year, unless prices for locally caught fish change substantially.

Figures for employment in fisheries vary widely by measurement method. The 2011 Census reports 955 workers in 'market-oriented skilled forestry, fishery, and hunting' and 859 responses that 'fishing mainly for sale' is their main activity (Tonga Statistics Department 2011). In addition, 1,413 adults reported that the main activity of their employer was 'fishing and aquaculture' (Tonga Statistics Department 2011). A 2005 socioeconomic survey estimated the number of people engaged in fishing activities to be 12,898: 6,470 in Tongatapu, 2,053 in Ha'apai, 4,375 in Vava'u (Tonga Fisheries Project 2005). This was approximately 13% of the national population. From survey results, this report gave the percentage of self-employed fishers in each island group: 5% in Tongatapu; 18% in Ha'apai; and 7% in Vava'u. Recent household surveys in Vava'u found that 29% of households fished at least once a month during the previous year (Salcone 2015). If this percentage applied nation-wide (18,156 households) the total number of fishing households would be 5,265 households.

15 This is due to the introduction of licensing of foreign vessels in 2012.

INSHORE FISHERIES

The inshore commercial fishery in Tonga can be split into three main categories: artisanal commercial, *bêche-de-mer* (sea cucumber), and the aquarium trade. There is also a small seaweed harvest and export industry in Tonga. Tonga has 5,780 square kilometres of lagoon, reef, and intertidal mangrove area that can support the growth and reproduction of inshore species. The map in Figure 1 shows the location and extent of these inshore habitat areas.

6.2.1 ARTISANAL COMMERCIAL FISHERIES (REEF FISH AND INVERTEBRATES)

6.2.1.1 IDENTIFY

Tonga's reefs, lagoons, and other coastal habitat support abundant food species, including ark-shell clams (*Anadara* spp.), octopus, prawns, groupers, parrotfish and surgeonfish. At the domestic fish markets in Tonga, a majority of the marine products sold are reef fishes and invertebrates caught by small-scale or artisanal fishers. A large portion of reef fishes and invertebrates are caught, sold, and consumed near Tongan shores. These marine products are a major source of protein for local people and a large percentage of Tongan fishers are involved in extracting them.

Most fishing households consume most of their catch and sell what they do not need (Kronen and Bender 2007; Salcone 2015). However, demand for cash income can cause fishers to sell for income first, and consume only what they do not sell. Reef fish have not been formally exported recently, but two small companies may be starting up in 2015. It is important to note that large amounts of reef fishes and invertebrates are taken by Tongan travellers for household consumption overseas.

As in most Pacific Island countries, reef fish and invertebrates are harvested in Tonga by gleaning, hand-lining (from shore and boat), hand-netting (in shallow waters) and spearfishing. Tonga is unique in that fishing is permitted at night. Free-dive spearfishing at night is very common. Tonga has a *bêche-de-mer* management plan and an aquarium fishery management plan, but no dedicated management plan for other inshore finfish and invertebrates.

6.2.1.2 QUANTIFY

Most inshore fish and invertebrates are sold in local markets. Aside from *bêche-de-mer* and the aquarium trade (discussed in Sections 6.2.2and 6.2.3), very limited quantities of reef fish and other reef seafood products are formally exported, although a significant amount of reef fish may be carried by Tongans travelling overseas and given, sold, or exchanged among relatives.

Until recently, Tonga Fisheries Division did not collect data on the local reef fish market. The prices and quantities of inshore seafood products sold at local markets is now being collected through an ongoing survey conducted every Saturday morning at Faua Market and other smaller markets in Tongatapu. Surveyors record unit prices and estimated quantities of all marine products sold. These data are analysed on a monthly basis. Data are available for two quarters (6 months), starting in 2014 (Table 4). More than 50% of the mass and value is reef finfish, with *Anadara*, octopus, tuna, and other pelagic fish making up another 30%. The Fisheries Division has not yet determined how much of the domestic small-scale harvest is represented in the market surveys. A few more quarters of data will be needed before efforts can be made to extrapolate this data to the rest of Tonga.

In addition to the market survey, a creel survey will be undertaken by the Fisheries Division in an attempt to quantify the production from inshore resources. The survey methods are still being tested and altered (as of February 2015) to produce reliable data on subsistence and commercial harvest and to estimate CPUE. The data collected by the creel and market surveys include the price per unit for all of the marine products landed and sold. Preliminary results from the surveys reveals that the prices for reef fishes and invertebrate differs only a little between the market sites sampled. Approximately 20 sites are being sampled, all on Tongatapu, including Faua (the main market). The other sites are all small roadside markets. Market surveys will begin in Vava'u and Ha'apai in 2015. Later in 2015, the Fisheries Division will provide data from the creel and market surveys to the Statistics Department to use to calculate the CPI[16] and the overall contribution to GDP by the fisheries sector.

16 The Consumer Price Index (CPI) is used to gauge *inflation* of prices.

TABLE 4 • Tongatapu 2014 Market Survey (6 months)

	Faua			Other sites			Total		
Product	**Total weight (kg)**	**Gross value (T$)**	**Av price (T$/kg)**	**Total weight (kg)**	**Gross value (T$)**	**Av price (T$/kg)**	**Total weight (kg)**	**Gross value (T$)**	**Av price (T$/kg)**
Anadara	3,211	14,110	4.39	1,591	5,285	3.32	4,802	19,395	4.04
Crustacean	767	11,680	15.22	120	1,400	11.70	887	13,080	14.74
Dried fish	138	1,204	8.72	3	20	6.67	141	1,224	8.67
Dried octopus	84	3,413	40.44						
Deep-water finfish	622	5,645	9.08	8	40	5.00	630	5,685	9.03
Inshore finfish	15,225	123,452	8.11	5,705	39,664	6.95	20,929	163,116	7.79
Giant clam	647	9,625	14.87	49	560	11.34	697	10,185	14.62
Jellyfish	108	1,935	17.95	69	1,040	15.12	177	2,975	16.85
Mix holothuria	214	4,305	20.11	346	2,705	7.81	560	7,010	12.51
Octopus	1,643	19,090	11.62	38	510	13.46	1,681	19,600	11.66
Other bivalve	389	2,590	6.65	74	330	4.45	464	2,920	6.30
Other molluscs	465	2,505	5.39	92	550	5.98	557	3055	5.48
Other pelagic fish	3,004	27,928	9.30				3,004	27,928	9.30
Porcupine	17	40	2.42				17	40	2.42
Sea anemone	55	500	9.04				55	500	9.04
Sea hare	1	5	6.25	4	50	12.50	4	45	11.84
Seaweed	274	2,660	9.70	153	1,110	7.25	427	3,770	8.82
Swordfish	171	1,851	10.80				171	1,851	10.80
Tuna	1,717	15,918	9.27				1,717	15,918	9.27
Turtle	79	1,020	12.91				79	1,020	12.91
Sea urchin	638	9,295	14.56	403	3,240	8.04	1,041	12,534	12.04
6 month total	29,470	258,770		8,655	56,504		38,124	315,264	8.27

Source: Tonga Fisheries Department 2014b

Because inshore harvest data is scarce, the artisanal fishing ecosystem service is quantified by evaluating income from household fishing and expenditure on seafoods from the 2009 HIES. The 2009 HIES measured the value of 'subsistence income', meaning income earned by household activities such as fishing, farming, and handicrafts (not the value of own consumption[17]). Figure 7 shows the relative distribution of income among different household activities in 2009. Fishing made up a greater share of subsistence activity in urban areas than in rural areas. However, the total subsistence income was much higher in rural areas (T$ 54.9m/US$ 27.3m) than in urban areas (T$ 12m/US$ 6m). Therefore, the *nominal* fish and seafood subsistence income (which totalled T$ 7.36m/US$ 2.32m) was also higher in rural areas (T$ 4.64m/ US$ 2.31m) than in urban areas (T$ 2.72m/US$ 1.36m) (2009 prices). Income from household fishing was estimated to total T$ 7,363,000 (2009 prices), equivalent to T$ 8,339,000 in 2013 prices (Tonga Statistics Department 2009).

17 Note that what the Statistics Department calls 'subsistence income' is, in fact, the *value-added* proportion of goods produced and sold by households, not the value of household consumption.

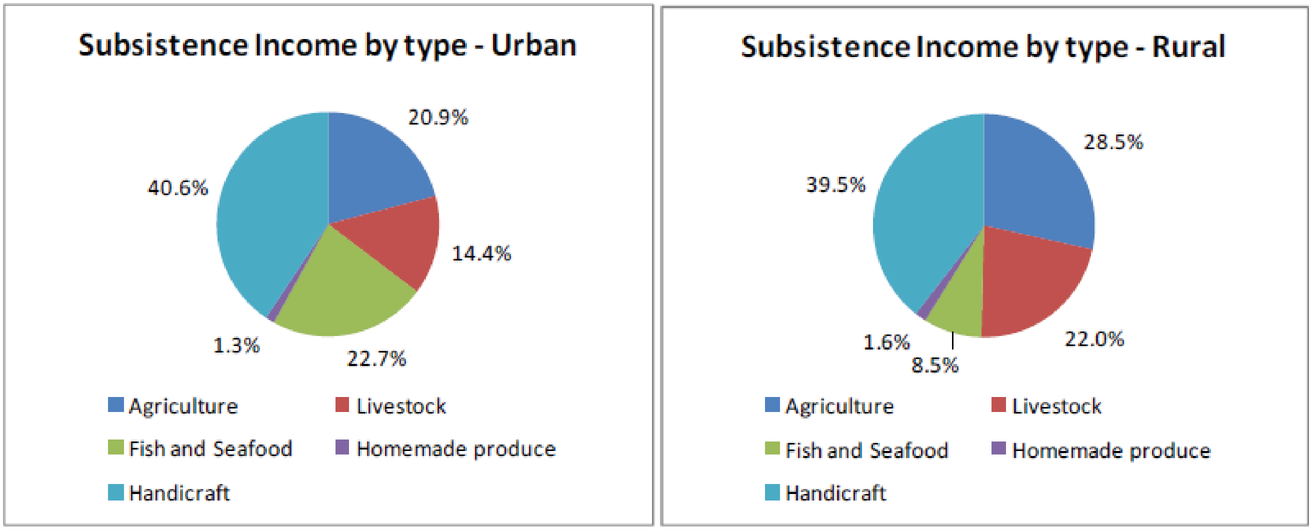

FIGURE 7 • Distribution of types of subsistence income, urban and rural. Source: Tonga Statistics Department 2009

Another measure of domestic inshore fisheries production is household expenditures on fresh fish, which is also captured by the HIES conducted by the Statistics Division. The 2009 survey reported average household cash expenditure on fish and seafood products was T$ 37/month (plus T$ 22/mo for canned fish). Non-canned fish and seafood expenditure would therefore equate to T$ 503 per year, per household (inflated to 2013 prices) or T$ 9.13 million nation-wide (US$ 5.1m) (18,156 households, Tonga Statistics Department 2011). Some of this expenditure included imported frozen fish, and commercial tuna and deep-water snapper sold locally.

The market survey seems to be effective at capturing average prices for domestic fish products, which will be useful in updating the CPI. Using the average price per kilogram of fish, T$ 8.27/kg, the gross expenditure on fish (T$ 9.1m, from HIES) would equate to about 1,104 tonnes of seafood. This is likely an underestimate (approximately 10.5 kg/person/yr), but until the creel and market surveys are improved, the HIES data is the only way to estimate inshore harvest. Note that this per capita average is additional to the annual per capita fish consumption estimated from subsistence fishing.

In the 2011 Census, 859 people reported ‘fishing mainly for sale’ as their primary activity during the previous week, about 2.5% of the economically active population. This number is in contrast to the 437 individuals who reported ‘fishing for own consumption’; many of these individuals may occasionally sell excess catch.

A recent survey of 150 households in Vava’u concluded that most households fish primarily for their own consumption or to share with family and community members (Salcone 2015). Only 9% of households (29% of fishing households) reported selling at least some of their catch and few of those households were fishing primarily for sale. Many fishing households donated part of their catch to churches or other households. The PROCFish project analysed inshore finfish and invertebrate fishing at four sites in Tonga. The proportion of finfish sold (versus consumed at home) varied among the villages from 23% to 85% of the total annual artisanal catch (Friedman et al. 2009).

Households from the Vava’u survey who recorded earning income from reef fishing earned on average T$ 900/month (median T$ 600/mo); households who recorded earning income from gleaning earned an average of T$ 430/month (median T$ 150/mo). Average total income per household from reef fishing and/or gleaning was T$ 1,192/mo (approximately T$ 14,000/yr). However, because the range in income (T$ 20–7,000 per month) was so great, averages may not be representative of household fishing behaviour. The median income per month from all types of fishing was T$ 600/mo or T$ 7,200/yr. See also Table 5.

TABLE 5 • Additional artisanal fishing statistics

Artisanal fisheries	Statistic	Data source
Average/median annual household income earned from selling seafood	T$ 14,000 / T$ 7,200	Vava'u household Survey
Average/median annual fishing costs (variable costs only)	T$ 815 / T$ 736	Vava'u household Survey
Average annual household expenditure, fresh and frozen seafood	T$ 503/household (All Tonga: T$ 9.13m)	HIES 2009
Average price of seafood, Tongatapu markets	T$ 8.27/kg	Tonga Fisheries Division 2014b

6.2.1.3 VALUE

The value of each commercial fishery sector is calculated as the difference between what fishers earn from sales and what it costs for them to fish. This is the *profit* of the fishers, calculated by the equation:

$$\text{Value to Producers} = \text{Sales Revenue}_{(\$)} - \text{Fishing Costs}_{\$}$$

The value of the commercial inshore fishery is the *profit* earned by individuals and households that catch and sell seafood products from Tongan waters. This includes the *profit* earned from domestic sales and exports of inshore seafood products. Export of inshore products (aside from *bêche-de-mer* and aquarium products) has been very limited. Export of reef fish, clams, crustaceans and other reef products has not exceeded T$ 100,000/yr in the past eight years, according to Fisheries Division estimates[18]. A *resource rent* tax is charged on the *free-on-board* (FOB) value of any exports. *Free-on-board* value is the taxable value, set by the Fisheries Division, for each different species. This value theoretically represents the *market value* of the product, although this is not always the case in practice. The Fisheries Division has not updated the FOB value estimates in many years and, therefore, they may underestimate the gross value of exports. The *resource rent* tax rate is 5% for most inshore fish species, or less than T$ 5,000 annually.

The value of the commercial inshore fishery is mostly revealed in domestic fish markets. Current market surveys do not appear sufficient to estimate national production of inshore fisheries, although they serve well to determine average prices for seafood products. The annual gross value of the inshore fishery is likely close to the T$ 9.13 million estimated from the HIES. Using the income data (T$ 8.3m) and the same fish prices, total harvest would equate to about 1,008 tonnes of seafood.

The *net value*[19] of the commercial inshore fishery is calculated by subtracting fishing costs from *gross revenue*. Tonga Fisheries Division has not estimated harvest costs for artisanal fishers[20]. Artisanal fishing costs include basic fishing gear, such as line, hooks, nets, spears, goggles and lights as well as boats and related expenses such as fuel and maintenance. These capital and variable costs are subtracted from the gross value of harvest to determine the net *economic value* of the inshore artisanal fishery. O'Garra (2007) estimated costs for artisanal fishing in Fiji, including the *opportunity cost* of labour. If those estimates are converted to 2013 Pa'anga, the total 'running costs' (variable costs) per fishing household would be T$ 849 per year (details in Appendix III: Additional data and methods). A re-analysis of the cost data without the *opportunity cost* of labour found average costs of T$ 481/household/yr, or T$ 2,882/household/yr for owners of a boat with motor. A recent household survey in Vava'u found average variable fishing costs per household, excluding outliers, were about T$ 815/yr; the median was T$ 736[21]. This average represents typical variable artisanal fishing costs in Vava'u well, and is close to the O'Garra (2007) estimate. Capital costs or depreciation and the *opportunity cost* of labour were not included in this measure. Starkhouse (2009) estimated the costs of artisanal fishing in Fiji to be approximately 50% of the gross value, including *opportunity costs* of labour. Cost estimates are summarised in Table 6.

18 The gross values of export products are calculated by the Fisheries Division based on *free-on-board* prices which have not been updated recently. The gross value of inshore exports may be slightly underestimated, but regardless, they are not a significant percentage of the total value of the resource.

19 Net value represents the true benefit of an activity, in this case the benefit to fishers from selling fish captured. See methods (Chapter 5) or Salcone et al. 2015.

20 Household fishing costs have been studied in Fiji by O'Garra (2007). O'Garra's costs estimate, converted to 2013 Pa'anga, is T$ 9,127 per year per household. This estimate seems much too high for Tonga subsistence fishers since the per capita GDP is only T$ 8,000 (US$ 4,500) per year.

21 Averages may not be very telling. Just 15 households reported fishing expenses; for those households, annual expenses ranged from T$ 75 to T$ 14,400. Average for all fishers was T$ 1,575/yr.

TABLE 6 • Annual artisanal fishing costs per household

Annual fishing costs per household	Costs/yr	Source
Average variable costs including labour and capital depreciation	T$ 849.07	O'Garra 2007
Average variable costs, no labour	T$ 815.00	Salcone 2015
Variable costs including capital depreciation, no labour	T$ 481.32	This study, using O'Garra (2007) data
Variable costs for boat owners, no labour	T$ 2,881.95	This study, using O'Garra (2007)data
Costs/*revenue* ratio	50%	Starkhouse 2009

In the 2011 Census, 859 individuals reported 'fishing mainly for sale' as their primary activity. The census is likely an underestimate of total commercial fishers because it does not include part-time fishers or mainly subsistence fishers who sell excess catch. The Vava'u survey revealed that 9% of households fished for income, which would equate to 1,634 fishing households nation-wide. Comparing this estimate to statistics from the 2009 HIES, Vava'u residents appear to fish less than residents of Ha'apai and Tongatapu, suggesting that 1,634 fishing households would be an underestimate.

The lack of inshore harvest data and lack of accurate estimates for the number of inshore fishers makes it difficult to estimate the value of artisanal fishing in Tonga (Table 7). Assuming a cost ratio estimate of 50%, and using the income estimate from the HIES for Tongan fishers (T$ 8.34 million), the value of the domestic commercial fishery would be around T$ 4.17 million per year (US$ 2.3 million). Other cost ratio estimates are much lower than 50%, so this would be a minimum estimate (M. Masila, Tonga Statistics Department, pers. comm. 2015; Gillett and Lightfoot 2001; Salcone 2015). Using domestic expenditure on seafood and an 80% *value-added* ratio, net benefits from seafood consumption by Tonga households is estimated as T$ 7.3 million per year (US$ 4.1 million).

TABLE 7 • Value and quantity of annual small-scale commercial seafood harvests

Source	Gross value	*Value-added* range (net benefit)		Tonnes seafood per year		Kilograms per capita, per year	
		50%	80%	T$ 8.27/ kg	T$ 5/kg	Min	Max
Annual domestic expenditure, fresh and frozen seafood	T$ 9,132,000	T$ 4,566,000	T$ 7,305,600	1,104	1,826	10.5	17.3
Annual household 'subsistence income' from fishing	T$ 8,339,000	T$ 4,169,500	T$ 6,671,200	1,008	1,668	9.6	15.8

Source: Tonga Statistics Department 2009 and authors' estimates

6.2.1.4 UNCERTAINTY

Inshore fisheries data are extremely limited. Currently, the most accurate estimates of the commercial value of inshore seafood products comes from extrapolations from household expenditures on fish and seafood, but this estimate also includes offshore seafood sold through local stores and markets as well as imported fresh or frozen fish and seafood products. Therefore the HIES gross value of T$ 9.13 million is likely an over-estimate. Costs data are equally scarce, but a cost ratio of 50% is a conservative estimate for small-scale fishing in the Pacific. Gillett and Lightfoot (2001) analysed the literature and found *value-added* ratios for small-scale commercial fishing ranged from 55% to 70% (30–45% costs). However, the estimate of the gross value of expenditure included sales of bycatch from deep-sea demersal and tuna fisheries which likely have a different ratio of costs to *value-added*.

The price estimate used to calculate harvest quantity (T$ 8.27/kg) reflects 2014 prices in Tongatapu markets. This is likely higher than the national average, and is more than three times higher than estimates used by Gillett and Lightfoot in 2001. Dividing gross values by a high price of fish per kilogram will underestimate the total harvest. Using a replacement cost of seafood of T$ 5/kg would increase harvest estimates by 40% (Table 7).

Market surveys and creel surveys were initiated in 2014. The results from these surveys will be the most reliable source for data on commercial sales of inshore products, and will allow more accurate estimates of the value of this ecosystem service.

6.2.1.5 SUSTAINABILITY

Tonga has significant lagoon and reef habitat relative to the Kingdom's small population. Annual seafood consumption in Tonga is likely between 3,200 and 8,400 tonnes per year (FAO 2007–2011; Friedman et al. 2009). Assuming approximately 50% of seafood consumption derives from inshore domestic fisheries (and the other 50% from offshore and imported seafood products), Tongan inshore habitats must produce 1,600–4,200 tonnes of seafood annually. Healthy island coral reef fisheries have been estimated to support an average sustainable yield of 5 tonnes/km^2/yr (Newton et al. 2007). According to these sustainable yield estimates, Tonga reef areas could produce 16,000 tonnes of seafood annually. Tonga's inshore areas should be able to support the total inshore seafood demand of the domestic population for the foreseeable future. However, this assumes a homogeneous spread of fishing effort which is not the case for Tonga. Recent scientific studies have indicated marked overfishing and stock declines in some areas. The PROCFish project evaluated CPUE for finfish in four villages. CPUE varied significantly between villages, indicating variable resource pressure (Friedman et al. 2009; Webster 2014). In general, the reef fisheries in Tonga have been characterised as moderately to seriously over-exploited (Friedman et al. 2009):

> "Some species have become less abundant while others have decreased in average size. On Tongatapu, one of the local mullet species, *Mugil cephalus*, which formed about 70% of the commercial mullet landings in the 1970s, is believed to be on the verge of becoming locally extinct. This trend has been attributed to the effects of introducing highly effective fishing methods, such as fish fences made from chicken wire to catch mullet as they migrate out from the lagoon to their spawning grounds."

Declining stocks and CPUE could be caused by overfishing, pollution and habitat destruction, exports, and discarded catch (mortality not associated with consumption or sale). Because of very high global demand for seafood products, export fisheries can be quickly over-exploited and therefore need strict harvest limitations. Also, domestic demand and harvests vary throughout the year[22] and are geographically concentrated around villages, especially those with access to markets.

Given Tonga's small population, domestic fisheries should be sustainable. The sustainability of the fishery, however, cannot be based on economic information; it must be based on scientific measurement of fisheries metrics such as biomass, stock trends, CPUE trends, age/size structure of populations and information on reproductive capacity.

Tonga's main tools to protect inshore fisheries are fisheries management plans and the establishment of SMAs. Under the *Fisheries Management Act* of 2002 coastal communities can establish SMAs to control fishing activities, restore fish stocks in no-fishing areas, and raise awareness of fisheries conservation and resource management. This is a good mechanism to respond to the inherent danger of an open-access resource. SMAs provide a type of property right to the villages that manage these areas. Property rights remove the risk that someone from outside the area will exploit the resource. Clear property rights are an important step towards assuring a resource is managed sustainably.

6.2.1.6 DISTRIBUTION

Tongan households, and particularly fishing families, receive most of the benefits from commercial artisanal fisheries. A high portion of household seafood consumption is from reef fishes and invertebrate resources and since the harvest is done predominantly by the local people, any income generated from their sales goes directly to the local people.

6.2.2 *BÊCHE-DE-MER* (SEA CUCUMBER)

6.2.2.1 IDENTIFY

Sea cucumbers are echinoderms that move slowly across the sea bottom, consuming dead and decaying matter. Sea cucumbers are important for decomposition of waste. Dried for export, sea cucumbers are often referred to by the French name *bêche-de-mer*. Sea cucumber harvesting is an easy-access industry. It requires very little technology and minimal capital investment. Sea cucumbers can be harvested by divers or simply collected by individuals wading through lagoons, particularly at low tide. Because these sluggish invertebrates cannot swim away, they are particularly easy to catch, requiring nothing more than hands and perhaps a dive mask.

The commercial bêche-de-mer fishery has been through several cycles of boom and bust.

22 For example, the majority of the smaller reef fishes are caught by night spear fishing and more spear fishers work in the warm season than in the cold season (Tonga Fisheries Division 2014c). Demand for seashells during New Year and Christmas seasons increases harvest of those species during that time of year.

Tongan waters are home to approximately 15 sea cucumber species of greatly differing commercial value (Friedman et al. 2009). Tongans distinguish between low-value species that are caught mostly in coastal waters, and high-value species that are caught in deeper water and are typically dried for export. Deep-water species are mostly harvested by scuba divers or divers using hookah gear despite the fact that using a breathing apparatus to catch fish or other marine products is illegal. *Bêche-de-mer* is important to most fishing communities in Tonga. There is direct involvement from the community when harvesting *bêche-de-mer* as it can be done by men, women and children. Commercial harvesters must register with Tongan Fisheries Division, and no processing or exporting can be done without a licence.

Consumption of high-value *bêche-de-mer* is not common in Tonga. However, the consumption of lower-value sea cucumber is common. Sea cucumber is mostly consumed by low-income families, and thus is not used in any typical Tongan dishes or feasts. However, since it can be harvested by women and children, sea cucumber is an important food source for most families in fishing and coastal communities. The high value of *bêche-de-mer* and the ease of access and harvest has led to a depletion of stocks which may diminish income-earning potential for coastal fishers and impact food security.

6.2.2.2 QUANTIFY

The sea cucumber industry in Tonga has followed a boom-and-bust cycle (Figure 8). Production peaked in 1992 when 67 tonnes were exported by 13 registered exporters at a total estimated FOB value of T$ 615,432. Production declined until 1998 when a 10-year ban was implemented after a stock assessment survey reported very low stocks (Lokani et al. 1996). The 10-year moratorium was lifted in 2008. The next year, 370 tonnes of *bêche-de-mer* were exported, but the resource could not sustain this pressure and exports declined to 313 tonnes in 2010 and to 79 tonnes in 2011. Exports have been declining steadily since (Figure 7).

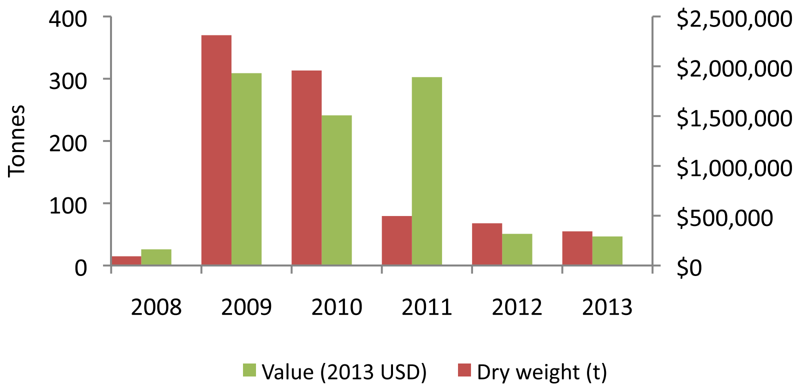

FIGURE 8 • Bêche-de-mer exports, value and tonnes, 2008–2013
Source: Tonga Fisheries Division

Sea cucumber for domestic consumption should not follow this same boom-and-bust pattern as prices are lower and demand relatively consistent. Sea cucumber for domestic sale is included in Section 6.2.1.

6.2.2.3 VALUE

Sea cucumbers are harvested mostly by Tongans who then sell them to exporters. The potential export prices, and thus the commercial value, of *bêche-de-mer* vary among species. Because sea cucumber is typically dried for export, fishers receive a much lower price for fresh products.

The gross value of exports is shown in Figure 8. The value was estimated by multiplying the weight of each species exported by the FOB prices estimated for those species. Although the FOB value varies greatly between species, the *resource rent* is 5% on all *bêche-de-mer* exports.

The harvest moratorium ended in 2008. The gross value of exports was nearly US$ 2 million in 2009 (370 t), but judging from the drastic reduction in harvests in 2012 and 2013 (68 t and 55 t, respectively), these yields were unsustainable. Because of the boom-bust cycles Tonga has experienced it is difficult to estimate the value of a sustainable yield, but we assume that it would be similar to or less than post-boom exports of about US$ 500,000/yr (T$ 900,000).

The Fisheries Division has not estimated harvest and processing costs for *bêche-de-mer*. Harvest of *bêche-de-mer* usually involves free-diving from a boat, sometimes with the use of scuba or hookah underwater breathing devices. Since costs for these activities have not been estimated, a 50% *value-added* ratio is used to estimate the benefit of the industry to harvesters and exporters. Post-boom benefits are about T$ 400,000 per year (US$ 250,000). Government tax *revenue* on post-boom exports would be T$ 45,000 per year.

6.2.2.4 UNCERTAINTY

Prices vary significantly by species, so gross harvest is not a good indicator of gross value. The FOB prices used by the Fisheries Division to calculate the gross value above are unique to each species, but have not been updated in many years and therefore may underestimate the true export value of *bêche-de-mer*. Furthermore, FOB values are not equivalent to the true export value, which would be a better representation of the value of the resource. Overall, market prices can be expected to continue to increase due to scarcity of sea cucumbers and growing Asian markets (Purcell 2014).

6.2.2.5 SUSTAINABILITY

A number of factors make *bêche-de-mer* particularly prone to over-exploitation: large and lucrative international markets, ease of harvest, and ease of storage and export (when dried). Currently, the production rate is very low, mainly because extraction has been high in recent years, leaving fewer sea cucumbers to reproduce. Habitat loss, pollution and predation do not appear to be threatening factors. The low harvest is due to a low reproduction rate which relies on density-dependent spawning. Low densities are, in turn, due to the high extraction rate. The few remaining sea cucumbers are distributed widely resulting in a low spawning rate. The fast deterioration of this resource is due to overharvesting alone.

Tonga has a national Sea Cucumber Management Plan to regulate exploitation of this resource, but the plan has not estimated a maximum sustainable yield (MSY). The Fisheries Division is advocating for a 3–5 year moratorium during which time the management plan will be updated. The Fisheries Division is also looking into culturing certain species of sea cucumber for restocking purposes.

Of additional concern is the use of mangrove wood to smoke-dry *bêche-de-mer* for export. According to the Sea Cucumber Management Plan, it may take as much as 10 tonnes of mangrove wood to dry one tonne of sea cucumbers (Tonga Fisheries Division date unknown).

6.2.2.6 DISTRIBUTION

A large portion of the benefits from this ecosystem service goes to the exporters, which are mostly Chinese[23]. However, the people of fishing communities also benefit from selling their harvest to the exporters, albeit at a low price because almost all of the harvest is sold in fresh form. The Fisheries Division is running training in communities so they can process their own products before selling them to the exporters, thereby increasing their *value-added*. Lower-value species that are not exported provide food for fishing communities and contribute to food security of these villages (see Section 6.1).

6.2.3 AQUARIUM FISH AND CORAL TRADE

6.2.3.1 IDENTIFY

Tropical fish and coral for display in aquariums are exported from Tonga, particularly to North America. In 2004, a study estimated that the export of hard and soft corals, fish, invertebrates, live rock, and giant clams brought in US$ 2.2 million in 2000, representing a significant *economic activity* for the country (Lindsay et al. 2004). At that time, there were direct flights from Nuku'alofa to Los Angeles, which no longer exist. All aquarium products are transported on commercial passenger airlines. Currently, the only export market is USA. However, some exporters are trying to enter the Japanese and other markets.

Few people participate in this fishery; only the exporters and their employees are involved in capturing live fish and coral. The Tonga Aquarium Fishery Management Plan regulates this fishery sector. Export licences can be issued to a maximum of five companies; in 2014 there were three Tongan companies and one foreign company registered to export. Harvest of aquarium products is limited to Tongatapu. Companies are limited to 100,000 fish per year; there is no quota on invertebrates or soft corals. The aquarium trade is the only fish harvest activity for which scuba gear is permitted under a licence from the Fisheries Division.

23 At time of writing there was one Tongan exporter.

The harvest and export of live coral is limited to 150 pieces per week, per company. The export of live rock was banned in 2009 due to complaints from communities that their reefs had been destroyed by the aquarium exporters. The ban is still in effect but some illicit live rock exports continue. Coastal communities are not compensated for fish, coral, or live rock removed from their fishing areas.

6.2.3.2 QUANTIFY

The Fisheries Division has records on the quantity and value of exports of live fish, live rock and invertebrates including live hard coral, shellfish and soft coral for 2006–2013. Since 2006, exports have averaged about 240,000 pieces each year, varying from 520,000 pieces in 2006 to 93,000 pieces in 2012. The gross value of these exports is shown in Figure 9. The export of live rock, which was banned in 2009, was a significant part of the aquarium trade, but it was not solely responsible for the drop in exports. After the largest company left Tonga in 2009, export of most aquarium products dropped and has remained lower since. Only the export of live coral, which is still legal with a permit, has not decreased. Pa'anga export values have been converted to 2013 US$ to control for price index fluctuations. The average gross value of exports for the past five years is approximately US$ 443,000 (T$ 794,000).

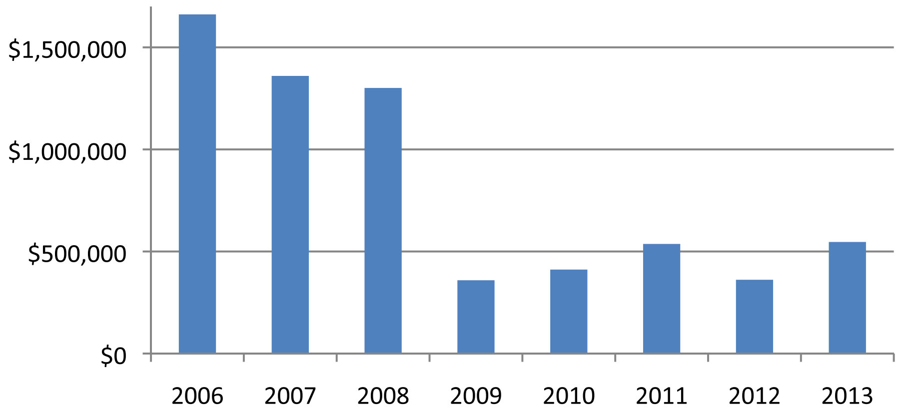

FIGURE 9 • Gross value of aquarium and live rock exports 2006–2013

Source: Tonga Fisheries Division

The export value above is based on FOB prices which were revised drastically lower by the Fisheries Division in 2013. *Resource rent* (export tax) rates were also lowered from 5% to 0.5% of FOB value. It is not clear why the FOB prices were revised so drastically, but again, FOB values are not directly related to market prices[24].

6.2.3.3 VALUE

Export companies pay a licence fee of T$ 1,000 per year to export and T$ 2,000 per year to fish, a total of T$ 15,000 for all five companies. Additionally, exporters pay 0.5% *resource rent* tax based on the FOB export value, and a 15% consumption tax based on the *resource rent* (i.e. 15% of 0.5%). Table 8 shows a summary of government *revenue* from the aquarium trade before taxes were reduced in 2014. Tax *revenue* would be significantly less under the new tax rate.

TABLE 8 • Average annual government revenue from the aquarium trade, 2008–2013

Aquarium trade government *revenue*	
Licensing fees	T$ 15,000
Resource rent	T$ 65,701
Consumption tax	T$ 9,855
Total	T$ 90,556

24 FOB prices and *resource rent* could be used to incentivise or de-incentivise export of certain products. Lowering the FOB value decreases the export tax liability.

The remaining T$ 703,500 (US$ 392,500) in *gross revenue* goes to the exporters, but they must subtract wages, capital expenses, equipment fees, and other operating costs. The operating costs to support aquarium exports have not been estimated for Tongan harvesters and exporters. Lal and Kinch (2005) estimated that the financial *profit* of the coral and aquarium product industry in the Solomon Islands was about 32% of the FOB value. This *profit* is the true *economic value*, which goes to the export companies. In Tonga that would be about T$ 254,000 (US$ 142,000) per year.

6.2.3.4 UNCERTAINTY

Operations costs, transportation in particular, are likely to be higher in the Solomon Islands than in Tonga, so we can presume our producer benefit estimate of T$ 254,000/yr underestimates the *producer surplus* of the aquarium trade in Tonga. Government tax rates seem to change substantially from time to time. Current tax *revenue* is much less than the T$ 90,000/yr average estimated for 2008 – 2013. Again, the value of exports is based on FOB values that may not reflect current *market value* of these exports.

6.2.3.5 SUSTAINABILITY

Similar to reef fishes and invertebrates, the value of this resource does not take into account under- or over-exploitation. Rare species are often more valuable and thus highly sought after since the transportation costs are relatively fixed. The sustainability and thus future expectations of the value of this ecosystem service depend on the aquarium products and their abundance. For example, current aquarium exports are dominated by low-value invertebrates. The low value could be an indicator of abundance, therefore export prices are not expected to increase.

Trade in threatened or endangered aquarium species is governed by CITES. CITES prohibits trade of species listed in CITES Appendix I, and mandates documentation for trade of species listed in CITES Appendix II. Both Tonga and the USA, the major export market, are CITES members, which should deter importation of threatened or endangered species.

The Aquarium Trade Management Plan is specifically designed to prevent over-exploitation of the fishery. Most aquarium species are small herbivores that reproduce rapidly and abundantly. The most unsustainable activity, live rock harvesting, has been banned. If the regulations of the management plan are enforced the aquarium trade should remain a sustainable industry in Tonga.

6.2.3.6 DISTRIBUTION

All aquarium products are exported, providing a consumer benefit to aquarium enthusiasts in America. The producer benefit of this resource is distributed among the aquarium exporters and their divers. Three of the four export companies are Tongan companies. Currently, two of the exporters are renting space and tank facilities at the Fisheries Division offices. The rent they pay contributes a small amount to government *revenue.* The Fisheries Division also benefits from the licence fees and taxes. The average value of these benefits from 2008 to 2013 was approximately T$ 90,000/yr (US$ 50,000). The estimated benefit to the harvest and export companies was at least T$ 254,000/yr (US$ 142,000/yr).

Tongan communities complain about the aquarium trade damaging reefs. Communities do not receive any direct benefit from the aquarium fishery.

OFFSHORE FISHERIES

Like most Pacific Island countries, offshore fishing in Tonga is mostly for commercial sale and mostly for export. Although deep-water and pelagic fish species are sometimes caught by artisanal fishers near to shore, offshore fishing is generally characterised by more expensive and sophisticated equipment than is used for inshore fishing. Tongan offshore fisheries can be split into two main categories: tuna and deep-water snapper. Tuna fisheries target the four main tuna species (albacore, bigeye, skipjack and yellowfin) as well as other bycatch such as marlin, mackerel and swordfish. The deep-slope demersal fishery, commonly called the deep-water snapper fishery, also includes species such as jobfish and groupers.

6.2.4 TUNA FISHERY

6.2.4.1 IDENTIFY

The tuna fishery in Tonga is notably smaller than in most other Pacific Island countries. Tonga is located further south and east than the largest Pacific tuna stocks. Albacore is the dominant commercial tuna species in Tonga, making up 25–50% of the annual catch, followed by yellowfin and much smaller numbers of bigeye. Few skipjack are caught at latitudes as far south as Tonga. Tuna fishing in Tongan waters is mainly done by longline to target albacore, which do not school in the same way as skipjack.

Tuna generates a large income to the government from the fisheries sector and is the dominant fisheries export product. The industry provides employment on fishing vessels, at landing sites and in processing facilities. Government *revenues* are generated from access fees through licensing, and also through a *resource rent* tax.

A moratorium was placed on foreign vessels from 2004 to 2011. Licences were again sold to foreign vessels in late 2011 as a way to generate *revenue* because most of the local fleet was tying up at the wharf or leaving the industry; only three vessels remained in 2011 (Tonga Fisheries Division 2012). As a result of allowing foreign boats to enter the fishery, the magnitude of catch and exports increased dramatically in 2012 and 2013. The local fleets were complaining that the foreign vessels are taking all the fish and are a threat to the local fishers' livelihoods because they are highly subsidised. The Tuna Management and Development Plan was reviewed to reconsider the licensing of foreign fishing vessels. In order to achieve the objective of gradually reducing the number of foreign licenses issued and increase local (and locally-based foreign) licenses over time, the issuing of licenses preference will be given to local and then locally-based foreign vessels.

The amount of bycatch, fish accidentally caught while pursuing tuna, is significant. Longline vessels catch a large number of sharks, blue marlin, and mahi mahi while fishing for tuna in Tongan waters[25]. Halafihi and Fa'anunu (2008) estimated bycatch to be 26–32% of total fish harvest by tuna vessels in Tonga. It is possible that tuna vessels target these bycatch species by fishing at different depths; the export value of shark fin is more than five times greater than the value of processed tuna loins.

6.2.4.2 QUANTIFY

Data on tuna catch is more robust than for any other fishery sector in the Pacific. Catches are measured and verified using a combination of log-sheets, ship captains' estimates, and actual weight measured dockside[26]. Annual catch data held by the Tonga Fisheries Division is consistently 35% higher on average than that recorded by SPC. SPC data are used in this analysis because they are the regional standard.

Total tuna harvest in Tongan waters has averaged around 920 tonnes annually over the past 15 years (Figure 10). Before 2011, Tonga did not license foreign vessels and therefore all of Tonga's tuna was caught by the Tongan fishing fleet. Only 128 tonnes were harvested in 2010. In 2011 there was just one local tuna vessel and one locally-based foreign vessel operating. Tonga sold licences to foreign fishing vessels in 2011. Consequentially, catches increased five-fold from 2011 to 2012 and doubled again in 2013 to 2,913 tonnes (increasing similarly across species). Adding 10% (FFA 2014) to 29% (Halafihi and Fa'anunu 2008) to account for bycatch would increase the annual average to about 1,010–1,185 tonnes and the 2013 catch to 3,200–3,760 tonnes.

25 For purse-seine vessels, bycatch is highest when netting is done near fish aggregating devices (FADs) (Pilling et al. 2013). FADs and purse-seine fishing are less common in Tonga than in other areas of the Pacific.

26 The Tonga National Tuna Fisheries Management and Development Plan (2015–2017) states that "All licensed fishing vessels shall offload all catch in the authorized ports of Tonga.

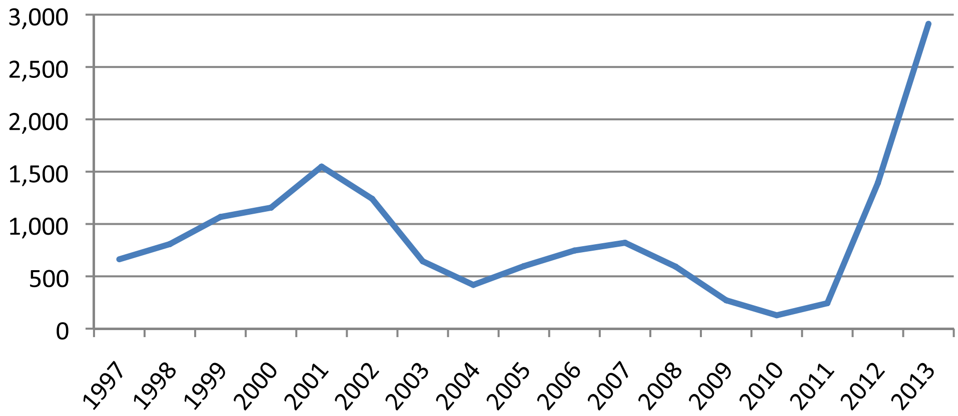

FIGURE 10 • Total tuna catch in Tonga EEZ, 1997–2013

Source: FFA WCPFC 2014[27]

In the first six months of 2014, only 550 tonnes of tuna was caught and landed in Tonga compared to 1,400 tonnes landed in the same period in 2013, but the number of local boats expanded in late 2014. At the end of the third quarter of 2014, four foreign fishing vessels and four local vessels were licensed to fish in Tonga's EEZ. Tonga recorded exports of 572 tonnes in 2012 and 258 tonnes in 2013, just 41% and 9% (respectively) of the recorded catch for the year. The remaining catch could have been consumed locally and/or carried overseas by DWFN vessels that did not land in Tonga. The FOB value of tuna exports averaged US$ 880,000/yr (T$ 1,575,000/yr) from 2006 to 2013. This included tuna exports only; shark meat and shark fin exports averaged US$ 578,000/yr (T$ 1,036,000/yr), much of which may have been bycatch of tuna vessels.

Revenue from licensing fees, *resource rent* and other fees are collected by the Ministry of Finance. Licensing fees for local fishing vessels are based on the size of the vessel; a consumption tax (15%) is charged on the licence fee. Total fees for local fishing and sport fishing vessels range from T$ 250 to T$ 2,000 per year. Average total licence fees for vessels fishing in Tongan waters during the past three years were approximately US$ 735,000/yr (T$ 1,317,000/yr). Almost all (99%) of that *revenue* was from DWFN vessels and the South Pacific Tuna Treaty. Tonga is one of 17 FFA member countries that are party to the Tuna Treaty which was negotiated to allow US vessels 8,300 days fishing in Western and Central Pacific waters in 2015 for US$ 90 million. Tonga also charges a 1% *resource rent* tax on all tuna exports, which is approximately US$ 8,800/yr (T$ 15,750/yr). This is a *resource rent* tax on tuna exports only; *resource rent* on shark meat and shark fin exports would be an additional US$ 5,780/yr (T$ 10,360/yr).

Employment in the tuna industry is another interesting measure of the value of the resource. A study by the FFA tracked the number of Tongan citizens employed in the country's offshore fishing industry during the 2000s. There was a consistent decline in Tongan employment in the tuna industry from 2002 to 2012 (Table 9; Gillett 2008; FFA 2014). However, more Tongan vessels entered the fishery in 2013 and 2014, so presumably tuna fishing employment has grown.

TABLE 9 • Employment in the tuna fisheries of Tonga, 2002–2012

	2002	2006	2008	2010	2012
Local jobs on vessels	161	75	45	17	6
Local jobs in on-shore facilities	85	35	35	14	6
Total	**246**	**110**	**80**	**31**	**12**

Source: Gillett 2008; FFA 2014

27 All catch data is sourced from the Oceanic Fisheries Program (OFP) of the SPC (Peter Williams, Fisheries Database Supervisor, pers. comm., July 2014)

6.2.4.3 VALUE

The FFA calculates the gross value of tuna using global prices: the Thai import price is used for albacore; the Yaizu price is used for yellowfin caught on longline; and the price at Japanese ports is used for bigeye (FFA WCPFC 2014). Prices are specific to each year, so the total values have been inflated to 2013 USD using the FAO Fish Price Index. The average gross value of the catch for the past 15 years is US$ 4.67m (T$ 8.37m) although there is annual variation around this average.

The FFA Economic Indicator report (FFA 2014) inflates longline value estimates by 10% to account for bycatch *revenue*, which would increase the average gross value of tuna catch to US$ 5.14m (T$ 9.21m). Since bycatch has been estimated to be much higher in Tonga, ranging 26–32% of the value of the catch (Halafihi and Fa'anunu 2008) and because shark meat and shark fin exports totalled more than T$ 1.5m in 2012 and 2013, T$ 9.21m is most likely a conservative estimate of the gross value of the tuna fishery catch.

Exports of tuna (fish that is landed in Tonga before shipping elsewhere) averaged 252 tonnes over 2006–2013, with an average value of US$ 1.65m (T$ 2.96m). The value of the total catch and the value of exports are shown in Figure 11. Data on exports before 2006 were not available.

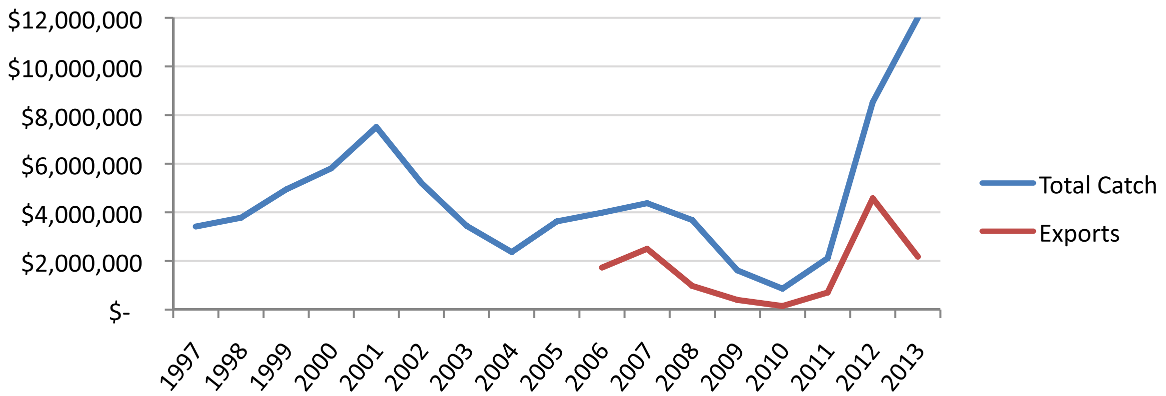

FIGURE 11 • Value of Tuna caught in Tonga EEZ, 2000–2013.
Source: Catch — FFA WCPFC 2014; Exports — Tonga Fisheries Division

The net *economic benefit* (to fishers) of this ecosystem service can be estimated by subtracting fishing costs from the *gross value* of the catch. The remaining value is the *value-added* of the sector. Distant water longline vessels have average costs of US$ 7,407 per day; locally-based vessels have costs of approximately US$ 4,338 per day (R. Banks, FFA, pers. comm.). Data on the annual number of fishing days for local and foreign vessels was not available to calculate total fishing costs.

The FFA estimates the *value-added* ratio for locally-based longline fishing to be about 20%[28] (FFA 2014). Since most Tongan tuna fishing is done by longline vessels, the annual average *net value* of tuna and bycatch harvests in Tonga is estimated at US$ 1–1.2 million (T$ 1.8–2.2 million). This is a conservative estimate of the annual *value-added* benefit to fishing fleets in Tongan waters.

FFA also estimates *value-added revenue* per tonne for different types of vessels. The benefits of longline vessels without a local cannery are estimated at US$ 513/tonne (FFA 2014). Using this estimate and the average tuna and bycatch harvest of 2000–2014 of about 1010–1185 tonnes per year, the *value-added* to fishers in Tonga waters would be US$ 518,000–1,206,000 (T$ 930,000–1,090,000) per year, calculated using estimates of *value-added* per tonne (Table 11). These estimates represent the net benefit of the fish catch to fishing fleets and do not include benefits from fishing licence fees, exports or processing.

Some foreign-based fleets, Chinese in particular, may receive a government subsidy from their home nation. In this case, the true *value-added* may be zero, or even negative, yet the subsidy could provide an incentive to continue fishing despite the fact that it is not profitable.

28 FFA estimates purse-seine and pole-and-line fishing *value-added* ratios to be between 50% and 60%

The Government of Tonga receives significant benefits from licences, fees, and other taxes. Average total licence fees for vessels fishing in Tongan waters 2012–2014 was approximately US$ 735,000/yr (T$ 1,317,000/yr), 99% of which was from foreign vessels (Table 10). An additional US$ 8,800 (T$ 15,750) was earned per year from the 1% *resource rent* tax.

TABLE 10 • Summary of average tuna value estimates, 2013 currency

<table>
<tr><th></th><th colspan="2">Gross value of catch*</th><th colspan="2">Net value</th><th colspan="2">Gross value of exports</th><th colspan="2">Government revenue</th></tr>
<tr><th></th><th>US$</th><th>T$</th><th>US$</th><th>T$</th><th>US$</th><th>T$</th><th>US$</th><th>T$</th></tr>
<tr><td>Min</td><td>5,138,647</td><td>9,207,395</td><td>518,130</td><td>928,382</td><td>878,786</td><td>1,574,603</td><td rowspan="2">745,000</td><td rowspan="2">1,330,000</td></tr>
<tr><td>Max</td><td>6,026,231</td><td>10,797,763</td><td>1,205,246</td><td>2,159,553</td><td>1,456,842</td><td>2,563,153</td></tr>
</table>

* The variability in these values derives from different estimates of bycatch. See Table 11

6.2.4.4 UNCERTAINTY

Tuna data are relatively robust in the Pacific. Coverage by on-ship observers has increased to 80–90% in recent years (Pilling et al. 2013).There is, however, some discrepancy between Tongan catch data and that recorded by SPC. Although the SPC data are the most commonly cited tuna data for the region, Tonga catch data may be more accurate because it measures actual dock weight.

Table 11 shows the collection of statistics that quantify the magnitude and value of commercial tuna fishing. This is not an exhaustive list but does represent much of the information currently available about this important marine resource. The values are derived from a range of estimation methods and data. There is great uncertainty about the precise economic value because of the range of methods that have been used over the years. In particular, estimates for bycatch and fishing costs (which are used to produce value added ratios) vary greatly.

TABLE 11 • Tonga tuna and tuna bycatch data

<table>
<tr><th>Statistic</th><th colspan="3">Data</th><th>Author/source</th><th>Comments</th></tr>
<tr><td rowspan="2">Tuna harvest</td><td colspan="3">920 t</td><td>FFA WCPFC 2014</td><td>Average 1999–2013</td></tr>
<tr><td colspan="3">1,160 t</td><td>Tonga Fisheries Division</td><td>Average 2005–2013</td></tr>
<tr><td rowspan="2">Bycatch</td><td colspan="3">10% (90–104 t)</td><td>FFA 2014</td><td rowspan="2"></td></tr>
<tr><td colspan="3">26% – 32% (234–332 t)</td><td>Halafihi and Fa'aunu 2008</td></tr>
<tr><td>Gross value of tuna and bycatch</td><td colspan="3">US$ 5.14m–6.0m
(T$ 9.2m–10.8m)</td><td>All above</td><td>(Range of bycatch 10–29%)</td></tr>
<tr><td rowspan="2">Value-added</td><td colspan="3">US$ 1.0m –$ 1.2m
(T$ 1.8m–2.2m)</td><td>All above</td><td>Typical value-added for longline vessels (20%)</td></tr>
<tr><td colspan="3">US$ 518,000 –608,000
(T$ 930,000 – 1,090,000)</td><td>All above</td><td>Value-added per tonne ($ 513/t) for longline without processing</td></tr>
<tr><td>Exports</td><td colspan="3">US$ 880,000 – 1,450,000
(T$ 1,570,000 – 2,560,000)</td><td>Tonga Fisheries Division</td><td>FOB prices; average of 2006–2013</td></tr>
<tr><td>Government revenue</td><td colspan="3">US$ 745,000
(T$ 1,330,000)</td><td></td><td>Local and foreign licence fees, US treaty revenue, and resource rent revenue</td></tr>
<tr><td>Fishing costs</td><td colspan="3">Locally-based: US$ 4,338/day
DWFN: US$ 7,407/day</td><td>R. Banks, FFA, pers. comm.</td><td>Longline variable (operating) costs</td></tr>
<tr><td>Boats and vessel-days</td><td colspan="3">Not available</td><td></td><td></td></tr>
<tr><td rowspan="3">Employment</td><td></td><td>2002</td><td>2012</td><td rowspan="3">FFA 2008 and 2014</td><td rowspan="3">As of 2014, four locally-based vessels were operating, so employment has likely increased since 2012</td></tr>
<tr><td>Vessels</td><td>161</td><td>6</td></tr>
<tr><td>Processing</td><td>85</td><td>6</td></tr>
</table>

6.2.4.5 SUSTAINABILITY

Stock assessments from 2010 show that South Pacific albacore stocks remain sustainable despite perennial increases in fishing effort and decreases in CPUE that have been forcing a significant contraction of commercial longline fishing (SPC 2014b). The longline technique of fishing tends to harvest older fish that have already had a chance to reproduce, making longline fisheries less susceptible to overfishing than purse seine fisheries. However, fleets report significant declines in harvest and decline in CPUE. In fact, much of the Tongan national fleet sat anchored in 2010 and 2011 because CPUE had dropped too low for economic viability of un-subsidised fleets. This encouraged the Government of Tonga to re-allow foreign fishing vessels in Tongan waters.

The catch in 2013, 2,913 tonnes, was the largest on record, yet still much lower than the total allowable catch (TAC) specified in the Tongan Tuna Management Plan 2012–2015. The Tuna Management Plan lists a cap of 50 vessels and a TAC of 8,000 tonnes annually (including bycatch). Neither of these caps has ever been reached. However, the behaviour of fishing fleets indicates that fishing returns are not great enough to warrant harvests as high as the TAC. The TAC may be aspirational, rather than based on sound assessment of fish stocks (C. Reid, FFA, pers. comm. 2015).

The TAC is set at 8,000 tonnes for all target tuna and associated species in the longline fishery and does not distinguish among species. While albacore stocks remain relatively healthy, yellowfin stocks show signs of overfishing and bigeye stocks are becoming dangerously low (SPC 2014b). A TAC across all species does not sufficiently regulate fishing to protect at-risk species. Longline boats may target non-tuna species (e.g. sharks) simply by setting lines at different depths or locations. Since it is unlikely that boats will release live bigeye and other at-risk species back to the sea in good condition, limiting fishing effort is the only way to protect bycatch species. Improved hooks and other technology may allow fleets to be more selective (Pilling et al. 2013), but will require investment and enforcement.

In summary, the albacore fishery is likely to remain sustainable as long as returns-to-costs ratios remain low enough to limit fishing effort. Fishing subsidies distort natural market controls, which can lead to unsustainable harvests. Stocks of bigeye and yellowfin tuna and some shark and marlin species have been over-exploited and are at risk of collapse (SPC 2014b).

6.2.4.6 DISTRIBUTION

In 2015, both domestic and foreign fishing vessels are fishing for tuna in Tonga’s EEZ. The majority of the foreign fishing vessels are Taiwanese and Chinese boats. There is one Tongan tuna and deep-water demersal export company (Pacific Sunrise Tuna).

Tonga earns less benefit from the vessels that land 100% of their catch outside of Tonga, as the catch does not factor into Tonga exports, is not taxed, and does not employ Tongan fish processors. The only benefit Tonga receives from these vessels is from their licence fees. The catch from boats that land some of their catch in Tonga is mostly frozen tuna that is packed into containers and shipped by container ship. However, some portion of their catch is sold in local shops.

Locally-based foreign fishing vessels and local fishing vessels must unload 100% of their catch in Tonga. They mostly supply fresh tuna that is shipped by air to Japanese and US sashimi markets or sold locally. The local demand for tuna is strong and, as a result, sometimes more than 50% of the catch of these vessels are sold in the local market; the majority of local sales are of bycatch species.

Locally-based tuna fishing provides benefits to consumers because a significant number of the locally-based boats sell tuna and tuna bycatch within Tonga. Locally-based fleets provide some employment, and their catch supports a modest processing industry. There are no canneries or sophisticated processing facilities in Tonga, so Tonga does not capture much *value-added* benefit.

Much of the gross and *net value* of the tuna industry accrues to stakeholders outside of Tonga. A few Tongans are employed in the tuna industry and that number is increasing as locally-based vessels return to the industry. Government *revenue* from licence fees, part of the fishing costs subtracted to yield the *net value* estimates above, is a benefit to Tonga. Fish that is landed for export also benefits Tonga, as does any tuna sold locally.

6.2.5 DEEP-WATER DEMERSAL FISHERY

6.2.5.1 IDENTIFY

The deep-water demersal fishery is significant in Tonga due to the unique geography and proximity of deep-slope habitat. Bottom-feeding snapper, grouper and jobfish cluster near seamounts and banks in Tongan waters. These slow-growing fish are caught with bait on hook-and-line gear by boats less than 20 metres long. Tonga has the largest catches of deep-slope demersal fish among all Pacific Island countries (Gillett 2011). All boats are locally based and locally owned and operated. Since 2006, an average of about 60% of the annual deep-water demersal catch has been exported and the remaining 40% sold and consumed in Tonga.

6.2.5.2 QUANTIFY

The Tongan deep-water demersal fishery has progressed through a boom-and-bust cycle. The total annual catch fell each year through the late 1980s, only to grow again after fishing effort was reduced. The annual catch has stabilised near the average catch since 2005 of 165 tonnes per year (Figure 12). This is slightly below the estimated maximum economic yield. There are now fewer than 20 licensed deep-water demersal vessels, down from more than 40 in the 1980s (Figure 11). Vessels are also making fewer trips (Figure 12). The Fisheries Division now believes that fish stocks are stable, but the fleets lack the capacity to ensure the level of product quality required for a financially sustainable export market.

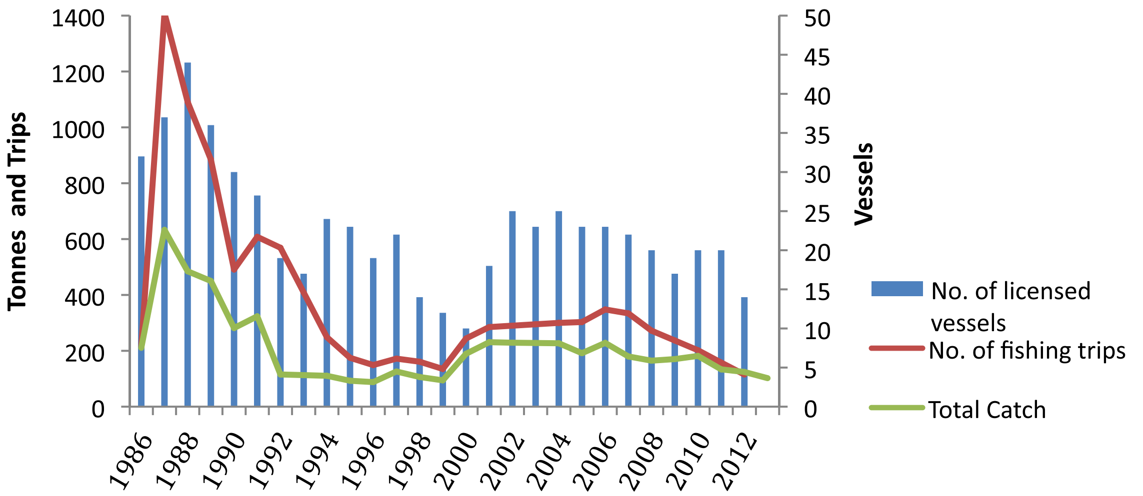

FIGURE 12 • Deep-water demersal catch, vessels and fishing trips 1986–2013

Source: Tonga Fisheries Division 2014a.

6.2.2.3 VALUE

An average of approximately 40% of the deep-water snapper catch is sold locally and 60% is exported to the USA (59 tonnes and 101 tonnes, respectively). The gross value of snapper exports has averaged T$ 461,000/yr (US$ 257,500/yr) since 2006, based on export data using FOB values. Those values were increased from T$ 3.00/kg to T$ 6.00/kg for most deep-slope species to more closely reflect the true market prices. Using T$ 6.00/kg FOB price now used for most deep-slope species, the estimated export value of the average exports (101 t) would be T$ 606,000/yr (US$ 338,200). The gross value of the deep-slope fish that are not exported (average 59 t/yr), based on the average domestic price of deep-water finfish at Tongatapu markets (T$ 9.00/kg, Tonga Fisheries Division 2014b) would be about T$ 534,000 (US$ 298,000). The average annual gross value of domestic and export deep-water demersal fish is thus T$ 1,140,000/yr (US$ 636,000/yr).

The Fisheries Division has not estimated costs for this fishery. Commercial fishing *value-added*/cost ratios range from 80% (Tonga Statistics Department 2013) to 20% (FFA 2014). Because deep-sea demersal fishing uses larger boats (up to 20 metres) that travel far offshore to fish, often for multiple days at a time, we assume fishing costs are closer to longline tuna fishing than they are to inshore artisanal fishing. Using a 20% *value-added* ratio, the *net value* of the deep-slope demersal fishery in Tonga would be approximately T$ 228,000/yr (US$ 127,000/yr).

6.2.5.3 UNCERTAINTY

Export prices (FOB prices) do not reflect current market prices of these fish products. Given global increases in fish prices, the gross value of exports is likely somewhat higher than calculated above.

There is much uncertainty about appropriate fishing costs or *value-added* ratios for this fishery. Fishing *value-added/* cost ratios range from 80% to 20%. The 20% *value-added* ratio used above is a conservative estimate, which may underestimate the true *economic value* of the fishery.

6.2.5.4 SUSTAINABILITY

Deep-water demersal species are generally slow-growing, long-lived fish that aggregate to spawn and must be relatively old and large before they can reproduce. Natural reproductive rates and mortality rates are low. These characteristics make them prone to overfishing. The Tonga Deepwater Fisheries Management Plan estimates that the MSY is about 200 tonnes/year from seamounts and 50 tonnes/year from shallower banks (Tonga Fisheries Division 2014a). The maximum economic yield (MEY), which would maximise *resource rent* (net *profits*), occurs at much lower levels of fishing effort than the MSY. Wilson (2007) and Langi and King (1994) both estimated that the MEY would occur at approximately 50% of the fishing effort used to reach MSY (i.e. half the number of boats).

The size of snapper fishing vessels has increased significantly since the fishery started in the 1980s (Gillett 2011), causing Tonga to consider boat size and gear limits. The 2014–2016 management plan, however, eschews gear restrictions for a TAC restriction, a more economically efficient way to ensure sustainability of the fishery. The TAC was set at 200 tonnes/yr. The MEY is likely closer to 125 tonnes/yr. Although recent catches (~165 tonnes/yr) should be sustainable, Tonga could increase economic yield at slightly lower catch rates because CPUE would be higher.

6.2.5.5 DISTRIBUTION

The benefits from deep-water demersal fishing accrue mainly to Tongan fishers and Tongan consumers. All deep-water demersal boats are Tongan-owned vessels. Tonga benefits economically from export *revenue* and Tongan consumers benefit from the availability of deep-slope fish at local markets. There is some benefit to the Government of Tonga, but fee *revenues* are very modest compared to tuna licences.

6.3 MINERALS AND AGGREGATE MINING

Sand and gravel aggregate used in concrete, roads and bricks can be mined from beaches and lagoons. Concentrated mineral deposits can be found on the deep seafloor. Both goods are generally considered non-renewable, but their extraction may offer significant income and tax *revenue* for Pacific Island countries. Since aggregate and sand are important construction materials and minerals are important to the production of luxury goods such as cell phones and flat screen televisions, these ecosystem services have substantial value to businesses and consumers. Mining, however, can also have significant *negative externalities*, un-priced costs or harms that accrue outside of the mining industry. For example, if sand mining on a beach induces saltwater intrusion that contaminates the groundwater supply to local villages, the loss of clean groundwater is a *negative externality* of beach mining. Coastal erosion and siltation of reefs are other potential externalities of aggregate mining, which suggests that mining may be mutually exclusive with other ecosystem services such as coastal protection or fishing.

6.3.1 SAND AND AGGREGATE MINING

6.3.1.1 IDENTIFY

Concrete and asphalt construction requires sand and aggregate. This material is either quarried from rock, or mined from land or sea. In Pacific Island countries, which have limited land and rock resources, sand and aggregate is often mined from beaches and lagoons and is often composed of dead coral. In some places (Tarawa, Kiribati for example) entire structures and sea walls are constructed from coral that has been broken into stackable bricks. Clearly this material provides an important service to island communities. Unfortunately, coral does not grow fast enough to be considered a renewable resource. Beach and coral mining destroys habitat for fish, crabs, turtles and other species. It can also leave coastal areas more vulnerable to erosion and sea-surge inundation and lead to saltwater intrusion into the groundwater.

Uses of sand and coral rubble in Tonga can be split into two main categories: commercial uses, such as for road and building construction; and household uses, mostly for funeral burials. There has been a ban on beach sand mining for construction purposes since 2004 (Taaniela Kula, Department of Natural Resources pers. comm., 2015). A private company used to collect sand offshore from Tongatapu using a floating dredge and sell it to the construction industry. The dredging machine failed in late 2013 and the company stopped operations. Since then, the Ports Authority has been providing sand and aggregate to the commercial market and the Department of Natural Resources has been providing sand to the household market[29]. The Department of Natural Resources oversees beach mining for provision of sand and coral rubble for funeral services. Beach sand mining is permitted for funeral purposes only. The primary source for beach sand is Halaika Beach at Lavengatonga in Tongatapu; a secondary source is Fanga-ko-fefe Beach at Fua'amotu, Tongatapu (Figure 13). Currently, a Natural Resources officer accompanies individuals to beaches to monitor the collection of sand and to collect a fee of T$ 34.50/tonne.

The Department of Natural Resources recognises that beach mining has negative consequences and has requested funding from the European Union to institute a dredging operation (such as has been implemented in Tarawa Lagoon in Kiribati).

Sand and aggregate from offshore dredging undertaken by the Ports Authority serves the demand for commercial construction and other purposes. Currently, the Ports Authority is the only approved entity to mine sand and aggregate from offshore.

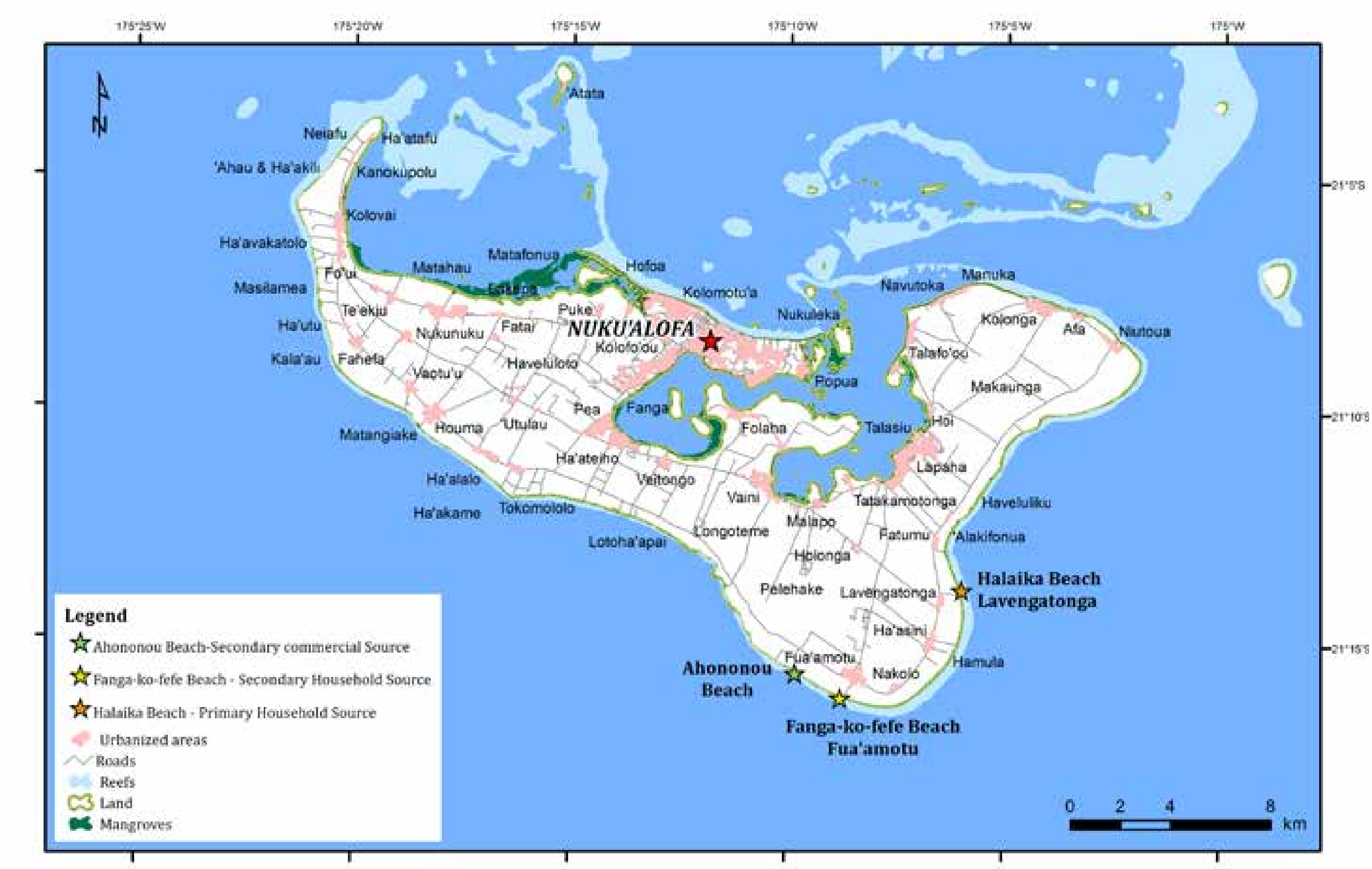

FIGURE 13 • Map of Tongatapu showing beach mining sites.
Source: Ministry of Lands, Environment, Climate Change and Natural Resources 2013.

29 The Natural Resources Division identified 'Ahononou' Beach as the secondary source for construction purposes.

6.3.1.2 QUANTIFY

Beach mining

In 2012–2013, The Geological Services Unit in the Department of Natural Resources recorded mining of 1,020 tonnes of sand and 5 tonnes of coral rubble for funeral purposes (Table 12).

TABLE 12 • Tonnes of sand and coral rubble extracted for household uses, 2013

Aggregate type	Amount	Source
Sand	1020 tonnes	Halaika Beach
Coral rubble	500 bags (each bag ~25 kg)	Halaika Beach

Source: Ministry of Lands, Environment, Climate Change and Natural Resources 2013

Offshore sand and aggregate mining

Offshore sand and aggregate mining to supply the construction industry extracts more sand than beach mining for household purposes. Table 13 shows the amount of sand sold by the Ports Authority 2010–2014. Average annual sales were approximately T$ 255,000 (US$ 142,000); average costs were approximately T$ 175,000 (US$ 98,000) for an average of 9,114 tonnes/yr.

TABLE 13 • Sand and aggregate dredged by the Ports Authority for commercial purposes (Nominal T$)

Ports Authority sand sales	FY2010	FY2011	FY2012	FY2013	FY2014
Sand sales	$ 254,390	$ 408,304	$ 328,068	$ 100,017	$ 184,848
Cost of sales	$ 220,298	$ 211,541	$ 229,772	$ 78,204	$ 130,946
Sand volume (cubic yards)	5,300	6,289	6,535	1,691	N/A
Sand volume (tonnes)	9,751.60	11,571.28	12,023.91	3,111.31	

Source: Ministry of Lands, Environment, Climate Change and Natural Resources 2013 and personal communication, Ministry of Lands and Natural Resources

6.3.1.3 VALUE

The Department of Natural Resources recorded 1,020 tonnes of sand removed from beaches for funerals in 2013. Of this, extractors paid for 754 tonnes at T$ 34.50/tonne, providing the government with T$ 26,000 in *gross revenue*. The department monitors activity and collects fees but the exact costs are unknown. If staff spent an estimated 10 hours per month on this activity at a pay rate of T$ 10 per hour, the cost to the division would be approximately T$ 1,200 per year in wages. Therefore, we estimate that the government earned T$ 25,000 in *net revenue* from beach mining in 2013. If fees were collected for all 1,020 tonnes of sand, the *net revenue* would be approximately T$ 34,000 (US$ 19,000).

The average *gross revenue* earned by the Ports Authority 2010–2014 was T$ 255,000 per year; the average costs for extracting sand were T$ 175,000/yr. *Net revenue* (benefit to the Ports Authority) has averaged T$ 80,000/yr (US$ 45,000).

Because of substantial information gaps, we cannot estimate the value of this ecosystem service. The *net revenue* estimates above simply reflect the benefits received by the Natural Resources Department and Ports Authority; they do not reflect societal benefits, which would require estimating the benefits to consumers of sand and aggregate in construction and funeral activities. Furthermore, to accurately estimate the true *economic value* of this ecosystem service, the negative externalities from beach mining and dredging should be subtracted from *net revenues*. This would require a very specific CBA involving collection of geological and socioeconomic data (in other words, a study of the environmental damage and the communities or households that would suffer the consequences of the damage).

6.3.1.4 UNCERTAINTY

The estimate of costs from collection of beach mining fees presented above is an approximation; the true costs may differ significantly. However, even 100% variance to costs would only marginally change the *net revenue* estimates. These estimates closely approximate the benefits of sand and aggregate mining to the Natural Resources Department and the Ports Authority. Of much greater significance is uncertainty around the negative externalities — the social and environmental costs from damages caused by beach mining — which render a true economic valuation impossible.

6.3.1.5 SUSTAINABILITY

Beach mining on small islands is an unsustainable activity. The removal of sand and aggregate material from beaches can increase rates of coastal erosion, induce saltwater intrusion into ground water aquifers, damage beach and associated ecosystems and leave adjacent areas more vulnerable to coastal flooding. Because of these negative consequences, small island nations should support dredge operations that source construction material from offshore areas, not within reef lagoons. These areas should be chosen carefully not to disturb important fishing areas or reproductive habitats of fish and invertebrates.

In sparsely inhabited areas small-scale beach mining could be economically sustainable, meaning that the benefits continue to outweigh the costs. Conversely, costs may quickly outpace benefits for larger mining operations or for frequent small-scale beach mining in more densely inhabited areas. Sustainability of beach mining must be evaluated on a case-by-case basis.

6.3.1.6 DISTRIBUTION

Benefits from sand and aggregate mining in Tonga accrue to three groups: the Natural Resources Division or Ports Authority (i.e. government); the individuals and businesses that use the materials in construction projects (producers); and the consumers who receive the benefits of the construction projects and who use sand and coral rubble in funeral practices. The *net revenue* estimates of beach sand and aggregate mining (total ~T$ 100,000–120,000/yr) represent benefits to government only.

6.3.2 DEEP-SEA MINERALS

6.3.2.1 IDENTIFY

There are three main types of deep-sea mineral (DSM) deposits: seafloor massive sulphides (SMS); cobalt-rich ferromanganese crusts; and manganese nodules. These deposits commonly contain iron, manganese, copper or zinc, and may also contain cobalt, nickel, silver and gold. Little is known about DSM reserves, costs of extraction and environmental externalities. There are very few deep-sea mining operations underway; most operations remain in the exploration phase. The only deep-sea mining occurring in the Pacific is in Papua New Guinea by Nautilus Minerals, a Canadian mining firm. Nautilus has produced extensive and detailed environmental impact statements and feasibility studies (Nautilus Cares 2015).

The absence of deep-sea mining operations suggests either that returns on such investments are low or that risks of investment are high. However, because some minerals have become increasingly scarce in recent years (copper for example), it is likely that interest in deep-sea mining will continue to grow. As with land-based mining, Pacific Island countries could stand to earn substantial royalties on these activities, and mineral extraction may offer significant benefits (SPC 2013).

The environmental impacts (negative externalities) of deep-sea mining are largely unknown. All types of deep-sea mining are likely to produce a debris plume which will disrupt species living at those depths. Benthic organisms (those that live on or near the sea floor) are likely to be disrupted and killed (SPC 2013). Mining of seamounts (for ferromanganese crusts) is likely to disrupt deep-water demersal species and potentially destroy suitable habitat for these slow-growing fish. Of great concern to Tonga may be the disruption of migrating whales. However, SMS deposits that occur at vents in the ocean floor may be renewable within a human timescale, creating the potential for sustainable seabed mining (SPC 2013).

The Kingdom of Tonga issues licences for companies to explore specified areas within Tongan waters for the presence of mineral resources and feasibility of extraction. Three foreign companies have been investigating areas for mining, one Korean, one Australian, and one Canadian. They must report their results to the Natural Resources Department when exploration activities are completed. The South Pacific Applied Geoscience Commission (SOPAC, now the Geoscience Division of the SPC) has produced a number of reports, studies and guidance documents in recent years about potential costs, benefits, and legal issues surrounding deep-sea mining. SOPAC has helped Tonga promote deep-sea mining, advise government policy, and build capacity for DSM resource management. Tonga has developed deep-sea mining legislation and is preparing a deep-sea mining policy to guide government decision-making (A. Palaki, pers. comm. 2015).

6.3.2.2 QUANTIFY

There are three exploration companies in Tonga with valid permits and licences to undertake exploration and prospecting for seabed minerals in Tonga territorial water: Nautilus Minerals Tonga; KoRDI Minerals Limited; and Blue Water Metals. The price of an exploration licence is T$ 3,000 per tenement. A tenement is the area for exploration. Within each tenement are blocks 10 minutes longitude by 10 minutes latitude on which companies must pay rent (T$ 6,500/yr). There are 34 exploration tenements in Tonga (Figure 14). In 2012, one company conducted explorations and undertook 12 dives in their licensed tenement. In 2013, a T$ 1.8 million withholding tax was paid up front to the Revenue Department as tax for any anticipated activities in the Kingdom's jurisdiction (Tonga Ministry of Lands, Environment, Climate Change and Natural Resources 2013). This is based on a percentage of the estimated budget of the DSM Project of Nautilus Minerals Tonga only.

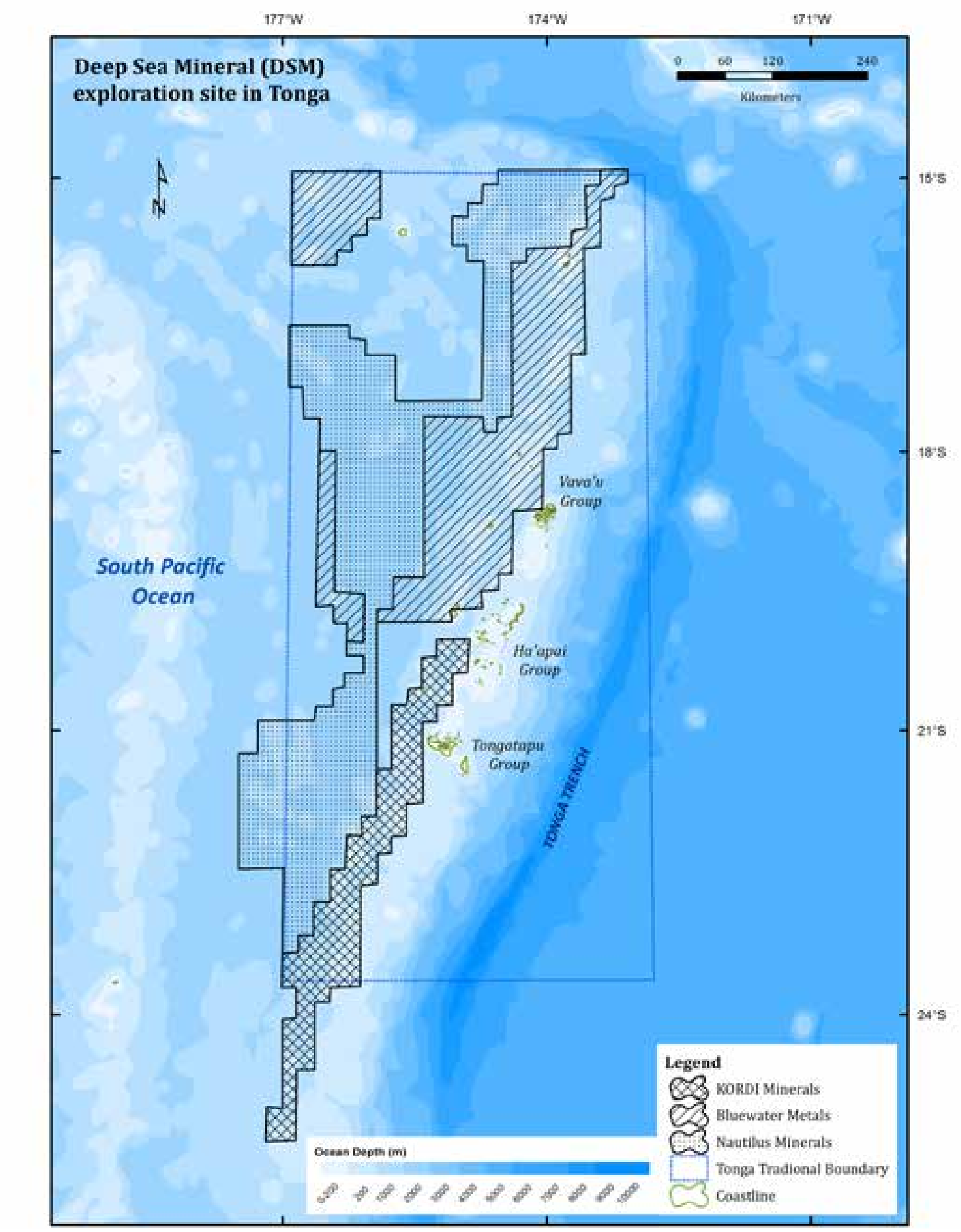

FIGURE 14 • Deep-sea mining tenements (2014).
Source: Ministry of Lands, Environment, Climate Change and Natural Resources 2013.

6.3.2.3 VALUE

It is currently only possible to estimate benefits to government from selling exploration licences and charging taxes. While this an important benefit, it is likely to represent only a fraction of the value of the resource. The majority of the benefits are likely to accrue to foreign mining companies and the foreign industries that use the minerals. However, the T$ 1.8 million withholding tax paid in 2013 represents an enormous benefit to the Government of Tonga. Since this was a one-time payment from one company, the costs to administer this tax were presumably quite minimal. The tenement and exploration licences are valued at much more than T$ 100,000/yr (T$ 3,000 per tenement licence x 34 tenements + T$ 6,500/block/yr rent).

The net benefit of deep-sea mining depends on the market prices of minerals extracted, the extraction costs, and the costs of externalities. Since the extraction costs and externalities are largely unknown, a true valuation of DSMs is not yet possible. Nautilus Minerals operations in Papua New Guinea may be the best reference for producer benefits, although it may be years before the benefit/cost ratio is understood.

6.3.2.4 UNCERTAINTY

The benefits of deep-sea mining remain unknown. The SPC has been evaluating the potential deep-sea mining in the Pacific in 2015. However, because so few deep-sea mining operations exist, the costs and benefits remain largely speculative. Because of this great uncertainty, countries are being advised to proceed with caution and avoid taking on significant financial risk investing in deep-sea mining enterprises. From an ecosystem services perspective, the risk lies in jeopardising other services, particularly deep-sea and pelagic fisheries.

6.3.2.5 SUSTAINABILITY

Mining is necessary for production of many of the products on which civil society and most business sectors depend. Although some SMS may regenerate quickly enough to be considered renewable resources, mining is generally a non-renewable extractive industry and therefore cannot be ecologically sustainable. However, if negative externalities are minimised, deep-sea mining may be economically sustainable and efficient, particularly if it can be shown to be less environmentally damaging than land-based mining. Of greatest concern for Tonga should be competition with commercial fishing ecosystem services and tourism (whale watching and diving) ecosystem services. For more information about deep-sea mining, see detailed reviews published by the SPC (e.g. SPC 2014a).

6.3.2.6 DISTRIBUTION

Since the mining operations are most likely 100% foreign-owned, most of the producer benefits (*profit*) will go to foreign companies and the consumers who benefit from lower cost metals and minerals. In the near term, most local benefits are likely to accrue to government in the form of licence fees, taxes, and royalties. These benefits may be redistributed to civil society by way of improved social programs, infrastructure or other public services. There are some potential employment opportunities for Tongans, but most employment will be for highly specialised, overseas-trained ocean miners.

6.4 TOURISM AND RECREATION

Marine and coastal ecosystems offer a variety of passive and active recreational activities that attract local and distant visitors. Recreational activities provided by the sea, reef, and beach include a wide range of pursuits including swimming, diving, snorkelling, charter fishing, fishing from the shore, recreational gleaning, kayaking, surfing, free-diving, beach activities and passive appreciation of beautiful coastal vistas. These activities can be collectively defined as marine and coastal tourism and recreation.

The participants in or consumers of marine and coastal tourism and recreation are diverse and can be from nearby communities, other parts of Tonga or from distant countries. Therefore, tourism and recreation can be further categorised into international tourism or domestic recreation and tourism. This distinction is made because much domestic recreation and tourism involves non-market activities, while international tourism is more closely linked to charged activities and associated expenditures. This has implications for which valuation methods are applicable in each case and the extent to which value estimates can be made within this valuation.

Tonga is in the migratory route for humpback whales, making whale watching a popular tourist attraction.

Opportunities for tourism are dependent on two things: the natural and cultural amenities that people find attractive; and the man-made amenities that support travel, accommodation and recreation. The extent to which tourism and recreation are ecosystem services depends on how much the consumers' activities depend on the natural ecosystem. Snorkelling, for example, is an activity that is almost entirely dependent on the state of the ecosystem. Individuals go snorkelling and appreciate snorkelling if there are healthy and interesting coral and fish to look at. The more interesting coral and fish there are to see, the more likely tourists will be attracted to go snorkelling. Other activities are only partially linked to the status of the ecosystem. For example, tourists sitting at a beachside bar may enjoy a view of an unpolluted beach, but they also want a quality drink and quality service. Furthermore, while they may be interested in the beach, they may be largely uninterested in what is going on beneath the water surface. The differences between activities complicate the calculation of tourism and recreation ecosystem services. In short, tourism demand is associated with the quantity and quality of environmental characteristics but is also influenced by infrastructure, distance, substitute activities, and other non-environmental factors (Adamowicz et al. 2011).

6.4.1 INTERNATIONAL TOURISM

6.4.1.1 IDENTIFY

People from around the world treasure the unique marine and coastal ecosystems of the South Pacific. White sand beaches, coconut trees, warm turquoise water, brightly-coloured live coral and exotic fish — many people from higher latitudes dream of experiencing these tropical island ecosystems and make significant expenditures to do so. Because of their small size, small population, and isolated locations, Pacific Island countries have very limited opportunities for generating export *revenue*. Natural beauty offers the opportunity to 'export' the service of tourism to foreigners. The annual Gross National Income (GNI) per capita of countries with well-developed tourism industries, such as Fiji and Vanuatu, is much higher (US$ 4,690 and US$ 4,300, respectively) than in countries with minimally developed tourism sectors, such as Kiribati and the Solomon Islands (US$ 3,870 and US$ 2,130) (World Bank 2012). Clearly this is not a rigorous economic analysis; nevertheless, the correlation between tourism development and GNI motivates analysis of the international tourism value of marine and coastal ecosystems.

Tonga is home to a wide variety of attractive natural areas, from dramatic cliffs and sea caves in 'Eua and Vava'u, to picture-perfect beaches and placid coral-filled lagoons among the tiny islands of Ha'apai. Additionally, great numbers of endangered humpback whales travel to Tongan waters to mate and give birth before returning to krill-rich Antarctic waters during summer. Tonga is one of only three places on earth where tourists can enter the ocean with humpback whales and watch them at close range gliding majestically through crystal clear water. Whale-watching, diving and snorkelling operators can earn significant returns from helping tourists see and appreciate Tonga's natural wonders. In short, Tonga's marine and coastal ecosystems provide real and measurable benefits to international tourists and tourism businesses.

Tonga's natural ecosystems, however, are only one part of the equation. Tourism requires marketing, infrastructure, accommodation, transportation and communication systems. Tonga has direct flights from Australia, New Zealand and Fiji, but there is no longer a direct flight to Los Angeles or Honolulu. Internet and phone communications in Tonga are improving rapidly and Tonga is making efforts to improve marketing materials. Improvements to infrastructure are also occurring, such as a new wharf that will accommodate larger cruise ships, but marketing, infrastructure, amenities and activities will all need to improve significantly if Tonga is going to compete for tourists with neighbours like Fiji and Tahiti. However, any investment in the tourism sector would be worthless without protection of the natural resources that draw tourists to these picturesque tropical islands.

6.4.1.2 QUANTIFY

Tonga has a moderately developed tourism industry. Relative to Fiji or Tahiti, the tourism industry in Tonga is small, with approximately 12,000 international tourists entering each year by plane, 2,000 by yacht, and 10,000 by cruise ship (~30,000 total). Although this is a small number of visitors (for comparison, Fiji receives more than 500,000 annually), it is significant relative to Tonga's small population (1 tourist per 3.5 Tongans) and it is growing. Many visitors to Tonga come to visit friends and relatives. This study disregards these visitors and their expenditure and focuses on leisure and holiday visitors only to conservatively estimate the contribution of marine and coastal ecosystems to tourism. Figure 15 shows a break-down of different visitor types arriving by plane. We presume all yacht and cruise visitors are holiday visitors.

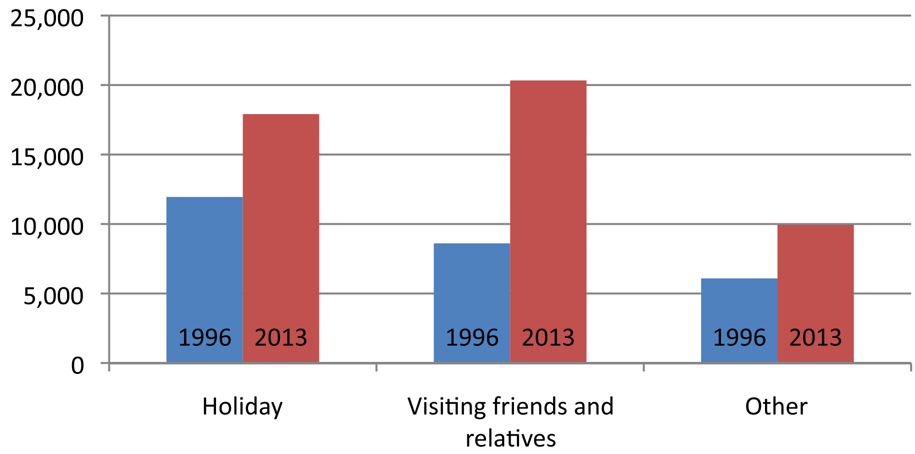

FIGURE 15 • Types of visitors arriving by air, 1996 versus 2013

Source: Tonga Tourism Statistics 2012–2013

According to the National Reserve Bank of Tonga, tourist receipts accounted for 7.7% of GDP in 2011–2012, more than twice the proportion contributed 2001–2002[30]. Aside from this broad measure derived from balance of payments statistics, the Tongan Ministry of Tourism has minimal data on *economic activity* from tourism. This is not surprising as it is notoriously difficult to differentiate tourist spending from household and business expenditures on retail and transportation services. Exit surveys estimate that the average expenditure per visit is about T$ 1,400 for air visitors, T$ 97 for cruise visitors, and T$ 1,000–2,000 for yacht visitors. Table 14 shows that estimated total expenditure of holiday visitors is nearly T$ 30 million per annum.

TABLE 14 • Estimates of holiday visitor expenditure by type of visitor

Mode of arrival	# of holiday visitors	Average expenditure (T$)	Total expenditure (T$)
Air	18,000	1,400	25,200,000
Cruise ship	10,000	97	970,000
Yacht	2,000	1,500	3,000,000
Total	30,000		**29,170,000**

Source: Tonga Tourism Statistics 2012–2013

The 2011 Census recorded approximately 1,300 individuals employed in tourism-related jobs, although many of these positions (such as bus drivers) provide services to the resident population as well. A broader definition of jobs that support tourism activities, such as all health care and food provision jobs, could push that employment statistic much higher[31]. The Ministry of Tourism and Commerce reports 388 businesses in Tonga support tourism. Of the total businesses, 30 are related to accommodation, 60 are related to food, and 68 are outdoor activity businesses (64 marine related). The remaining 230 include transportation services, health and massage, retail and local products.

Visitors who come to Tonga for holiday and leisure come largely because of Tonga's climate, coastal beauty, and uncrowded and relaxing atmosphere. In a 2012–2013 tourist exit survey conducted for the Ministry of Tourism and Commerce, 75% of holiday and leisure visitors noted that swimming and beaches were 'very influential' or their 'prime reason for visiting'. Similarly, 68% of visitors rated snorkelling as very influential or their prime reason for visiting, and

30 The World Travel and Tourism Council estimate that in 2013 travel and tourism directly contributed 5.6% of GDP and indirectly another 10% for a total contribution of 15.6% of GDP or US$ 127.4m (T$ 228.3m) (WTTC 2014).

31 The World Travel and Tourism Council estimates that travel and tourism in Tonga supported approximately 5,000 jobs in 2013 (WTTC 2014).

47% of visitors applied the same ratings for whale watching. The number of visitors who ranked whale watching as 'very influential' or their 'primary reason for visiting' rose to 60% during the whale-watching season (July–September). Other factors influencing tourist visitation to Tonga are shown in Table 15. It is evident that beaches, snorkelling, whale watching, and scuba diving attract many international tourists to Tonga (Table 15). Seven of the 13 factors that were strongly influential are directly related to marine and coastal ecosystems.

The whale-watching industry has exploded in the past ten years. The number of whale-watching operators, the number of visitors, the average number of trips per visitor and the cost per trip have all increased significantly in the past decade. In 2013, there were 14 licensed whale-watching operators in Tonga. A recent tourism study estimated that US$ 665,000 in direct expenditure was made during 2,400 patron-trips taken in Vava'u in 2009, resulting in over US$ 5 million in total *economic activity*, including all travel, food, and accommodation expenditures, tourism wages and expenditures by tourism-related businesses (Orams 2013).

Tongan seas are also good habitat for sharks. Tonga harvests and exports a significant number of sharks as food products, shark fins in particular. However, it has been shown that sharks could be much more valuable to tourism than they are as food products (Vianna et al. 2012). The shark diving industry in Fiji was estimated to generate US$ 4 million annually to local communities, mostly through salaries of employees of the dive industry (Vianna et al. 2011). In 2010, shark diving generated about US$ 17.5 million in taxes to the Fiji government. This is another case where ecosystem services are in competition. Killing sharks for food exports limits the potential *revenue* of a shark diving industry.

Tonga is trying to expand its tourism sector. The IMF and other development agencies recognise tourism as one of Tonga's few opportunities for generating export *revenue*. New Zealand Aid has dedicated NZ$ 4.5 million for three years from 2015 towards increasing the tourism industry's contribution to the economy via a flagship tourism support programme and is supporting upgrades to the runway and terminal on the island of Eua (NZAID 2014).

Many tourism providers are foreign nationals; some of the *profits* from tourism may be remitted or invested overseas. Therefore, domestic *economic activity* associated with tourism may be a more interesting measure for policy-makers than the *profit* of foreign-owned resorts. Domestic *economic activity* includes wages paid to staff and expenditures on local inputs. Both of these measures are useful ways to quantify tourism ecosystem services.

TABLE 15 • Factors influencing visitation to Tonga

Factors influencing visitation	% strongly influenced*
Swimming and beaches	**75.4**
Unspoilt and uncrowded	73.5
Quiet and relaxing atmosphere	73
Snorkelling	**67.8**
Whale watching	**46.9**
Local food and entertainment	42.4
Tongan culture and heritage	37.8
Adventure tourism	37.4
Nature – bush walks, bird watching, etc.	33.4
Scuba diving	**29.6**
Fishing	**20.5**
Yachting	**18.6**
Surfing	**14.8**

Source: Ministry of Commerce, Tourism and Labour 2013.
Factors related to coastal ecosystems in **bold.**
* Respondents who chose either (4) very influential or (5) prime reason for visit.

6.4.1.3 VALUE

The benefits from marine and coastal tourism accrue to tourism providers (producers) and tourists (consumers). The benefits of a tourism activity to producers (their *profit*) are the service providers' *revenue* from tourist expenditure, minus the costs of providing the service. The benefit that tourists receive is measured as the difference between what they would be willing to pay for activities, travel, and lodging, and what they actually paid[32]. It is difficult to estimate consumer (tourist) benefits without conducting a detailed survey. Although the benefits to tourists accrue to foreign individuals, they are significant and important benefits that are closely related to health and beauty of natural ecosystems. Unfortunately, they cannot be estimated within the scope of this study.

Recreational activities that involve marketed services, such as diving and charter fishing, can be quantified by measuring direct expenditure by tourists. Other activities, such as swimming, beach activities and appreciation of coastal views, can only be quantified by indirect expenditure (i.e. transportation or equipment costs, or the *opportunity costs* of time spent participating) or by a *willingness-to-pay* survey. Both direct and indirect tourism expenditures contribute to the value of the ecosystem service.

The gross value of tourism expenditures is estimated to be about T$ 29.2 million per annum (US$ 16.3 million). The difficulty in estimating the value of tourism as an ecosystem service, both to producers and consumers, lies in determining how much of the tourist expenditure is directly related to natural ecosystems. Reefs, beaches, ocean biodiversity and charismatic megafauna all contribute, to varying degrees, to the marketability of tourism activities. The degree of association between marine and coastal ecosystems and different tourist activities is the *ecosystem contribution factor*. The net producer value of the ecosystem services is calculated by multiplying the ECF by the difference between tourist expenditures and the tourism industry's costs.

For some tourist expenditures, such as snorkelling, it may be safe to assume the ECF of healthy reefs and clean waters is 100%, meaning that the ecosystem is the sole factor contributing to the tourists' decision to go snorkelling. For less direct uses, such as beachside accommodation, there needs to be an estimate of how much the environmental attributes contribute to the tourists' decisions and expenditures.

Approximately 30% of visitors surveyed responded that scuba diving either strongly influenced or was their primary reason for visiting Tonga. Assuming that scuba diving is 100% dependent on marine ecosystems (ECF = 1), 30% of tourism expenditure is a minimum estimate of the value of marine ecosystems. Similarly, 75% of visitors responded that swimming and beaches either strongly influenced or were their primary reason for visiting Tonga, therefore 75% of tourism expenditure is the maximum estimate of the value of marine and coastal ecosystems. This equates to a gross value of T$ 8.8 million to T$ 21.9 million (US$ 4.9 million to US$ 12.2 million). This gross value is distributed between the businesses' *intermediate costs*, taxes paid to government, and the businesses' *profits*. Cost ratios vary widely from business to business, and cost data for Tongan businesses are unavailable. *Value-added* ratios of 25% for Guam (Van Beukering et al. 2007b) and 40% for the Northern Mariana Islands (Van Beukering et al. 2006) have been used to estimate the net producer benefit of gross tourism *revenue*. We use the 25% *value-added* ratio as a minimum estimate of net producer benefits. Table 16 shows an estimate of the net *producer surplus* (*profit*) generated annually by marine and coastal ecosystems.

TABLE 16 • Gross tourism expenditure and net tourism benefit from marine/coastal ecosystems

Gross expenditure	Marine/coastal ecosystem contribution		Value-added	Net ecosystem benefit	
	Min	Max		Min	Max
T$ 29,170,000	30%	75%	25%	T$ 2,187,750	T$ 5,469,375
US$ 16,279,777				US$ 1,220,983	US$ 3,052,458

The Government of Tonga benefits from marine and coastal tourism through tax *revenue*. The consumption tax rate in Tonga is 15%. Tourists pay an additional 15% on most purchases, including restaurants and hotels. Working backwards from the total gross expenditure related to marine and coastal ecosystems (T$ 8.8–21.9 million), we estimate that the Government of Tonga should receive about T$ 1.31–3.28 million in *revenue* from this ecosystem service.

32 For example, if a tourist is willing to pay up to $ 200 for a two-tank dive, but the dive operator only charges $ 150, the tourist benefit is $ 50 ($ 200 – $ 150 = $ 50).

The *total economic value* of an ecosystem service is the sum of the producer, government, and consumer benefits. The producer and government benefits are estimated at T$ 3.5–8.8 million per year (US$ 2–4.9 million). The benefits that tourist visitors receive from marine and coastal ecosystems have not been quantified in this study. Estimating the consumer benefits would require a detailed survey of tourist preferences and behaviour. The estimates above should be regarded as minimum estimates of the value of this service.

6.4.1.4 UNCERTAINTY

Table 17 summarises the information available about international tourism in Tonga. There are a number of sources of uncertainty in each estimate. Each tourist site has different environmental attributes that influence producer earnings and tourist benefits, such as quantity of fish to see while snorkelling or the quality of water for swimming. Tourist benefits are also influenced by man-made amenities and proximity to transportation or other tourist sites. To determine the effect that environmental attributes alone has on tourism demand models must control for non-environmental factors and be able to rank environmental amenities (Adamowicz et al. 2011).

The greatest uncertainty in the estimates comes from the *ecosystem contribution factor* and the *value-added* ratio. By providing a range for the ECF (30–70%) we can be fairly certain that the true value lies within these minimum and maximum estimates. The *value-added* ratio (25%) is based on previously published work and is not specific to Tonga. Some businesses may earn *profits* closer to 60% or 70% of *gross revenue*; others may have *profits* even lower than 25%. We use 25% as a conservative lower-bound estimate.

As with most of the ecosystem services in this study, we presume that the estimates of producer and government benefit underestimate the total social benefit of the ecosystem service because they do not include the consumer benefits. Producer and government benefits, however, may be most relevant because they accrue in Tonga, whereas consumer benefits accrue to foreigners. Lastly, there are some costs associated with collecting consumption tax which have not been subtracted, so the tax *revenue* benefits are slight overestimates.

TABLE 17 • Summary of tourism statistics

Statistic	Data			Author/source
Holiday visitors	Air		18,000	Tonga Tourism Statistics Report 2012–2013
	Cruise ship		10,000	
	Yacht		2,000	
Businesses	Total tourism-related		388	Ministry of Commerce, Tourism and Labour 2014
	Accommodation		30	
	Food and dining		60	
	Marine activities		64	
	Other related		230	
Employment	1,319–5,000			2011 Census 'Tourism Characteristic Industries' World Travel and Tourism Council 2014
Visitor expenditures		Per visit	Total	Tonga Tourism Statistics Report 2012–2013 Departure surveys (2012–2013) Cruise and yacht surveys (2011)
	Air	T$ 1,383	T$ 25m	
	Cruise ship	T$ 97	T$ 1m	
	Yacht	T$ 1,000–2,000	T$ 3m	
	Total		T$ 29m (US$ 16.3m)	
Visitor participation in different activities	Unknown			None
Relationship between expenditure and ecosystems (ECF)	Minimum: 30% Maximum: 75%			Visitor exit survey (2011) Tonga Tourism and Statistics Report 2012–2013
Tourism industry costs (*Value-added* ratio)	25%			Van Beukering et al. 2007b (Guam)
Producer net benefit	T$ 2.2 million–5.5 million (US$ 1.2 million–3.1 million)			This study
Government *revenue*	T$ 1.31 million – T$ 3.28 million (US$.75 million – US$ 1.8 million)			This study

6.4.1.5 SUSTAINABILITY

If managed responsibly, tourism can be a lucrative and sustainable ecosystem service. Because tourists generally seek out healthy ecosystems, tourism can create an incentive to protect and even rehabilitate marine ecosystems. If tourists are educated properly, the direct impacts to ecosystems from snorkelling, diving, swimming and beach walking may be minimal. However, tourism can also increase demand for energy, infrastructure and imported goods, and generate harmful waste. Fulfilling these demands can lead to degradation of the ecosystems the tourists were originally attracted to.

Compared to other Pacific Island countries, tourism in Tonga might be considered an under-exploited ecosystem service. However, there is some indication that the whale-watching industry in Vava'u is nearing capacity. The industry currently sends out as many boats as can be filled; there is no restriction to the number of vessels or individuals per day, yet there are a finite number of whales to be seen. Tongan regulations allow only one whale-watching boat at a time to approach a group of whales and only four persons plus a guide are allowed to enter the water at a time, but these rules are not strictly enforced. There have been recent calls for control of the manner in which boats and swimmers approach whales to ensure sustainability of the whale-watching industry (Kessler et al. 2013). Close approaches by boat and loud, splashing approaches by swimmers seem to disrupt whales and may alter their behaviour.

Humpback whales are well protected from whaling in most of their habitat and populations are increasing. If appropriate whale-swim methods are enforced, this ecosystem service could remain lucrative indefinitely.

6.4.1.6 DISTRIBUTION

The benefits of tourism are split among government (tax *revenue*), business owners, employees, and the tourists themselves. Producer *profit* (local businesses) and government *revenue* are benefits received within Tonga. Some tourism businesses are foreign-owned, some of their *profits* will be re-invested in Tonga and some will be leaked to expatriates' home countries. Employment, although a cost to tourism businesses, is a benefit to Tongans. International tourism *revenue* is cash flowing into Tonga from overseas. Like exports, international tourism generates positive foreign exchange.

6.4.2 DOMESTIC RECREATION AND TOURISM

6.4.2.1 IDENTIFY

When domestic tourists participate in market-based activities, such as joining commercial dive trips, staying in hotels and eating in restaurants, the domestic recreation and tourism ecosystem service is much the same as international tourism. However, tourism or recreation activities that do not involve fees or direct costs also have *economic value*, although different methods must be used to quantify and value these activities. Just like international tourism, domestic recreation and tourism depends on two things: the availability and quality of natural areas; and infrastructure and service investments, such as transportation systems, beach and boat access areas, and businesses that facilitate use and appreciation of natural areas. Although Tongan residents may participate in different activities and hold different values from international tourists, some of their leisure and recreation, such as swimming or reef-walking, is dependent on marine and coastal ecosystems. Even activities as simple as watching the tide come in use a marine ecosystem service.

While fisheries ecosystem services are rival (meaning the more one individual benefits from the ecosystem service, the less others may benefit), recreation is generally a public good. Public goods are non-rival activities for which one individual's benefit does not impinge on another's benefit. This means that although per capita benefits may be small in magnitude, the total benefit to all of Tonga could be quite large.

6.4.2.2 QUANTIFY

The magnitude of this ecosystem service can be measured by quantifying and ranking the preferences of Tongans for different natural areas. The simplest set of data would be the numbers of individuals participating in marine and coastal based activities such as swimming, snorkelling, surfing, kayaking, recreational fishing, wildlife viewing or picnicking on the beach. A more descriptive data set could include details about how and when individuals participate in these activities, what kinds of associated expenditures are made to participate, and what individuals would be willing to pay or trade, including time, to enjoy these activities. To the best of our knowledge, no such studies or surveys of domestic recreation and tourism have been conducted. This is a significant data gap and prohibits the valuation of domestic recreation and tourism.

Some studies of the value of domestic recreation have been conducted in other Pacific Island countries. The *contingent valuation* method was used to estimate *willingness-to-pay* a hypothetical entrance fee to Palolo Deep Marine Reserve in Samoa. Using Palolo Deep Marine Reserve as a proxy, Samoa's marine recreational services were estimated to have a non-market value of US$ 1,123,941 per year for international visitors and US$ 652,783 for domestic visitors (Mohd-Shahwahid 2001).

6.4.2.3 VALUE

An estimation of consumer benefits from non-market recreation activities by local residents would require the use of *stated preference survey methods*, which is beyond the scope of this project. Costs associated with domestic recreation and tourism include public infrastructure development, minor transportation costs for those participating, and externalities such as solid waste pollution from human visitation. In order to know the true *economic value* of domestic recreation and tourism these costs would need subtracted from the total consumer benefit or *willingness-to-pay*.

6.4.2.4 UNCERTAINTY

Although we know that domestic recreation and tourism related to marine and coastal ecosystems has value to Tongans, there is insufficient data to estimate an economic value. The value of domestic recreation and tourism should be further evaluated and included in marine and coastal resource management and planning.

6.4.2.5 SUSTAINABILITY

As a non-rival public good, domestic recreation and tourism is a sustainable ecosystem service. The one caveat is the potential pollution and disruption caused by visitors to marine and coastal areas. Recreation and tourism can be conducted without these impacts, but investments in measures such as public awareness campaigns and waste removal systems may be required to assure sustainability.

6.4.2.6 DISTRIBUTION

Most of the benefits from domestic recreation and tourism accrue to Tongan civil society. Some associated expenditures may create benefits to import industries or foreign-owned businesses, but most of the benefits go to the individuals participating in marine and coastal recreation and leisure activities. These activities may generate broader benefits to society by supporting the health and happiness of individuals, and they may generate support for government infrastructure investment and nature conservation.

6.5 COASTAL PROTECTION

This section on coastal protection was summarised from Pascal (2015), a report exploring the coastal protection ecosystem service in all five MACBIO countries and prepared for the MACBIO project. For more details on the methods or results, refer to Pascal (2015).

6.5.1 IDENTIFY

Coastal protection is a concept that includes different roles that ecosystems can play in protecting coastal areas. The two main roles identified and described here are:

- Prevention of erosion, sediment provision and/or accretion
- Mitigation of storm surges.

These two different forms of coastal protection differ in their impacts. The first provides long-term protection against the wearing away of land and removal and deposition of sediments (erosion, accretion). The second offers short-term protection against coastal floods and storm surges. The short-term protection happens episodically, and the damage avoided is clearly identifiable (damaged buildings, roads, crops), while the effects of long-term protection are more diffuse over time.

6.5.1.1 EROSION PREVENTION AND SEDIMENT PROVISION

Coastal ecosystems in Tonga play an important role in stabilisation of shorelines. The increase of human density along coasts and the resultant increasing pressures on coastal ecosystems leads to a paradox: an increased need to stabilise shorelines, but a decline in natural stabilising processes.

The role of mangroves in coastal stabilisation is well known (Marchand et al. 2011; Lovelock et al. 2012). Sediment processes protect coastal soil from erosion, and in some cases permit reinforcement of shoreline materials. In the same way, seagrasses form extensive meadows in the coastal areas they colonise. Their roots and rhizomes fix the material in which they grow and their leaves slow currents, thus enhancing the stability of their sedimentary substrates. This action dissipates wave energy (up to 40% of erosive energy when seagrasses are dense; Barbier et al. 2011) and also increases the rate of sedimentation (Pearson 2001). As such, seagrass beds effectively contribute to protection against waves and limit coastal erosion.

In addition, reefs are known to contribute to beach formation, even though the processes involved are not yet well described (Pérez-Maqueo et al. 2007). Beach formation occurs with accumulation of sediments from various origins (marine or alluvial), a phenomenon known as sedimentation. Coastlines near coral reefs receive sediments from this ecosystem in the form of small dead coral particles. Accumulation on the coastline of those sediments is the source of beach formation. Sedimentary accretion also maintains and nourishes beaches, in opposition to natural or anthropogenic erosion (Huang et al. 2007).

The scope of this study was to identify all ecosystem services at a national scale and, where possible, quantify and value those with readily available data. Many authors agree that assessment of erosion prevention and sediment provision is a data-demanding exercise and requires a fine resolution of analysis (Lugo-Fernandez et al. 1998; Penning-Rowsell et al. 2003; Van Der Meulen et al. 2004). For example, on a 1 km scale, neighbouring beaches can experience both erosion and sand accretion depending on geomorphological and biological factors (Brander et al. 2004). Although it has not been possible to precisely quantify the ecosystem service of protection against erosion, three major aspects have been identified for Tonga:

1. stabilisation of shorelines, critical in high human density sites (e.g. Nuku'alofa)
2. beach formation and stabilisation, important in tourist areas
3. atoll formation and stabilisation, very important for atoll islands.

In Tonga, reefs may play a major role in the formation and stabilisation of beaches (Fua'amotu, Liku'alofa, Ha'atafu), which are important assets for local tourism. Mangroves may contribute to stabilisation of beach sands in isolated areas.

The role of coral reefs in erosion protection (sedimentation and accretion) is less well understood than the role of mangroves. Although some natural processes involved in erosion protection are well described, it is still difficult to quantify precisely and estimate the *economic value* of such processes.

Storm surge mitigation

This study focuses mainly on the value of storm surge mitigation by coral reefs, which is one of the most important aspects of coastal protection provided by marine ecosystems (Laurans et al. 2013). As a point of reference, average annual direct loss caused by flooding associated with tropical cyclones in 15 South Pacific countries was calculated to be up to US$ 80 million (2009 prices), with 60% of the damage resulting from loss of residential buildings, 30% from loss of cash crops and 10% from damage to infrastructure (PCRAFI 2011).

Storm systems such as tropical cyclones and mid-latitude storms and their associated cold fronts are the primary causes of storm surges[33]. Storm surges can interact with other ocean processes such as tides and waves to further increase coastal sea levels and flooding, and have maximum impact when they coincide with high tide. Breaking waves at the coast can also produce an increase in coastal sea levels, known as wave setup. Storm surges occurring at higher mean sea levels enable damaging waves to penetrate further inland, which increases flooding, erosion and damage to built infrastructure and natural ecosystems. The effect of rising mean sea levels due to climate change will be felt most profoundly during tsunamis or extreme storm conditions (CSIRO and Australian Bureau of Meteorology 2007)[34].

33 A storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide.

34 A tsunami differs from a wind-generated wave in that the former is much larger and its energy is distributed throughout the water column. The impact of bathymetry in wave attenuation is even more important in tsunamis due to this vertically continuous distribution of energy throughout the column water rather than the surface distribution of storm surge waves.

Coastal bathymetry (shape and depth of sea or ocean floor) and the presence of bays and headlands and the proximity of other islands also affect the height of storm surges. Wide and gently sloping continental shelves amplify storm surges, while bays and channels can funnel and increase the height of storm surges.

Coral reefs, seagrass and mangroves provide protection against waves by forming barriers along the coastline. As a result, lagoons, which are protected by barrier reefs, are relatively calm areas that provide multiple ecosystem services (e.g. biomass production, scenic beauty). Several studies have shown that reefs act in a similar manner to breakwaters or shallow coasts(Lugo-Fernandez et al. 1998; Brander et al. 2004; Kench and Brander 2009). They impose strong constraints on the swell of the ocean, resulting in transformations of wave characteristics and a rapid attenuation of wave energy.

Waves formed by the wind store a large part of their energy at the surface, and this force can be absorbed by fringing reefs and reef crests, sometimes up to 90% at low tide (Lugo-Fernandez et al. 1998). The degree of energy absorption is highly variable and depends on the type of reef, the depth and the waves (Kench and Brander 2009). The role of coral reefs and mangroves in coastal protection is difficult to isolate from other variables and, in fact, a combination of factors impact on the level of protection provided. The primary factors influencing attenuation of wave energy are:

1. bathymetry (shape and depth of sea or ocean floor)
2. geomorphology (soil origin and composition)
3. topography (coastal and inland surface shape, as well as shoreline indentations) and,
4. the biological cover (presence of other ecosystems in the coastal area) (Burke 2004).

Few studies have focused on isolating the specific role of coral reefs within this combination of factors (Badola and Hussain 2005). In addition to the complexity of quantifying the specific contribution of coral reefs to coastal protection, an analysis by Barbier et al. (2008) found that the relationship between reef area and absorption of wave emerge was nonlinear. Similar nonlinear effects have been measured for the effect of mangroves on wave height. Waves of 1.1 m in the sea are reduced to 0.91 m in the mangrove forest if the forest has an extension of 100 m. The wave continues to decline, at a slower rate, for each additional 100 m of mangroves extension inland. For a forest extending 1000 m inland, the waves would be reduced to a negligible 0.12 m[35] (Barbier et al. 2008).

6.5.2 QUANTIFY

Coastal protection index

Two methods can be used to assess the role of coral reefs[36] in coastal protection: methods based on biological properties of reefs, and methods based on physical and mechanical properties of the reefs. Due to the large quantity of information required for the biological method, and the requirement of small study areas, we chose to use a physical and mechanical model for our evaluation. One of the main limitations of such models is that we were not able to assess the true relationship between coral mortality and its role in loss of coastal protection service.

The model used for this study scores coastal stability based on seven physical characteristics (Table 18). These physical characteristics were given a score between 1 and 5 and the average was calculated to produce a unique index value for each segment of shoreline: the coastal protection index.

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35 In addition, some studies have shown that the extent of reefs or mangrove may not be the main factor influencing the reduction of damage on the coast from tsunamis (Done et al. 1996; Greer Consulting Services 2007; Pérez-Maqueo et al. 2007).

36 Three major ecosystems contribute to coastal protection: coral reefs, mangroves and seagrasses. Nonetheless methodologies to assess ***economic impacts*** of mangroves and seagrass in terms of coastal protection are not yet consolidated (Huang et al. 2007; Pérez-Maqueo et al. 2007; IFRECOR 2011; Pascal 2014), the specific role of those ecosystems is not monetised in the present study; they are only used in the coastal protection index as one of the main factors contributing to coastal protection.

TABLE 18 • Calculation of the coastal protection index based on characteristics of the coastline

Factor	Score				
	Very strong	Strong	Medium	Low	Null
	5	4	3	2	1
Geomorphology	Rocky shore	Mix of rocks/ sediments/ mangroves	Mangroves	Sediments	Beaches
Coastal exposure	Protected bay	Semi-protected bays	Artificial reefs	Low protected bay or coast	No protection
Reef morphology, area and distance to coastal physical structure	Continuous barrier (> 80%) close to the coast (<1 km)	Continuous barrier (> 50%), patch reef, close to the reef	Fringing reef (width > 100 m)	Coral formation discontinuous	No reef
Inner slope, crest width	Very favourable conditions (gentle slope, large crest width)	Favourable conditions (slope, large crest width)	Favourable conditions (at least one condition: slope, crest width)	Reduced favourable conditions (strong slope, reduced crest width)	None
Platform slope	6–10%	2.5–6%	1.1–2.5%	0.4–1.1%	< 0.4%
Mean depth (< 1 km from the shoreline)	< 2 m	< 5 m	> 5 m	< 10 m	< 30 m
Other ecosystems	Mangroves and seagrasses > 75% coastline	Mangroves and seagrasses > 50% coastline	Mangroves and seagrasses > 25% coastline	Mangroves and seagrasses < 25% coastline	None

Two main GIS databases were used for data related to reefs (i.e. type of reefs, area and distance to the coast) PCRAFI and Reefbase data.

The value of coastal protection as an ecosystem service is quantified for Tongatapu only, due to the lack of data for the other islands. The island was divided into four specific segment areas with relatively more homogeneous morphology of the reefs and exposure to waves.

The four segments are (see Figure 16):

- shoreline from Ha'atafu beach to the capital, Nuku'alofa (north-west coast)
- shoreline from Nuku'alofa to Finehika beach (north-east coast)
- shoreline from Finehika beach to Fua'amotu beach (south coast)
- shoreline from Fua'amotu beach to Ha'atafu beach (south coast)

Coastal protection produces a value of T$ 12.9 – 21.5 (US$ 6.5 – 10.9m) million annually.

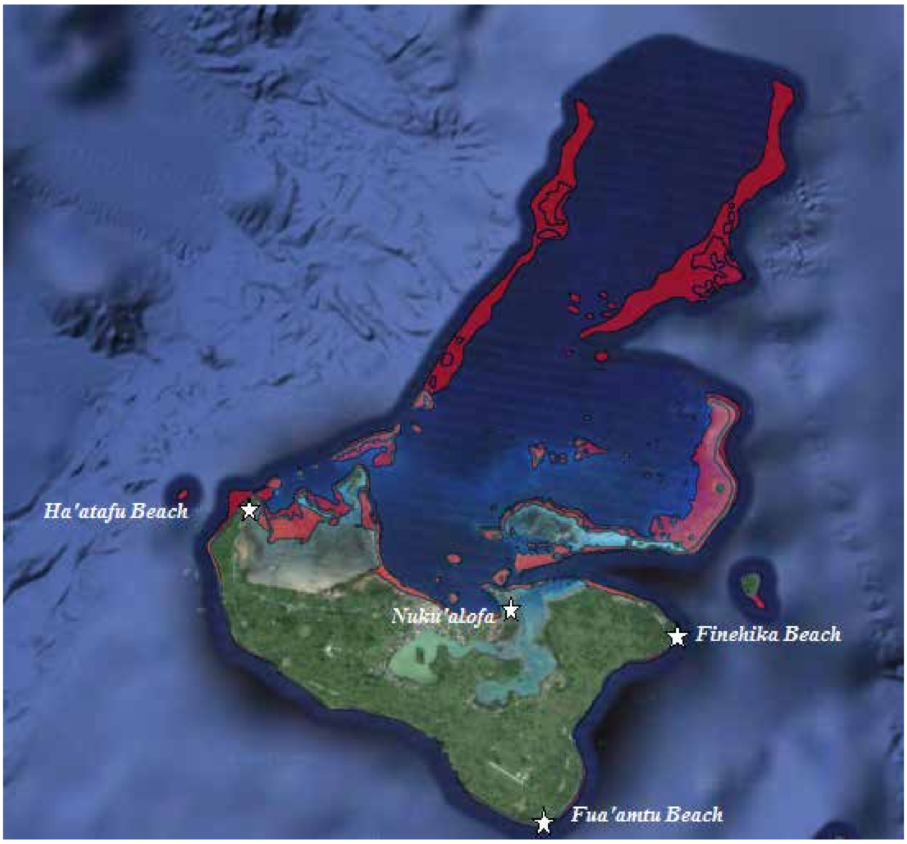

FIGURE 16 • Coral reefs in Tongatapu

Source: PCRAFI 2011; Google Earth 2012

Geomorphology: The north coast of the island is a mix of elements of sedimentary origin, soil, beaches and urban areas. The score for geomorphology for the northern segments is low (2). In the south, some cliffs are present along the shoreline. The score for geomorphology for the two southern segments is very strong (5).

Coastal exposure: The north-west of the island is partially protected by a small bay, while Nukualofa is protected by a big bay. Scores for coastal exposure are strong (4) for the first segment and very strong (5) for the second segment.

In the south, there is no remarkable shoreline organisation that can protect coastal assets. However, the third segment is a little less exposed (low, 2) than the fourth segment (null, 1).

Reef morphology, area and distance to the coast: The fringing reef is more developed in the north than in the south. The southern shoreline is characterised by a very thin coastal fringing reef, while there are several coral formations with a lagoon in the north. Scores for reef morphology, area and distance to the coast are medium (3) for the two north segments and low (2) for the south segments.

Inner slope, crest width: The crest is relatively narrow (10–25 m), while the inner slope is medium or absent. In every study area, the score for this factor is medium (3).

Platform slope: The deep ocean is near the shoreline of the island, so the platform presents a steep slope. However, the reef flat on the north shore is not well developed, so the slope is less important on that side of the island. Scores for this factor are strong (4) in the south and medium (3) in the north.

Main depth (1 km from the shoreline): The deep ocean is near the shoreline, so the main depth is greater than 30 metres less than 1 km from the coast. The reef flat is little developed in the north of the island, so the average depth on that side of the island is less important than for the south shore. Scores for this factor are null (1) in the two southern study areas, and low (2) in the north.

Other ecosystems: Mangroves are present in Tonga, but they are not well developed. Official data with the precise location of mangroves along the shoreline could not be obtained and so a 'best guess' was made of an average abundance of mangroves. On average, the score for other ecosystems is low (2) in Tonga.

The coastal protection index is summarised in Table 19.

TABLE 19 • Coastal protection index for the four coastal sectors of Tongatapu

	Sector			
Factor	**Ha'aNuku**	**NukuFine**	**FineFua**	**FuaHa'a**
Geomorphology	2	2	5	5
Coastal exposure	4	5	2	1
Reef morphology, area and distance to the coast	3	3	2	2
Inner slope, crest width	3	3	3	3
Platform slope	3	3	4	4
Main depth (1 km from the coast)	2	2	1	1
Other ecosystems	2	2	2	2
Average	**3**	**3**	**3**	**3**

MAIN NOTABLE ASSETS AT RISK

We assessed the number, type and location of residential buildings and hotels at risk from coastal flooding and tsunamis. No robust information related to other construction works, such as public buildings and infrastructure (e.g. roads, bridges and airports) was available. Agricultural crops were also not included in the study, due to the absence of intensive crop production in the areas at risk. Data on indirect tangible damage (e.g. loss of tourism *revenue*, emergency costs, traffic disruption) were also unavailable.

Main cities: there is only one major city on Tongatapu, Nuku'alofa, where around 40% of the population of Tonga lives. The second largest city of Tongatapu is Mu'a (the ancient capital), located in the bay of the north-east coast.

Tourism: four of seven hotels on the island are located in Nuku'alofa. The others are situated on the principal beaches of Fua'amtu, Liku'alofa and Ha'atafu. Tongatapu also has 24 bed-and-breakfasts.

6.5.3 VALUE

The method used to value the service of protection against storm damage by coral reefs is the avoided damage cost method. First the assets protected are identified and quantified. Then, the *ecosystem contribution factor* of coral reefs and associated systems is applied. Finally, the ecosystem service is valued in terms of the cost of damage avoided due to the presence of coral reefs. One of the main challenges is that coastal protection against waves is complex, incorporating many factors such as geomorphology of the coast and the presence of other ecosystems. The identification of the contributing role of each of the different factors is a challenging task and is outside of the scope of this study. For more details on methods, see Pascal (2015).

Similar methodologies used to value this ecosystem service have been tested on Caribbean (Burke et al. 2008) and New Caledonian reefs (Pascal 2010).

Total avoided damage and annual avoided damage to human assets are presented for the island of Tongatapu in Table 20. The results for each sector separately are presented in Appendix III: Additional data and methods.

Coastal protection provided by coral reefs for hotels is a major service in Nuku'alofa and on the most famous beaches of the island (Table 20). In addition, the location of hotels near beaches leads to another issue of coastal protection: protection against erosion. Indeed, coral reefs can play a role in the processes of erosion regulation, preventing shoreline recession. However, this specific service is not valued here.

TABLE 20 • Residential and commercial avoided damage costs* due to the presence of coral reefs, Tonga consolidated results

	Number		Unit	Currency	Total value of avoided damages		Annual value of avoided damages	
	min	*max*			*min*	*max*	*min*	*max*
Houses	1,721	2,869	houses	US$	13,898,823	23,164,705	6,297,904	10,496,507
				T$	24,878,893	41,464,822	11,273,248	18,788,748
Luxury hotels	6,300	10,500	m²	US$	501,731	836,218	227,347	378,911
				T$	898,098	1,496,830	406,951	678,251
Total				US$	14,400,554	24,000,923	6,525,251	10,875,418
				T$	25,776,992	42,961,652	11,680,199	19,466,998

*Relative coastal protection index: 0.24; 100-year extreme climatic event probability of 0.45

6.5.4 UNCERTAINTY

This approach is exploratory. It aims to produce an overview of the quantification and valuation of coastal protection provided by coral reefs against flooding caused by storm surges. Many uncertainties are present in every step of the approach. The main uncertainties are: the choice of damage functions (flood damage percentage), definition of zones at risk, the data used for GIS analysis, the database of assets and valuations of construction costs. For details see Pascal (2015).

Our approach to defining zones at risk partly consists of counting assets at risk from satellite images, which is likely to lead to underestimates. The damage costs of flooding are therefore likely to be higher.

A standard construction cost was used across the five MACBIO countries, regardless of the type of structure and materials. Even if this cost reflects an average construction price per square metre, it is possible that it under- or overestimates the total repair cost of assets at risk.

The flood damage percentage used in the analysis came from estimates made by the US Federal Emergency Management Agency for houses in California. Houses in Tonga may suffer higher rates of damage since they are generally of lower construction quality. Again, this suggests that actual damage costs may be higher than estimated.

Minimum and maximum values are presented in Table 20 to reflect these uncertainties. The minimum value was calculated multiplying the estimated total number of houses by a factor of 0.75, while the maximum value was calculated by multiplying the total number of houses by a factor of 1.25.

This analysis provides an overview of the role of coral reefs in the coastal protection of some built assets (residences and hotels) at risk of extreme climatic events. Many additional parameters must be taken into account to better understand the link between coastal habitats and coastal protection. The role of seagrasses, live coral cover and processes involved in erosion regulation, and impacts on other built infrastructure and crops also need to be explored to fully value this ecosystem service.

The values in Table 20 can be compared to other coastal protection analyses that have been conducted in the Pacific. The *replacement cost method* was used to estimate the value of coastal protection in Samoa at US$ 5,193,970. This estimate reflects the assumption that mangrove forests protect 25.7 km of coastline and that typical seawall construction costs US$ 202–404 per linear metre (Mohd-Shahwahid 2001).

Coastal protection benefits were estimated at two sites in Vanuatu in 2013. In Crab Bay, mangrove coastal protection was valued at US$ 94.64 per hectare, and in Eratap it was valued at US$ 3,486 per hectare. These figures reflect real estate values and use of the avoided costs method. The difference in values for Crab Bay and Eratap is most likely due to the locales' different real estate uses; there are two resorts in Eratap, while Crab Bay is mostly surrounded by crops (Pascal and Bulu 2013).

6.5.5 SUSTAINABILITY

Reef, mangrove and seagrass ecosystems provide consistent coastal protection benefits indefinitely, as long as the ecosystems remain intact. Damage to reefs and mangroves from coastal development is an ongoing threat (Burke et al. 2008). The magnitude of the services could be increased in some instances by restoring blighted or damaged reefs, mangroves and seagrasses.

Climate change, in particular acidification of oceans and warmer water temperatures, could impact reefs and mangroves and threaten the sustainability of this ecosystem service. Climate change may also increase the intensity and severity of storms, increasing the importance of coastal protection services but also increasing the expected damage. Cyclone Pam demonstrated in Vanuatu that the most severe storms will cause catastrophic flooding and erosion. It is difficult to estimate how much damage would have occurred in Vanuatu if it were not for the presence of living reef and mangrove ecosystems.

6.5.6 DISTRIBUTION

The benefits of coastal protection accrue to anyone who owns or uses property along coastal areas. The beneficiaries may be nationals, expatriate residents or visitors. Protection of public infrastructure, such as wharfs, marinas and roads, benefits everyone who uses that infrastructure and could decrease the country's tax burden through avoided repair costs.

6.6 CARBON SEQUESTRATION

6.6.1 IDENTIFY

Carbon dioxide (CO_2) in the atmosphere causes a greenhouse effect that is results in changes to the global climate, sea temperatures, and sea levels which may have deleterious effects on Pacific Island countries. In addition, CO_2 in the atmosphere is absorbed by seawater resulting in lower sea pH levels and reduced availability of carbonate ions for marine animals that make calcium carbonate shells and skeletons (e.g. shellfish and corals). This process is termed ocean acidification.

Mangroves, wetlands, seagrasses and phytoplankton remove CO_2 from the atmosphere and store it in their fibres, in the soil and in the ocean substrate (Howard et al. 2014). This ecosystem service is called carbon sequestration, and refers to carbon that is removed from the atmosphere and/or prevented from release into the atmosphere.

The natural growth processes of seagrass, mangroves, plankton and other plants absorb carbon from the air. Some carbon is released back into the atmosphere during cell respiration, some is added to the plant's biomass, and some is deposited into the soil or ocean substrate. Carbon stored in the biomass of mature plants is relatively constant, but can be released into the atmosphere if the plants are killed and decay or burn. Carbon stored near the soil surface may be released over time if left un-vegetated, or released quickly if disturbed (Murray et al. 2011). Both the rate at which carbon is added to biomass and substrate, and the potential release of stored carbon are important. Together they represent the net CO_2 removed from the atmosphere and prevented from release into the atmosphere.

The amount of carbon that is captured and removed from the atmosphere by different plant species can be quantified in terms of a net rate of sequestration. The net amount of carbon sequestered by an ecosystem in a given time period is the sum of the rate of sequestration of each species and the release of stored carbon (Howard et al. 2014).

The magnitude of this ecosystem service is directly related to the prevalence of the ecosystems that sequester and store carbon. There are three main categories of organisms that sequester carbon in tropical Pacific marine and coastal environments: mangrove, seagrass and sea algae[37]. These are common in Tonga because the intertidal zones and coastal wetlands have very anaerobic soils (lacking oxygen), carbon-rich organic material decomposes very slowly. This means that wetland and seabed ecosystems store carbon well. Studies have shown that intact, growing mangroves and coastal wetlands sequester more carbon each year than even tropical rainforest (Murray et al. 2011). The destruction of these ecosystems stops the sequestration process and may release the stored carbon into the atmosphere if plants and trees are burned or decomposed and if the soil is exposed to oxygen.

Figure 17 shows the relative amounts of carbon that are typically stored in different ecosystems. Oceanic (coastal) mangroves are capable of storing more carbon than any other ecosystem.

37 Salt marshes also sequester and store carbon, but are uncommon in the Pacific. Coral reef may sequester carbon under certain circumstances, but reefs are generally a net emitter of carbon dioxide (Ware et al. 1991)

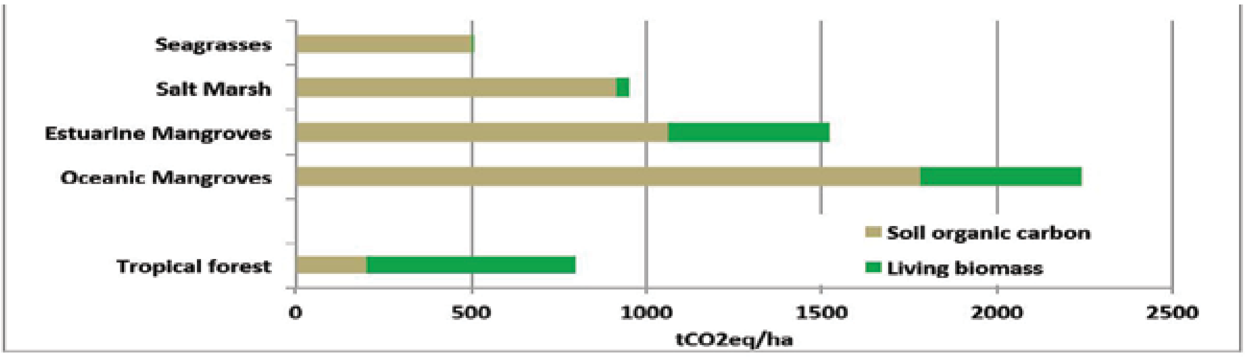

FIGURE 17 • Carbon storage abilities of different habitats

Source: Murray et al. 2011

Ocean phytoplankton consumes CO_2 and sequesters substantial amounts of carbon in the world's oceans (Reibesell 2004). Because the amount of marine phytoplankton, carbon sequestering properties of phytoplankton, and the influence humans have on phytoplankton are all very difficult to quantify[38] the carbon sequestering service of phytoplankton is not considered in this study. This study focuses on the carbon sequestration benefits of seagrasses and mangroves in Tonga.

6.6.2 QUANTIFY

The MESCAL project recently evaluated mangrove stocks in Tongatapu and Vava'u. There are 1,450 ha of mangroves in Tongatapu and 381 ha in Vava'u[39] (Yarita and Aholahi 2012; VEPA 2012). Experts believe that mangroves in these two island groups represent at least 85% of all mangroves in Tonga (T. Lepa, Dept. of Environment, pers. comm. 2014). It can be conservatively assumed that there is a total of 2,000 ha of mangroves in Tonga, including small areas in Ha'apai, the Niua islands and Eua.

There are four dominant mangrove taxa in Tonga: *Bruguiera gymnorhiza, Rhizophora* species*, Excoecaria agallocha* and *Lumnitzera littorea*. The average above- and below-ground biomass carbon was estimated for each vegetation type as part of the MESCAL project (Table 21). Biomass carbon (12 g/mol) can be converted to CO_2 (44 g/mol) by multiplying biomass carbon by 3.67 (Duke 2013).

TABLE 21 • Carbon storage by mangrove species in Tonga

Dominant taxon	Biomass carbon (t/ha)		Total CO_2 equivalent (t/ha)
	Above-ground	Below-ground	
Brugueira gymnorhiza	62.7	100.3	598
Rhizophora spp.	19.5	27.2	171
Excoecaria agallocha	64.1	80.5	530
Lumnitzera littorea	51.3	60.3	409

Source: Duke 2013

Rhizophora species were the most common dominant vegetation type in MESCAL test plots in Tongatapu (12 of 25 plots). The weighted average of CO_2 equivalent stored in mangrove biomass using the frequency of dominant vegetation types was 352 tCO_2/ha. This aligns with estimates from the Blue Carbon Initiative[40] of 237–563 tCO_2/ha for different types of mangroves around the world.

38 Research on the sequestration and storage process of phytoplankton is ongoing, and trials are being conducted to attempt to increase the rate of sequestration (Reibesell 2004; Riebesell et al. 2007).

39 MESCAL estimates were made by direct observation, video and photography. Note that these estimates of mangrove cover are significantly higher than those found in global GIS datasets (2000 ha vs. 1255 ha).

40 The Blue Carbon Initiative is a global program, such as the Global Distribution of Mangroves USGS (2011) or World Atlas of Mangroves (2010), working to mitigate climate change through the restoration and sustainable use of coastal and marine ecosystems. See www.thebluecarboninitiative.org

Unfortunately, soil carbon and carbon sequestration rates were not calculated by MESCAL. The Blue Carbon Initiative has summarised global coastal carbon data. The average sequestration rate for oceanic mangroves is 6.3 tCO_2/ha/yr; the amount of carbon stored in the top metre of soil beneath mangroves is typically between 1,000 and 2,000 tCO_2/ha (Murray et al. 2011; Sifleet et al. 2011). Using this information and the carbon storage quantities determined by the MESCAL project, the total carbon stores for Tongan mangroves are estimated at 1,237–2,563 t/ha, depending on the dominant mangrove species and the commensurate amount of biomass stored in the soil.

If mangroves are destroyed, the total carbon dioxide at risk of release depends on what happens to the mangrove biomass and carbon stored in the soil. If mangrove wood is used to build houses and furniture, much of the carbon remains in the wood structures; if mangrove wood is burned, most carbon is released into the atmosphere as CO_2. The fate of carbon in the soil when mangroves are destroyed is also important. We have limited our analysis to the top metre of soil, assuming carbon stored deeper than that will remain in the soil indefinitely. The greatest release of biomass and soil carbon would be in the first few years after destruction of mangroves, gradually decreasing over time. Eventually, all biomass carbon and most soil carbon may be released into the atmosphere. Because we do not know the future uses of land after mangrove destruction (e.g. agriculture or commercial development), we estimate the carbon released over 15 years following land-use conversion.

Following the estimates of Murray et al. 2011, we assume 75% of biomass carbon is released in the first year and the remaining 25% is released at a 15 year half-life. We assume that carbon in the top metre of soil is released at a 7.5 year half-life (i.e. 50% of the stored carbon is released in the first 7.5 years, 25% in the following 7.5 years, etc.) (Murray et al. 2011). This means that in the first 15 years, 87.5% of biomass carbon and 75% of soil carbon would be released into the atmosphere, which equates to 207.4–492.6 tCO_2/ha from biomass and 750–1,500 tCO_2/ha from the soil for oceanic mangroves in Tonga. The foregone average carbon sequestration rate (6.3 tCO_2/ha/yr) is added to these annual release estimates to produce the following range of carbon lost from mangrove areas over 15 years (Table 22).

TABLE 22 • Estimated carbon emissions from destruction of mangroves by carbon source

Source	Tonnes CO_2 per hectare over 15 years	
	Min	Max
Biomass	207.4	492.6
Soil	750.0	1,500.0
Foregone sequestration	94.5	94.5
15 year total	1,051.9	2,087.1

Globally there is much less data on the carbon sequestration and storage capacity of seagrasses. Tonga has very little data on seagrasses, aside from a study of the condition of seagrass beds in Fanga'uta Lagoon. The Blue Carbon Initiative estimates average sequestration rate of seagrasses to be approximately 4.4 tCO_2/ha/yr; somewhere between 0.4 and 18.3 tCO_2/ha are stored in biomass and approximately 500 tCO_2/ha in seagrass soils (Sifleet et al. 2011)[41]. Seagrasses are present in Tonga's lagoon areas, particularly in the large Fanga'uta Lagoon at Tongatapu Island. Unfortunately, the area of seagrasses in Tonga has not been determined, so they cannot be included in the valuation of the ecosystem service of carbon sequestration.

6.6.3 VALUE

There are two distinct approaches to valuing human benefits that result from carbon sequestration. The first approach is measuring the marketability of carbon offsets, that is, selling assurance that a carbon sequestering ecosystem will be protected from destruction and thereby reducing the amount of CO_2 in the atmosphere. This is termed the *market value* of carbon sequestration. The second approach is to measure the avoided *social cost of carbon.* The *social cost of carbon* (SCC) is the probable harm from additional CO_2 in the atmosphere. In other words, the SCC is the expected impacts of

41 Seagrasses vary considerably by species and location. In some areas sequestration rates are near zero or even negative (respiration > sequestration). Carbon dioxide stored in seagrass soils ranges from 66 to 1,467 tCO_2/ha.

climate change. SCC is measured as the monetary value of damage caused globally by emitting one more tonne of CO_2 in a given year (Pearce 2003). The SCC therefore also represents the value of damage avoided for a small reduction in emissions, in other words, the benefit of a CO_2 reduction[42] (US EPA 2013).

Market value, where it is realised, is an immediate and localised benefit that may accrue to those individuals who can protect an ecosystem from destruction, verify the carbon sequestration properties of that ecosystem, and sell the verified amount of carbon offset to willing buyers. The avoided SCC is a global value; it is a benefit that accrues to all who may suffer the consequences of climate change. The SCC more accurately represents the true benefits of carbon sequestration but may be less interesting to stewards of carbon sequestering ecosystems who potentially stand to gain monetarily from selling carbon offsets. When estimating the carbon offset value it is important to consider additionality, that is, how much of the carbon sequestering ecosystem would have been destroyed in the absence of the offset payment being made. Only areas that have been destroyed and can be rehabilitated or areas that are likely to be destroyed can be considered additional. In other words, it is not possible to sell a carbon offset for an area that is unlikely to be destroyed, because there would be no carbon 'saved' from the atmosphere.

Carbon sequestered by mangroves and seagrass represents a reduction in atmospheric CO_2. The estimated SCC used by the US EPA and other US agencies for appraisal of emissions reductions in 2015 is US$ 61, *discounting* future damages annually at 2.5%. Using this benefit estimate, the sequestration rates above, and the total estimated area of mangroves in Tonga, the annual social benefit of sequestration from mangroves in Tonga is T$ 1.4m/yr or T$ 688/ha (US$ 768,600/yr or US$ 384/ha).

An alternative value per tonne of CO_2 that is commonly used in the appraisal of the value of carbon sequestration is the potential value of carbon offsets sold in a carbon market. The carbon market prices can be used in financial assessments of conservation or restoration projects to reflect potential *revenues* for the project. The potential value of carbon offsets is directly related to the area of mangroves and/or seagrass that can be protected from destruction or rehabilitated. In 2000–2005 the average annual loss of mangroves in the Oceania region was 0.39%/yr. In Tonga this would mean a loss of about 7.8 hectares each year. Using the carbon release ranges in Table 22 and the current average market price of $ 4.90/t CO_2 (Forest Trends 2014), Tonga has the potential to sell US$ 40,000–80,000 in offsets each year, or T$ 72,000–143,000. That is US$ 5,150–10,227 per hectare of mangroves protected (Table 23).

TABLE 23 • Potential value of carbon offsets at a market price of $ 4.90/tCO_2

Value of potential carbon offsets (US$)		
	Minimum	**Maximum**
Per hectare	5,154	10,227
Total (7.8 ha/yr)	40,203	79,770

There are significant costs associated with protecting, verifying and marketing carbon offsets before they can be realised; these costs have not been estimated in this analysis. These costs would need to be subtracted from the potential value of the offsets to determine the *net value* to communities or agencies protecting mangroves.

6.6.4 UNCERTAINTY

The SCC is intended to be a comprehensive estimate of climate change damage but due to current limitations in integrated assessment models and data used to estimate SCC, the measure may not include all important damage and is likely to underestimate the full damage from CO_2 emissions.

The carbon offset value estimates in Table 23 are similar to those found elsewhere in the Pacific. In Vanuatu, carbon sequestration by mangroves was valued at US$ 6,985 per hectare in Crab Bay and at US$ 7,334 per hectare in Eratap using an estimate of volumes of carbon dioxide in the soil and applying the market price of carbon offsets (Pascal and Bulu 2013).

42 This is an average value, not a true ***marginal value***. As CO_2 levels increase, each additional unit may be more harmful than the last.

The uncertainty in the value of potential carbon offsets is high. Results are very sensitive to assumptions about carbon released from the soil, as this makes up most of the total carbon at risk for release. Additionally, the most common dominant vegetation type discovered in MESCAL test plots was *Rhizophora* species. *Rhizophora* spp. generally store less carbon in biomass than other species common in Tonga. Therefore protection or rehabilitation of other species (particularly *Bruguiera gymnorhiza*) would increase CO_2 savings and increase the carbon offset value.

Results are also sensitive to assumptions about the area of mangroves at risk of destruction. The average rate of mangrove loss in the Pacific (0.39%/yr) may not be representative of Tonga.

Lastly, the carbon offset value is based on a market price for carbon dioxide. Because this is an entirely voluntary market (such as the market for pearls or other non-essentials), the price is driven by marketing rather than true resource scarcity. With appropriate marketing, such as assurance of the protection of biodiversity, bird and fish reproduction, or other mangrove attributes, mangrove patrons could sell mangrove protection offsets at a much higher price than the current average CO_2 market price. If offsets could be sold at US$ 10/tCO_2, the value could be as high as US$ 21,000 per hectare or more than US$ 163,000 per year (see Appendix III: Additional data and methods).

6.6.5 SUSTAINABILITY

Carbon sequestration is an indefinite service. Protected mangroves and seagrasses continue to sequester carbon into the soil each year, and that carbon, unless disturbed, will remain there forever. Furthermore, mangroves and seagrasses provide habitat for young fish and invertebrates, thereby contributing to other ecosystem services.

6.6.6 DISTRIBUTION

Atmospheric carbon causing climate change is a global concern. There is no specific consumer and producer benefit, just global benefit. The benefits of selling carbon offsets would accrue to the resource stewards, presumably local communities. There is also a consumer benefit to those who purchase carbon offsets, which is related to their *willingness-to-pay* for verification that carbon is being stored in natural sinks rather than released into the atmosphere.

6.7 RESEARCH, MANAGEMENT AND EDUCATION

6.7.1 IDENTIFY

Although recognition of the value of biodiversity has grown significantly in the past two decades (most notably by the creation of the United Nations CBD), biodiversity remains extremely difficult to quantify and value at the national scale. One method to quantify the value of biodiversity is to evaluate the amount of public funds that are redistributed to help protect biodiverse areas. The unique biodiversity found in marine and coastal environments in the Pacific attracts investment in research and conservation from around the world. Furthermore, these biodiverse ecosystems offer education opportunities to students of all ages, and investment from schools and universities. This interest in studying and protecting biodiversity attracts grants, scholarships and aid which benefit Pacific Island countries.

Domestic and international government expenditures represent a redistribution of resources, not a true *economic benefit*, but foreign aid from wealthier countries, international organisations, non-governmental organisations and private donors contributes significantly to the economies of most Pacific Island countries. For example, MACBIO is funded by German tax *revenue*. The taxation may represent a cost or a benefit to German tax payers depending on whether or not they want to pay for biodiversity conservation in the Pacific. For MACBIO countries, this redistribution is a benefit, although it should be noted that some of the expenditure goes to the salaries of foreign nationals working in the Pacific.

6.7.2 QUANTIFY

Donor cash and in-kind contributions to government activities is expected to total T$ 248.38m (US$ 138.6m) in 2014–15, compared to T$ 235.3m (US$ 131.3m) in government *revenue* from taxation and other levies. Table 24 shows nine sectors of public expenditure and the origin of those funds. Tonga expects to receive about T$ 37m for 'cultural awareness and environmental sustainability', but the 2014–15 budget statement does not have sufficient detail to determine the amount of grant, scholarship and aid that is attracted specifically by marine and coastal biodiversity.

TABLE 24 • Kingdom of Tonga Government Budget Sectors, 2014 Pa'anga (T$ million)

Outcome objectives	Government (Local and budget support)	Projects			Total budget
		Donor cash	Donor in-kind	Total donor	
Strong inclusive communities	7.70	2.80	4.82	7.62	15.32
Dynamic public and private sector partnership	99.20	6.25	3.40	9.65	108.85
Appropriate, well planned and maintained infrastructure	9.80	35.00	114.21	149.20	159.00
Sound education standards	34.00	7.63	6.78	14.41	48.41
Appropriately skilled workforce	5.00	0.42	0.02	0.44	5.44
Improved health of the people	26.20	5.10	3.74	8.83	35.03
Cultural awareness, environmental sustainability	4.8	3.69	33.37	37.06	41.86
Better governance	23.10	3.62	5.98	9.65	32.71
Safe, secure and stable society	25.50	2.89	8.67	11.56	37.06
Grand total	235.30	67.40	180.99	248.38	483.70

Source: Tonga Ministry of Finance and National Planning 2014

Government budget statements for Environment, Climate Change and Fisheries Divisions are shown in Table 25. The total aid to these divisions for the 2014–15 budget is T$ 10.8 million (US$ 6 million), broken down into T$ 340,000 for the Environment Division, T$ 536,928 for the Fisheries Division, and T$ 9.9 million for the Climate Change Division. Presumably most of the fisheries aid is dedicated to marine ecosystems. It is unclear how much of the environment and climate change funds are directed towards marine and coastal and ecosystems. We assume that the total gross value of aid monies directed towards marine and coastal ecosystems is at least T$ 536,928 (US$ 300,000).

TABLE 25 • Funds by government division, government revenue and aid

Government Budget Division	Government	Donor	Total
Environment	$ 406,620	$ 340,000	$ 746,620
Climate Change	$ 146,069	$ 9,922,343	$ 10,068,412
Fisheries	$ 1,748,821	$ 536,928	$ 2,285,749
Totals	**T$ 2,301,510**	**T$ 10,799,271**	**T$ 13,100,781**

Source: Ministry of Finance and National Planning 2014

6.7.3 VALUE

There are costs associated with attracting and spending international aid that should be subtracted from the *gross revenue* to determine the true social benefit of these monies. To our knowledge, these costs have not been estimated. Because it is unknown how much of the Environment and Climate Change budget is dedicated to marine and coastal ecosystems, we assume that only Fisheries donor funds represent international investment in marine and coastal research, management and education. We estimate that the value of research, management and education of marine and coastal ecosystems in Tonga is at least T$ 540,000 (US$ 300,000). The gross value is likely much higher than this, although administration costs should be subtracted to determine the true net social benefit.

6.7.4 UNCERTAINTY

We presume that the estimate of the value of research, management and education of marine and coastal ecosystems (T$ 540,000) is a considerable underestimate because at least some of the environment and climate change funding is directed towards coastal and marine ecosystems. Additionally, funds directed towards other departments (e.g. the Maritime Department in the Ministry of Infrastructure, the Tourism Department and more) may also include aspects of enhancing sustainable use of marine resources. Furthermore, government aid monies are just one stream of research and education funds. Many such funds may not come through the government budget. Researchers arriving from foreign institutions, for example, may bring benefits to Tonga through their personal expenditure or employment of research assistants. These benefits are not included in the government budget *revenues*, but they are presumed to be relatively small.

6.7.5 SUSTAINABILITY

Research, education and management can include both direct and indirect use activities. They cannot be categorically labelled sustainable, but by and large activities related to biodiversity research, education and management are targeted towards scientific inquiry or sustainable resource management and have positive impacts. Furthermore, research and education funds may depend on the presence of healthy ecosystems, therefore creating an incentive for sustainable management.

6.7.6 DISTRIBUTION

A persistent criticism of international aid is that a large proportion of the benefits return to citizens of the donor countries or other wealthy countries in the form of salaries paid to international consultants and project managers. While the number of aid dollars and in-kind assistance are quite large, it should be noted that not all of this aid is direct benefit to Tonga.

6.8 CULTURAL AND LIFESTYLE VALUES

Cultural values refer to the "non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience" (MEA 2005). This could include cultural heritage, traditional education, spiritual, religious or moral values, or the value of a sense of place. A cultural connection to the ocean is fundamental to the people of Tonga. A range of traditions bind people to marine and coastal areas. For generations, Tongans have used marine resources in various ways including as traditional local food, money, traditional dancing costumes, gifts for the king and chiefs, traditional fishing methods, myths and legends, traditional songs, building materials, mangroves for making dye and traditional marine resource management systems. Some cultural and traditional benefits of marine and coastal resources have already been discussed, such as the use of coral rubble and sand to build sea walls, houses and graves. The cultural value of marine areas to Tongans is difficult to quantify, often because it does not involve direct or indirect monetary transactions. However, when individuals invest time and sacrifice other activities to practice or maintain cultural practices or traditions, they are demonstrating the *economic value* of culture. These types of non-market benefits can only be quantified and monetised using sophisticated *choice modelling* or *contingent valuation economic valuation* techniques, which were beyond the scope of this valuation. Below are descriptions of different practices and traditions involving marine areas that may have *economic value* to Tongan citizens.

Traditional dancing costumes, wedding and birthday attire: Tongan people use different shells from the ocean for making traditional dancing costumes. For example, the people of Talafo'ou village use pearl for their traditional dancing costumes for *lakalaka* (standing dancing) when they perform to the king and chiefs or other important occasions. The young single ladies used to decorate their dancing costumes with beautiful shells from the ocean. They also used to decorate bride and groom wedding and birthday attire, especially the mats (*ta'ovala*) that are worn around the waist and string (*kafa*), with different shells. Tongans use coral stones to bleach their Tongan mats (*lokeha* or *falavala*) for wedding, birthday and other important traditional occasions. They put the coral stones in their earth oven until they become *lahe* (white ashes), which is used to dye the mats white. "Those mats look beautiful and fine when they bleach with sea and coral stones" (A. Fonua, pers. comm., 2015).

Traditional fishing, weaving and meeting tools: The Tongan people have traditional fishing methods for catching different fishes and invertebrates, for example, *hi ‘atu* for catching *‘atu* (albacore), *no’o anga* for sharks, *moe kaloa’a* for shellfish, *finaki* (crabs and fishes). This traditional knowledge has value when used today or passed on to younger generations. Traditional fishing tools were made from marine items, including *maka feke* (fishing tools for catching octopus) and shells for fishing hooks. Shells were used as a weaving tool by old women and conch shells were used like a trumpet for calling village meetings in the old days (A. Fonua, pers. comm., 2015).

Gifts for king, chiefs and tourists: The Tongan people used to make necklaces, bracelets and other traditional handicrafts from corals, pearl oysters, tortoise-shell, and whale tooth (*lei*) from the ocean. These products are of high cultural value to the people of Tonga. They also used the items as presents to the king, chiefs and tourists (A. Fonua, pers. comm., 2015). The royal burial tombs (ancient *langi*) of the Tu’i Tonga Dynasty at Lapaha is a historical site made with big rocks from the ocean (Ma’u Matapule pers. comm., 2015). The fishers sometimes gave the best of their catches to the King of Tonga and the chief of their own village for food and sometimes to show their appreciation for work that the chief or king had done for the fishing families.

Myths, legends and songs: There are different myths and legends about different fishes and invertebrates in Tonga including sharks in ‘Eueiki Island, mullets in Folaha village, tilapia in Nomuka and Niuafo’ou Islands, sea snakes in Niuatoputapu Island, and more. Beach names and historical site names were adopted from different myths and legends. These sandy beaches and historical sites are part of Tongan cultural heritage. The different stories for different fishes, invertebrates and beaches reveal history and values to the people of Tonga. Therefore, the people from islands and villages where the stories originated try to conserve them for their cultural value. Some important fishes, invertebrates and beaches have their own traditional songs that demonstrate their history and the importance of their place of heritage (S. Latu pers. comm., 2015).

Money: The Tongan people used shells like money as a means for exchange in the past. They exchanged the shells they got from the ocean including pearl and other beautiful shells from the beach for fishes and shellfish. They also used shells to exchange for other traditional goods they needed such as crops, tapa cloth and mats (T. Taufa, pers. comm., 2015).

Making dye, firewood and traditional medicine: Tonga has always had cultural and historical affinities with mangrove ecosystems. Long before the introduction of modern technology and the industrial revolution, mangroves were part of Tongan life culturally and historically. For example, the bark of mangroves is squeezed and boiled to make dyes of different colours for drawing designs on the tapa cloth. *Lekileki* — *Xylocarpus moluccensis* (Lamarck) — is a mangroves species which has almost become extinct (Ellison 2000), especially in areas of Tongatapu. This mangrove species is culturally unique for Tongans as its bark is used for medicine as a treatment for internal bleeding, injuries, etc. However, this species is subject to destruction for firewood, similar to *Lumnitzera lottorea* (*hangale*). The bark of two other mangrove species, *Tongo Lei* (*Rhizophira mangle*) and *Tonga Ta’ane* (*Brugueira gymnorrhiza*) is harvested by local people for making tapa cloth (*ngatu*) but more recently, a replacement product for these mangrove species’ bark has proven very effective. *Lekileki* and *hanagle* species are endangered to critically endangered, while the other two indicated species are endangered (Ellison 2000).

Governance and resource management: Cultural practices also appear in community-based marine management. MPAs and SMAs demonstrate the importance of local governance structures and the four core Tongan values: respect, maintaining good relationships, humility and loyalty. Tongans can show respect to their local chiefs and highest people in the village by sharing with them the best of their catches. Communities practice traditional fishing methods in order to conserve their marine resources, reducing their adverse impacts on coastal ecosystems, and optimising production to meet local nutritional needs (P. Kara, pers. comm., 2015).

Display of traditional Tongan handicrafts at an agriculture show in Nuku’alofa

6.9 OTHER VALUES

Below are examples of marine ecosystem services that may be found in Tonga but have not been included in this research.

6.9.1 BIO-PROSPECTING

Bio-prospecting is the process of discovering and commercialising new products from natural sources. Marine resources, particularly in areas with high biodiversity such as coral reefs, or unique ecology such as deep-sea thermal vents, may house potentially marketable products or elements that lead to marketable products. If there is currently no exploitation of these products, bio-prospecting represents an *option value,* that is, the resources have value today because we have the option for new discoveries or commercialisation in the future. The pharmaceutical industry is an important *beneficiary* of bio-prospecting. *Option values* are discussed further in Section 6.10.

6.9.2 BIOREMEDIATION

In addition to providing habitat for inshore fisheries, protecting the coastline from erosion, and sequestering carbon, mangroves and coastal wetlands play an important role in filtering and remediating polluted water. This ecosystem service is called bioremediation. Although Tonga has relatively small mangrove forests, areas where they do exist, for example, around Fanga'uta Lagoon, benefit from this service. A study in Fiji estimated that the nutrient filtering services of mangrove soils yielded an average *present value* of US $ 192,723 per hectare over 50 years. This value reflects the difference between the cost of a conventional sewage treatment plant (US $ 4.5 million) and use of mangroves for oxidation ponds (US$ 1.4 million) (Lal 1990).

6.9.3 HANDICRAFTS

Handicraft production is an important Tongan activity that contributes significantly to the Tongan domestic economy (Tonga Statistics Department 2009). Tongan households produce handicrafts for commercial sale and for personal use. Handicrafts are measured in Tongan GDP and GNI estimates (Tonga Statistics Department 2012). Marine ecosystems provide materials for many Tongan handicrafts. Mangrove bark is used to make dye used for traditional tapestries. A variety of seashells are used to make traditional and contemporary jewellery. Pearls are harvested from wild and commercially cultivated oysters.

Handicrafts that are sold earn vendors a *resource rent*, the same as any market good that depends on 'free' natural inputs. The *resource rent* is the *net value* of the product after the value of labour time and other production costs have been subtracted. Handicrafts that are used at home have an avoided-cost value, meaning that they are worth what the household does not have to spend to purchase the items.

6.9.4 MARICULTURE

Some small-scale mariculture projects have been started in Tonga in recent years. Mariculture relies on the ecosystem service of good quality seawater and appropriate habitat for growth of the cultured species. Part of the value of harvested products comes from the features and processes of the natural marine habitat. Pearls are cultured in Vava'u and seaweed is grown for export. Both mariculture industries are currently very small scale in Tonga, but are worth noting because they have grown into large industries in other Pacific Island countries. Within a few years of initiating commercial farming of seaweed, Kiribati brought in a net income of US$ 5,440 per year per family unit for a farmed area of 900–1,000 square metres (Luxton and Luxton 1999). In 1997, more than 420 people received an income from seaweed and 29% of all households on Kiritimati recorded seaweed as their main source of income (Luxton and Luxton 1999). The total Kiribati harvest grew to more than 1,200 tonnes per year. In 2000, French Polynesia exported approximately US$ 275 million of raw pearls (from the *Pinctada margaritifera* oyster) (Cartier and Carpenter 2014). In 2011, pearl farming was carried out on 26 atolls and four high islands; a total of 10,000 hectares was authorised for pearl farming. The country produces more than 98% of the world's Tahitian pearls.

Giant clams have been cultured for many years in Tonga by the Fisheries Division. The young clams are used to stock inshore areas near some villages or sold to aquarium exporting companies. The Fisheries Division is currently experimenting with the propagation of sea cucumbers for the *bêche-de-mer* trade.

6.9.5 AESTHETIC VALUE

Many people appreciate marine and coastal areas for their natural beauty. The aesthetic value of marine and coastal areas is an ecosystem service that appears as a component of different activities and is not typically paid for directly. The *economic value* of aesthetic areas is often revealed through associated markets, in particular tourism, recreation and housing. Where this service is a component of market-based tourism and recreation (e.g. sailing, surfing, staying at seaside resorts), the value has already been captured by measurement of those ecosystem services. In other words, aesthetic value is a component of the tourism value of marine and coastal ecosystems. As a component of non-market tourism and recreation, a study (survey) of individuals' preferences and *willingness-to-pay* for coastal vistas would be required.

Aesthetic value also appears in the housing market. Individuals' housing decisions can reveal their preference for the aesthetic beauty of coastal areas by the difference between what they are willing to pay to live in coastal areas in contrast to inland areas. The *hedonic pricing method* is used to statistically analyse how the aesthetic value of coastal areas is embedded in the value of coastal property. This economic method requires substantial amounts of data about properties and their rental and sales prices, making it difficult to conduct in small island developing states (Van Beukering et al. 2007a).

An example of the aesthetic value of coastal areas can be drawn from Guam, where the value of proximity to reefs for beachfront housing was US$ 10.9 million per year, as estimated through a statistical analysis of a database of 800 house sales from 2000 to 2004 (Van Beukering et al. 2007b). Every additional kilometre a house was from the coast decreased its housing value by US$ 19,437. This value likely captures aesthetic value, shoreline protection and recreational values.

6.9.6 WOOD HARVESTING

Mangrove trees are used for firewood, charcoal production, construction materials and wood chips and paper pulp. Mangrove wood can have a subsistence value when harvested and used by households or a producer and consumer *market value* if it is bought and sold. The harvest, use, and sale of mangrove wood in Tonga is not measured or monitored. In order to estimate the benefits of this ecosystem service, data would be required that explained the quantity of harvest for each different use, and the value of those uses. In Vava'u, a household survey revealed that a third of households had harvested firewood for their own use in the past month, and half of those harvested at least one truckload in the past month (Salcone 2015). However, mangrove wood was not among the four most popular sources of firewood in the Vava'u group.

In Tonga, mangrove bark is used in making dye for the ubiquitous Tongan *tapa*; this seemingly simple ecosystem service may have substantial value to Tongan households.

6.10 NON-USE, BEQUEST AND OPTION VALUES

Ecosystems can have value to people even if they do not directly receive benefits from *ecosystem functions*. Individuals may simply appreciate knowing that ecosystems are healthy and that species are not going extinct. This is the *existence value* of ecosystems. Some individuals may also want to maintain options for future uses of the marine environment (*option value*) or preserve ecosystems so that they are available for future generations (*bequest value*). The Tongan national motto "God and Tonga are my inheritance" reflects the cultural value of preserving Tongan resources for future generations.

The *existence value* of nature's ecosystems, reserving the opportunity for future uses (*option value*) and the value of nature to future generations (*bequest value*) are non-market ecosystem services. The fact that these values are not reflected in markets or economies means that they are not easily visible to decision-makers, which can lead to poor resource management decisions (Cesar et al. 2003). Since there are no markets for these services nor any associated markets that can reveal their value, the only way to estimate their value is to ask people what they are worth using *stated preference* economic survey methods. Determining the value of an ecosystem service by asking what individuals would be willing to pay for its presence or maintenance is called *contingent valuation*. Asking individuals to make hypothetical trade-offs between different ecosystem services is called *choice modelling*. Both methods ask individuals, via surveys or interviews, to state their preference for the non-market ecosystem service either in monetary terms, or in terms of willingness-to-trade other goods or services for the non-market ecosystem service in question.

Although difficult to measure, *existence*, *bequest* and *option values* are a component of the *total economic value* of an ecosystem. A single individual may only be willing to pay a very small amount for the existence of or option for future use of a resource, but the sum of *willingness-to-pay* across many thousands of individuals may still represent considerable *economic value* (Loomis et al. 2000; Daubert and Young 1981).

A study by O'Garra (2007) of the Navakavu Locally Managed Marine Area in Fiji is a good example of this type of research. Navakavu residents were willing to contribute a mean 3.03 hours of their time (worth US$ 6.15–11.83 per month per individual) or donate an average of US$ 4.78 per individual per month (US$ 57.45 per individual per year) to conserve their traditional fishing grounds. This value is an *option* or *bequest value*. Although the *nominal* values per individual may seem small, the average monthly household income for local residents was only US$ 174.94. Individuals' mean willingness to contribute to conserve this marine resource represented 2.7% of their income (O'Garra 2007).

It was beyond the scope of this valuation to conduct *stated preference* surveys to elicit data about non-use benefits of marine and coastal ecosystems in Tonga.

6.11 SUPPORTING SERVICES: ECOLOGICAL PROCESSES AND BIOLOGICAL DIVERSITY

Some *ecosystem functions* do not directly benefit humans, but may be instrumental in supporting other *ecosystem functions*. Basic *ecosystem functions* such as photosynthesis, nutrient cycling, soil and sand formation and other so-called *supporting ecosystem services* are intermediate services to many human behaviours and activities. The ocean has an important role in the production of oxygen (phytoplankton produce half of the earth's oxygen), nitrogen fixation, waste assimilation and regulating global temperatures and climate (Samonte-Tan et al. 2010; Galland et al. 2012; NOAA 2012). While some of these *ecosystem functions* may not benefit humans directly, they underpin life on earth. None of the values identified and discussed in this study can exist without well-functioning ecological processes (such as production, growth, recruitment) underpinned by biological and abiotic diversity of marine ecosystems (MEA 2005). Their value, however, is often carried over into direct or final ecosystem services. To avoid double counting the value of supporting ecosystem services, ecosystem service valuation should focus on the final human benefits coming from the end-products of *ecosystem functions* (Boyd and Banzhaf 2007; Fisher et al. 2009). In so much as these *supporting services* facilitate more tangible ecosystem services, their value is captured in the valuation of those services; to value them separately from the end user values would be double counting their value.

Humpback Whales in Vava'u.

7. DISCUSSION

The information in Chapter 6 allows us to better understand the human benefits of Tonga's marine and coastal environment. The information can, and should, be used to compare the types, magnitude and distribution of benefits from different marine resources. For example, the subsistence fishery, *bêche-de-mer* export, inshore commercial fisheries, the aquarium trade, and the tuna industry are services of comparable orders of magnitude (between T$ 0.5 million and T$ 10 million annually), but the benefits accrue to different groups of people.

Knowing who receives the benefits of each ecosystem service identifies incentives to change or maintain management practices, helps prioritise allocation of government resources, and helps decision-makers understand who will benefit or suffer from a change in policy or resource use. For example, commercial tuna fisheries do not benefit average households in Tonga, but they do generate *revenue* for government operations. Government has an incentive to manage the tuna industry to provide that *revenue*, even though the impact on Tongan households is more ambiguous.

7.1 SYNTHESIS OF RESULTS

With an EEZ nearly 1000 times larger than the country's land area, it is no surprise that Tonga marine resources provide enormous benefits. Marine and coastal ecosystem services in Tonga serve as a vast bank account of natural wealth. Some withdrawals from this account have been unsustainable, such as the export of *bêche-de-mer*. Other services, such as tourism, could support much larger human benefits without depleting the nation's stores of natural capital.

The values presented in Chapter 6 for fisheries and tourism mostly represent benefits to *producers*, meaning those who harvest, extract or earn *revenue* from a resource. Coastal protection values represent benefits to all residents and visitors and carbon sequestration values are benefits to the whole world. Government benefits are included where they are significant. *Revenue* from taxes or fees to Tongan businesses and residents represents a redistribution of benefits within Tonga, not true *economic value*. When the tax or fee *revenue* derives from foreign visitors or foreign businesses, it represents true *economic value* to Tonga. However, the costs to administer licences and collect fees must be subtracted from *gross revenue*. Costs have been estimated and subtracted from sand mining and dredging *revenue*, but not from fishing export tax and licensing *revenue*, tourism tax *revenue*, or costs to receive aid and grant monies. Lastly, consumer benefits have not been estimated for fishing and tourism, with the exception of subsistence fishing where the producer and consumer are the same individuals. The greatest consumer benefits within Tonga are from the commercial inshore fishery, where almost 100% of the catch is consumed by Tongans, but again, these benefits have not been estimated in this study.

The ecosystem service of subsistence fishing provides benefits to many Tongan households, particularly rural and poor households. Although few households claim that subsistence fishing is their main activity (Tonga Statistics Department 2011), many supply at least some of their family's food needs by fishing (Friedman et al. 2009; Salcone 2015). It is very difficult to measure and monitor the harvest and pressure on this ecosystem service. Household income and expenditure surveys are the most common data source, which are used to extrapolate harvest estimates. CPUE measurements, albeit infrequent and very localised, provide the best indicators of resource pressure. In Tonga, with extensive inshore habitat and a small population, subsistence fishing should be a sustainable ecosystem service, although studies show indications of localised overfishing for some species (Friedman et al. 2009; Webster 2014). Commercial inshore fisheries such as the aquarium and *bêche-de-mer* trade improve Tonga's trade imbalance and provide government *revenue*, but could hurt Tongan households if they damage inshore habitat or disrupt the growth and reproduction of common food species.

Commercial fishing has many different sectors. They can be broadly classified into inshore or offshore by the habitat that supports the service. Most commercial fishing sectors are aimed at export markets except for artisanal inshore fishing for finfish and invertebrates, most of which is sold in local markets. Tongans are employed in commercial fisheries, but the tuna, *bêche-de-mer* and aquarium export sectors are mostly foreign-run industries. Tuna vessels that unload their catch in Nuku'alofa provide some jobs and *revenue* to Tonga. Distant nation fishing vessels now unload their catch in Tonga too and provide *revenue* from licence fees that can be negotiated annually with distant nations seeking permission to fish in Tongan waters. These licence fees are an important source of government *revenue*.

More Tongan households benefit from subsistence and commercial inshore fisheries than from any other marine ecosystem service. Inshore fisheries support the food security of most Tongan households. Because it is difficult to separate small-scale commercial fishing from small-scale subsistence fishing, it may be more appropriate to evaluate artisanal fishing as a whole, that is, small-scale fishing for home consumption and sale could be evaluated together since they depend equally on the productivity of inshore habitat. T$ 10 million is a minimum estimate of the annual value of Tonga's inshore subsistence and domestic commercial fisheries, from an annual harvest of between 2,360 and 6,560 tonnes per year, or between 0.4 and 1.1 tonnes per km^2 of inshore habitat.

Deep-sea demersal fishing and the aquarium trade are relatively small but consistent ecosystem services that provide some local employment and export *revenue* (approximately T$ 1.25m gross per year). Comprehensive management plans for these sectors have been improved over the past 20 years and, if enforced, should enable sustainability. The *bêche-de-mer* fishery has been much more volatile. Although this sector has provided occasional spurts of export *revenue* and employment for Tongan fishers, sustainable management of the fishery has not been established.

Dredging of sand and aggregate for commercial purposes provides benefits to the Ports Authority, construction industry and consumers, but the negative impacts of dredging could not be assessed in this study. Probable impacts include destruction and siltation of reef and lagoon habitat which may harm Tonga's largest domestic marine ecosystem service — inshore fisheries. Beach mining for domestic purposes provides minimal benefits to the Natural Resources Division, and real benefits that could not be quantified without a robust survey to Tongan households. The erosion impacts of beach sand mining and lagoon dredging are potentially damaging and warrant hydrogeological assessment.

Exploration for deep-sea mining is already providing significant benefits to the Government of Tonga, but no real benefits to Tongan households or the general economy. A comprehensive Deep-Sea Mining Act paves the way for oversight and benefit-sharing if mining operations occur in the future. The magnitude of threats to whale migration and tuna and deep-sea demersal habitat cannot yet be quantified, but must be considered. Tourism, tuna, and deep-sea snapper industries provide benefits to Tonga and may be impacted by deep-sea mining.

Tourism is a growing industry in Tonga that depends largely on healthy marine and coastal ecosystems. These ecosystems contribute T$ 9–22.5 million in annual *economic activity* in Tonga; a minimum estimate of the *net value* of those expenditures (25%) would be T$ 2.2–5.5 million each year. Tourism benefits a variety of businesses and their employees and provides government tax *revenue*. Tourism can be a sustainable ecosystem service if managed and regulated. Fishing, particularly destructive types of inshore fishing and nearshore sand and aggregate mining could negatively impact tourism.

Fringing reef, mangroves and seagrasses protect Tonga's coasts from erosion and flooding. Because many of the commercial and residential properties in Tonga are near the coast avoided costs could be quite significant. In addition to erosion protection and fish and invertebrate habitat, mangroves provide carbon sequestration benefits to the world worth about T$ 1.4 million per year. If protected, areas of mangroves at risk of destruction could be marketed and sold as carbon offsets, but the costs of verifying and managing the protected areas would need to be assessed on a case-by-case basis.

Marine and coastal areas attract foreign aid and research that benefits the Government of Tonga, bringing in T$ 540,000 to the Fisheries Division alone in 2015. Investment in marine and coastal biodiversity also includes many projects run through the Environment Division, so the total benefit is much greater. Money spent by individuals and institutions that research marine and coastal ecosystems or advocate for their protection mostly benefits government, although aid expenditure trickles through many sectors of the economy much like tourism expenditure.

Other marine and coastal ecosystem services include mariculture, handicrafts, bioremediation, cultural identity and aesthetic beauty. These services have not been quantified by this study because of a lack of data and human and financial resources, but they provide benefits to Tonga and the rest of the world.

8. RECOMMENDATIONS AND SUGGESTIONS

Because of the large scope of this project (national valuation of many services), no single topic has been analysed in great detail. Each subsection in Chapter 6 should serve as a base of information about each ecosystem service that Tonga can choose to explore more deeply as the need arises. Problematic data gaps are discussed in the **Quantify** section for each ecosystem service. If Tonga wishes to use economic information about ecosystem benefits, the gaps in data should be evaluated first to enable more rigorous assessment of the benefits.

Tongan households are greatly dependent on inshore fish and seafood. Resources need to be allocated to support inshore fishery data collection to better understand these ecosystem benefits.

Government should prioritise addressing the gap between the gross value of tuna harvested and the value captured within Tonga, in the short term by regional cooperation around limiting the TAC and increasing licence fees, and in the long term by replacing foreign vessels with a domestic fishing fleet and supporting domestic processing that adds value to the resource and benefits Tongans.

The costs and benefits of aggregate mining and deep-sea mineral mining need to be thoroughly explored, taking into account the potential effects on fishing and tourism ecosystem services. Whale migration routes and deep-sea snapper habitat need protection to preserve these ecosystem services.

This study is a step towards a national process of recognising the human benefits of natural ecosystems. Further valuation of ecosystem services should be targeted to the specific applications above leading to more equitable and sustainable management of Tonga's marine assets. More generally, Tonga should continue to make steps towards accounting for natural capital in order to ensure the sustainable prosperity of the Kingdom.

9. CAVEATS AND CONSIDERATIONS

The important qualitative and quantitative information presented in Chapter 6 can be compromised by the need to provide a simple and brief summary. Busy political leaders need clear and concise summaries of research, but over simplification of ecosystem service research can lead to misinterpretation and inappropriate generalisation of the results. The benefits quantified and valued above should be considered individually. Policy-makers must resist the urge to aggregate these values for the following reasons:

- Each value represents a slightly different type of benefit. Gross values, *net values*, employment, government *revenue* and *consumer surplus* are all units for measuring benefits but should not be combined together, despite the fact that they are all represented in Tongan Pa'anga (T$).
- Values represent current use, not sustainable use, equitable use, or maximum potential benefit. Some ecosystem services may be unsustainable at current rates of exploitation, while others may support greater expansion.
- Some ecosystem services complement each other, others compete. For example, growth in the aquarium trade may adversely impact the inshore finfish and invertebrate fishery, whereas protection of mangrove areas may increase coastal protection, increase carbon sequestration, and increase inshore fisheries productivity.

These three qualifications must be taken into account any time the results are used, reproduced, or updated.

The valuation results in Chapter 6 measure mostly *producer surplus*, not *total economic value*. The *total economic value* of an ecosystem service includes all net benefits humans receive from the ecosystem service. *Total economic value* is a quantification of the full contribution ecosystems make to human wellbeing, including benefits to consumers, producers, and government. It includes market and non-market values (i.e. *direct use value*, *indirect use value* and *existence/non-use value*) and therefore represents the full benefit humans receive from *ecosystem functions*.

In practice, *total economic value* is nearly impossible to calculate because the data required are rarely available. For example, fisheries resources offer benefits to those who harvest and sell seafood products (producers), as well as to those who consume seafood products (consumers). Governments benefit from charging for access to fish in their EEZ. The *total economic value* of the fishery is a sum of the producer, consumer and government benefits but consumer benefits are difficult to estimate and, in the case of export products, they accrue to individuals distant from the natural resource. Producer benefits alone are commonly used to estimate the value of fisheries, perhaps adding the benefits to government if tax and licence information is available. It should be noted, however, that these estimates are a lower-bound value and do not represent *total economic value*. This is the case with most of the ecosystem service values presented in this report.

Another important consideration is the relationship between ecosystem service values and human population density. Ecosystem service value is directly correlated to the number of people who receive benefits. Healthy, intact ecosystems often exist where there are few people. No matter how productive the ecosystem, the values of ecosystem services in remote places are often quite low, because so few humans receive the benefits of the *ecosystem functions*. More densely populated areas may have higher ecosystem service values because more of the benefits of *ecosystem functions* are captured by humans. Because of this phenomenon, it is very important to analyse the ecological sustainability of current resource use to assess whether the status-quo values can be maintained, or if they can be expected to decrease over time.

10. FUTURE DIRECTIONS

A significant limitation of this work is the lack of scenario analysis. Ecosystem services are valued according to their current use, usually using averages from the past five to ten years. This does not describe the *potential* value of the ecosystem. Scenario analysis considers different options of resource use and management and quantifies the ecosystem services that people would receive under the different scenarios. This is a type of *cost-benefit analysis* using the values of ecosystem services to quantify the costs and benefits. Tonga may wish to use this report as a starting point for these types of analyses.

At the national scale, ecosystem service valuation could support the adoption of the System of Environmental-Economic Accounting (SEEA). Although more detailed assessments of the national value of ecosystem services will be required, this report could serve as a *baseline* for natural capital accounting. Tonga may wish to build on this report to institute the SEEA and account for the value of the Kingdom's natural resources.

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13. APPENDIX I GLOSSARY

Avoided damage cost valuation method: A cost-based valuation technique that estimates the value of an ecosystem service by calculating the damage that is avoided to infrastructure, property and people by the presence of ecosystems.

Baseline: The starting point from which the impact of a policy or investment is assessed. In the context of ecosystem service valuation, the baseline is a description of the level of ecosystem service provision before a policy or investment intervention.

Beneficiary: A person that benefits from the provision of ecosystem system services.

Bequest value: the value to the current generation of knowing that something (e.g. pristine coral reef) will be available to future generations.

Choice modelling: Choice modelling attempts to model the decision process of an individual or segment in a particular context. Choice modelling may be used to estimate non-market environmental benefits and costs. It involves asking individuals to make hypothetical trade-offs between different ecosystem services.

Constant prices: Prices that have been adjusted to the price level in a specific year. Constant prices account for inflation and allow values to be compared across different time periods.

Consumer surplus: The difference between what consumers are willing to pay for a good and its price. Consumer surplus is a measure of the benefit that consumers derive from the consumption of a good or service over and above the price they have paid for it.

Contingent valuation: Contingent valuation is a survey-based economic technique for the valuation of non-market resources, such as environmental preservation or the impact of contamination. It involves determining the value of an ecosystem service by asking what individuals would be willing to pay for its presence or maintenance.

Cost-benefit analysis: An evaluation method that assesses the economic efficiency of policies, projects or investments by comparing their costs and benefits in present value terms. This type of analysis may include both market and non-market values and accounts for opportunity costs.

Direct use value: The value derived from direct use of an ecosystem, including provisioning and recreational ecosystem services. Use can be consumptive (e.g. fish for food) or non-consumptive (e.g viewing reef fish).

Discount rate: The rate used to determine the present value of a stream of future costs and benefits. The discount rate reflects individuals' or society's time preference and/or the productive use of capital.

Discounting: The process of calculating the present value of a stream of future values (benefits or costs). Discounting reflects individuals' or society's time preference and/or the productive use of capital. The formula for discounting or calculating present value is: present value = future value/$(1+r)^n$, where r is the discount rate and n is the number of years in the future in which the cost or benefit occurs.

Economic activity analysis: An analysis that tracks the flow of dollars spent within a region (market values). Both economic impact and economic contribution analysis are types of economic activity analysis.

Economic activity: The production and consumption of goods and services. Economic activity is conventionally measured in monetary terms as the amount of money spent or earned and may include 'multiplier effects' of input costs and wages

Economic benefit: the net increase in social welfare. Economic benefits include both market and non-market values, producer and consumer benefits. Economic benefit refers to a positive change in human wellbeing.

Economic contribution: The gross change in economic activity associated with an industry, event, or policy in an existing regional economy.

Economic cost: A negative change in human wellbeing.

Economic impact: The net changes in new economic activity associated with an industry, event, or policy in an existing regional economy. It may be positive or negative.

Economic value: i) The monetary measure of the wellbeing associated with the production and consumption of goods and services, including ecosystem services. Economic value is comprised of producer and consumer surplus and is usually described in monetary terms. Or ii) The contribution of an action or object to human wellbeing (social welfare).

Ecosystem contribution factor: The degree of association between marine and coastal ecosystems and different tourist activities.

Ecosystem functions: The biological, geochemical and physical processes and components that take place or occur within an ecosystem.

Ecosystem service approach: A framework for analysing how human welfare is affected by the condition of the natural environment.

Ecosystem service valuation: Calculation, scientific and mathematic, of the net human benefits of an ecosystem service, usually in monetary units.

Ecosystem services: The benefits that ecosystems provide to people. This includes services (e.g. coastal protection) and goods (e.g. fish).

Ecosystem: A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.

Evaluate: To assess the overall effect of a policy or investment.

Evaluation: The assessment of the overall impact of a policy or investment. Evaluations can be conducted before or after implementation of a policy or investment.

Existence value: The value that people attach to the continued existence of an ecosystem good or service, unrelated to any current or potential future use.

Factor cost: Total cost of all factors of production consumed or used in producing a good or service.

Financial benefit: A receipt of money to a government, firm, household or individual.

Financial cost: A debit of money from a government, firm, household or individual.

Free-on-board: The taxable value for each fished species. This value theoretically represents the market value of the product, although this is not always the case in practice.

Future value: A value that occurs in future time periods. See also present value.

Geographic Information Systems (GIS): An information system that captures, stores, manages, analyses and presents data that is linked to a geographic location.

Green accounting: The inclusion of information on environmental goods and services and/or natural capital in national, sectoral or business accounts.

Gross revenue: Money income that a firm receives from the sale of goods or services without deduction of the costs of producing those goods or services. Gross revenue from the sale of a good or service is computed as the price of the good (or service) multiplied by the quantity sold.

Gross value: The total amount made as a result of an activity.

Hedonic pricing method: A method for pricing ecosystem services. Hedonic price models assume that the price of a product reflects embodied characteristics valued by some implicit or shadow price.

Indirect use value: The value of ecosystems services that contribute to human welfare without direct contact with the elements of the ecosystem, for example regulating services such as plants producing oxygen or coral reefs providing coastal protection.

Inflation: A general rise in prices in an economy.

Instrumental value: The importance of something as a means to providing something else that is of value. For example, a coral reef may have instrumental value in reducing risk to human life from extreme storm events.

Intermediate costs: The costs of inputs or intermediate goods that are used in the production of final consumption goods. For example, the cost of fishing gear used to catch fish is an intermediate cost to the harvest and sale of fish.

Intrinsic value: The value of something in and for itself, irrespective of its utility to something or someone else. Not related to human interests and therefore cannot be measured with economic methods.

Marginal value: The incremental change in value of an ecosystem service resulting from an incremental change (one additional unit) in the quantity produced or consumed.

Market value: The amount for which a good or service can be sold in a given market.

Negative externality: NEGATIVE EXTERNALITIES occur when the consumption or production of a good causes a harmful effect to a third party.

Net revenue: Monetary income (revenue) that a firm receives from the sale of goods and services with deduction of the costs of producing those goods and services. Net revenue from the sale of a good is computed as the price of the good multiplied by the quantity sold, minus the cost of production.

Net value: The value remaining after all deductions have been made.

Nominal: The term 'nominal' indicates that a reported value includes the effect of inflation. Prices, values, revenues etc. reported in 'nominal' terms cannot be compared directly across different time periods. See also real and constant prices.

Non-use value: The value that people gain from an ecosystem that is not based on the direct or indirect use of the resource. Non-use values may include existence values, bequest values and altruistic values.

Opportunity cost: The value to the economy of a good, service or resource in its next best alternative use.

Option value: The premium placed on maintaining environmental or natural resources for possible future uses, over and above the direct or indirect value of these uses.

Present value: A value that occurs in the present time period. Present values for costs and benefits that occur in the future can be computed through the process of discounting (see discount rate). Expressing all values (present and future) in present value terms allows them to be directly compared by accounting for society's time preferences.

Producer surplus: The amount that producers benefit by selling at a market price that is higher than the minimum price that they would be willing to sell for. Producer surplus is computed as the difference between the cost of production and the market price. Value-added, profit, and producer surplus are similar measures of the net benefit to producers. Although they differ slightly, the terms are used synonymously for this report to represent economic value.

Profit: The difference between the revenue received by a firm and the costs incurred in the production of goods and services. Value-added, profit and producer surplus are similar measures of the net benefit to producers. Although they differ slightly, the terms are used synonymously for this report to represent economic value.

Purchasing power parity adjusted exchange rate: An exchange rate that equalises the purchasing power of two currencies in their home countries for a given basket of goods.

Purchasing power parity: An indicator of price level differences across countries. Figures represented in purchasing power parity represent the relative purchasing power of money in the given country, accounting for variance in the price of goods. Typically presented relative to the purchasing power of US dollars in the United States.

Real: The term 'real' indicates that a reported value excludes or controls for the effect of inflation (synonymous with constant prices). Reporting prices, values, revenues etc. in 'real' terms allows them to be compared directly across different time periods. See also nominal and constant prices.

Regulating services: A category of ecosystem services that refers to the benefits obtained from the regulation of ecosystem processes. Examples include water flow regulation, carbon sequestration and nutrient cycling.

Rent: Any payment for a factor of production in excess of the amount needed to bring that factor into production (see also producer surplus and resource rent).

Replacement cost method: A valuation technique that estimates the value of an ecosystem service by calculating the cost of human-constructed infrastructure that would provide same or similar service to the natural ecosystem. Common examples are sea walls and wastewater treatment plants that provide similar services to reefs, mangroves, and wetland ecosystems.

Resource rent: The difference between the total revenue generated from the extraction of a natural resource and all costs incurred during the extraction process (see also producer surplus). Refers to profit obtained by individuals or firms because they have unique access to a natural resource.

Revenue: Money income that a firm receives from the sale of goods and services (often used synonymously with gross revenue).

Social cost of carbon: The social cost of carbon is an estimate of the economic damages associated with a small increase in carbon dioxide (CO_2) emissions, conventionally one tonne, in a given year. This dollar figure also represents the value of damages avoided for a small emission reduction (i.e. the benefit of a CO_2 reduction).

Stated preference survey method: A survey method for valuation of non-market resources in which respondents are asked how much they would be willing to pay (or willing to accept) to maintain the existence of (or be compensated for the loss of) an environmental feature such as biodiversity.

Supporting services: A category of ecosystem services that are necessary for the production of all other ecosystem services. Examples include nutrient cycling, soil formation and primary production (photosynthesis).

Total economic value: i) All marketed and non-marketed benefits (ecosystem services) derived from any ecosystem, including direct, indirect, option and non-use values, or ii) The total value to all beneficiaries (consumer, producer, government, local, foreign) from any ecosystem service.

Use value: Economic value derived from the human use of an ecosystem. It is the sum of direct use, indirect use and option values.

User cost: The cost incurred over a period of time by the owner of a fixed asset as a consequence of using it to provide a flow of capital or consumption services; the implications of current consumption decisions on future opportunity. User cost is the depreciation on the asset resulting from its use.

Utilitarian value: A measure of human welfare or satisfaction. Synonymous with economic value.

Valuation: The process or practice of estimating human benefits of ecosystem services or costs of damages to ecosystem services, represented in monetary units.

Value: The contribution of an action or object to human wellbeing (social welfare).

Value-added: The difference between cost of inputs and the price of the produced good or service. Value-added can be computed for intermediate and final goods and services. Value-added, profit, and producer surplus are similar measures of the net benefit to producers. Although they differ slightly, the terms are used synonymously for this report to represent economic value.

Welfare: An individual's satisfaction of their wants and needs. The human satisfaction or utility generated from a good or service.

Willingness-to-accept: The minimum amount of money an individual requires as compensation in order to forego a good or service.

Willingness-to-pay: The maximum amount of money an individual would pay in order to obtain a good, service, or avoid a change in condition.

14. APPENDIX II STAKEHOLDER CONSULTATIONS AND ATTENDEE LISTS

25 FEBRUARY – 4 MARCH 2014

Jacob Salcone (MACBIO Technical Officer) trip to Tonga to introduce economic valuation and scope the Vava'u socio-economic survey. Individual consultations were made with:

Mr Saane Lolo	Ministry of Finance and Planning Aid Management Division
Mr Tevita Lautuha	Ministry of Tourism and Commerce, Tourism and Trade Division
Ms Mele	Department of Environment
Mr Tukia Lepa	Department of Environment (MESCAL)
Mr Bruce Jefferies	SPREP
Mr Tim Carruthers	SPREP
Ms Silika	Provincial Ministry of Fisheries representative (Vava'u)
Ms Lupe Matoto	Department of Environment
Ms Luisa	Director of the Climate Change Division
Ms Winnie	Provincial Ministry of Environment representative (Vava'u)
Ms Lesieli Tu'ivai	Department of Environment
Mr Siola'a Malimali	Fisheries
Ms Easter Galuvao	SPREP
Ms Eileen Founa	SPREP
Mr Semisi Fakahau	Private consultant on Minerva Reef protection
Ms Karen Stone	Vava'u Environmental Protection Association (VEPA)
Ms Kate Walker	VEPA

1–10 JULY 2014

Jacob Salcone (MACBIO Technical Officer) trip for the MACBIO resource economics workshop in Nuku'alofa, data collection, and Vava'u economic valuation surveyor training. Individual consultations were made with:

Dr Salome Tupou-Taufa	Fisheries Economist
Dr Malimali Siola'a	Fisheries Division
Mr Tatafu Moeaki	CEO, Ministry of Finance and National Planning
Mr Taniela Hoponoa	CEO, Ministry of Agriculture, Food, Forests, and Fisheries
Ms Pelenatita Kara	CSFT
Mr Tasi	CSFT
Mr Paula Ma'u	CEO, Ministry of Environment
Ms Lesieli Tu'ivai	Ministry of Environment

RESOURCE ECONOMICS TRAINING AND STAKEHOLDER ENGAGEMENT WORKSHOP

The first TEEB workshop in Tonga took place in the basement of the large Catholic Church in Nuku'alofa. Twenty-one individuals participated, including the Director of Environment Lupe Matoto and the new CEO of the Ministry (MEECCDMMIC) Paula Ma'u. The first half of the workshop included an overview of MACBIO and a basic training on resource economics and ecosystem service valuation. The second half of the workshop began with small group discussions about how resource economics has been used in the activities or initiatives of the participating ministries, how economics and particularly ecosystem service valuation could be used in the future, and lastly, who should be involved. The responses from the breakout groups were shared back with Tongan colleagues and used to inform the TEEB reports.

Participants in the economic valuation workshop (3 July 2014):

Ms Lupe Matoto	Environment Department, MLECCNR
Mr Tukia Lepa	Environment Department, MLECCNR
Mr Mafile'o Masi	Environment Department, MLECCNR
Ms Lesieli Tu'ivai	Environment Department, MLECCNR
Ms Dorothy Foliaki	Environment Department, MLECCNR
Ms Eileen Fonua	Environment Department, MLECCNR
Ms Ana Fekau	Environment Department, MLECCNR
Mr Viliami Hakaumotu	Environment Department, MLECCNR
Ms Siale 'Ilolahia	CSFT
Dr Salome Tupou-Taufa	Fisheries Division (MAFF)
Mr Sandy Tu'ipulotu	Tourism Department
Representative from Fisheries	
Representative from Agriculture	
Representative from Forestry	
Representative from Statistics Department	
Representative from Planning Department	
Representative from Internal Affairs	
Representative from Lands Department	

9–15 JULY 2014

Introductory trip for Dr Leanne Fernandes, Senior Project Advisor for MACBIO, to Tonga together with the Regional Director of ORO, IUCN Mr Taholo Kami.

Below is a list of individuals and organisations Leanne contacted to engage and collaborate with on the MACBIO project.

Ms Lupe Matoto	Director Environment Department
Mr Drew Havea	Chair of Board, Tonga National Leadership Development Forum and Chair of Board, Civil Society Forum of Tonga
Mr Vailala Matoto	ex-Director Fisheries
Mr Semisi Fakahau	ex-Director Fisheries, worked with the Commonwealth Secretariat
Ms Nunia Mone	Ministry of Agriculture, Food, Forestry and Fisheries (MAFFF)
Mr Bill Kami	Quarantine
Ms Siale Ilolahaia	CSFT
Mr 'Asipeli Palaki	Ministry of Lands and Natural Resources
Minister Ma'afu	Ministry of Lands and Natural Resources
Mr 'Aholotu Palu	Secretary to the Prime Minister and Cabinet

MEETING AT DAVINA'S 11/7/14

Mr Paula F Taufa	Pacific Adaptation to Climate Change Coordinator (until Dec 2014), Department of Environment
Mr Richard ‘Atelea Kautoke	GIS, Lands Department
Mr Tevita Lautaha	Ministry of Commerce and Tourism
Dr Malimali Siola’a	Fisheries Technical Division, Department of Fisheries
Mr Rennie Vaiomo’unga	Ministry of Lands and Natural Resources
Ms Eileen Fonua	NBSAP Project Coordinator (until Dec 2014), Environment
Ms ‘Emele Latu	Civil Society Forum Tonga
Ms Papiloa Bloomflield Foliaki	Tonga Community Development Trust
Mr Naaluse Taiala	Tonga Community Development Trust
Ms Nunia Mone	MAFFF
Mr Paula Pouvalu Ma’u	CEO for the Ministry of Environment, Energy, Climate Change, Disaster Management, Meteorology, Information and Communication
Mr ‘Asipeli Palaki	CEO for Ministry of Lands and Natural Resources
Mr Tukua Tonga	Director for National Planning Authority (Head of Urban Planning)
Ms Elizabeth Baker	Ministry of Finance and National Planning
Mr Samiuela Pakileata	Assistant Conservation Officer, MEECCDMMIC
Ms ‘Ana Fekau	Island Biodiversity Program, MEECCDMMIC
Mr Talo Fulivia	Joint National Action Plan for Climate Change and Disaster Risk Management, MEECCDMMMIC
Ms Lilika Fusimalohi	Australian High Commission (Department of Foreign Affairs and Trade) DFAT
Mr Mafile’o Masi	MEECCDMMIC
Ms Dorothy Foliaki	MEECCDMMIC
Mr Briar Thompson	Department of Environment
Mr Brad Moore (visiting)	Secretariat of the Pacific Community (SPC)

18–26 SEPTEMBER, 2014

Jacob Salcone (MACBIO Technical Officer) third trip to Tonga to support the economic valuation component of MACBIO and follow up on the Vava’u economic research study. Individual consultations were made with:

Mr ‘Ata’ata Finau	Statistics Department
Ms Siale ‘Ilolahia	Director, Civil Society Forum of Tonga (CSFT)
Ms Balwyn Fa’otusia	Finance Department
Mr Rennie Vaiomounga	Natural Resources Department
Mr Tevita Lautaha	Department of Tourism

9–14 MARCH 2015

Jacob Salcone (MACBIO Technical Officer) fourth trip to Tonga, for presentation of preliminary results of marine ecosystem service valuation and other data consultation. Individual consultations were made with:

Mr ‘Ata’ata Finau	Statistics Department
Mr Masiva’ilo Masila	Statistics Department
Dr Salome Tupou-Taufa	Fisheries Economist
Mr Keiran Kelleher	World Bank Fisheries Consultant

PRESENTATION OF PRELIMINARY RESULTS AND MARINE ECOSYSTEM SERVICE DISCUSSION

A presentation of the preliminary results and discussion of the marine ecosystem service valuation was held on Wednesday, March 11 at the NEMO office in Nuku'alofa. Twenty-seven individuals participated, including representatives from Fisheries, Environment, Finance and Planning, Infrastructure, Statistics and civil society. The first half of the workshop included a brief review of MACBIO, a basic introduction to the ecosystem service valuation methods used within the national report and a description of the timeline and approach. A 45 minute presentation was made highlighting the connection between nature and people for seven key marine ecosystem services. Value estimates were presented and a discussion ensued about the applications for this quantification of human benefits from marine resources. A summary of the discussion was shared with Tongan colleagues and used to inform the TEEB report.

Mr Masivailo Masila	Statistics Department
Mr Sione Tukia	MEIDECC/EIA Division
Ms Meliame Kakala	Ministry of Infrastruture
Iketau Kaufusi	Ports Authority of Tonga
Ms Paula F. Taufa	MEIDECC
Mr Viliami Kato	Forestry Division
Ms Saane Vea	Ministry of Finance and National Planning
Ms Lynette Sifa	MLSNR (GIS division)
Mr Kieran Kelleher	WB Consultant (Fisheries)
Mr Poasi Ngaluafe	Fisheries Division
Dr Salome Tupou-Taufa	Fisheries Division
Ms Pelenatita Kara	CSFT
Mr Mafile'o Masi	MEIDECC
Mr Tahirih F. Hokafonu	MEIDECC
Ms Seini Fotu	MEIDECC
Ms Lilu Moala	MEIDECC/Climate Change
Ms Colleen Moses	MEIDECC
Ms 'Ana Fekau	MEIDECC
Ms Siosina Katoa	MEIDECC
Mr Siosiua Latu	MEIDECC
Ms Siosi Fifita	MEIDECC/Climate Change
Ms Malini Teulilo	MEIDECC
Ms Na'a Taiala	Tonga Trust (TCDT)
Mr Viliami Hakaumotu	MEIDECC
Ms Eileen Fonua	MEIDECC
Ms Filimone Lapao'o	MEIDECC
Mr Sandy Tu'ipulotu	Tourism Department

15. APPENDIX III
ADDITIONAL DATA AND METHODS

TABLE 26 • Inshore fish habitat types and area, GIS data

Inshore fish habitat	Depth label	Area (km²)	Data source
Mangroves only	Intertidal/ coastal	12.66	Ministry of Lands, Survey and Natural Resource of Tonga, GIS Unit
Reefs (reef flat, back reef, fore reef — all reef areas)	Shallow, variable and deep	3210.74	Andréfouët et al. 2005. Millennium Coral Reef Mapping Project, Institute for Marine Remote Sensing, University of South Florida (IMaRS/USF) and Institut de Recherche pour le Développement (IRD/UR 128, Centre de Nouméa)
Non-reefs (shoreline, intertidal including seagrass, sandy areas), lagoon and bank and other patchy non-reef habitats	Shallow, variable and deep	2615.41	Same as above
Other non-reef habitat *Note that this includes mangrove areas as well so mangroves are not included in the total area calculations*	Shallow, intertidal	42.87	Same as above
Total area		5869.02	Same as above

TABLE 27 • Annual fishing costs per household (Fiji)

Household fishing costs*	2006 (FJ$)	2013 (US$)	2013 (T$)
Gear (estimated)	81.89	64.56	115.69
Maintenance	490.80	386.98	693.39
Fuel	1,467.24	1,156.87	2,072.87
Total for boat owners	2,040	1,608	2,881.95
Opportunity cost of labour	491	387.14	693.67
O'Garra average running costs including *opportunity cost* of labour	601	473.87	849.07
Total average costs, no labour (Salcone from O'Garra 2007)	340.69	268.62	481.32

* From O'Garra (2007)

15.1 COASTAL PROTECTION VALUATION METHODS

Tongatapu was divided into several segments according to the morphology of the reefs. First, the island was divided into north and south sectors by broad spatial patterns: the existence of a thin discontinuous fringing reef along the south shoreline; and several coral formations in the north along the coast and at sea. Next, the broad division was divided again into two study areas within the north and south sectors depending on coastal exposure. The north-east of the island is characterised by a specific organisation of the shoreline, making it more protected than the north-west coast. In the same way, the south-east coast is a little more protected than the south-west.

Disaggregated results for the value of coastal protection in each of the four segments of Tongatapu are presented in Tables 28–31.

TABLE 28 • Residential avoided damages costs due to the presence of coral reefs, Tongatapu shoreline from Ha'atafu beach to Nuku'alofa, Tonga

relative coastal protection index	**0.24**
extreme climatic event probability (100 years)	**0.45**

	Number		**Unit**	**Currency**	**Total value of avoided damage**		**Annual value of avoided damage**	
	min	*max*			*min*	*max*	*min*	*max*
Houses	281	468	houses	US$	2,165,109	3,608,516	981,065	1,635,109
				T$	4,330,219	7,217,031	1,962,130	3,270,217
Luxury hotel	3	5	hotels	US$	418,929	698,214	189,827	316,378
				T$	837,857.25	1,396,428.75	379,654.07	632,756.78
Total				US$	2,584,038	4,306,730	1,170,892	1,951,487
				T$	5,168,076	8,613,460	2,341,784	3,902,974

TABLE 29 • Residential avoided damages costs due to the presence of coral reefs, Tongatapu shoreline from Nuku'alofa to Finehika beach, Tonga

relative coastal protection index	**0.25**
extreme climatic event probability (100 years)	**0.45**

	Number		**Unit**	**Currency**	**Total value of avoided damage**		**Annual value of avoided damage**	
	min	*max*			*min*	*max*	*min*	*max*
Houses	1191	1985	houses	US$	9,676,875	16,128,125	4,384,834	7,308,057
				T$	19,353,750	32,256,250	8,769,668	14,616,113
Total				US$	9,676,875	16,128,125	4,384,834	7,308,057
				T$	19,353,750	32,256,250	8,769,668	14,616,113

TABLE 30 • Residential avoided damages costs due to the presence of coral reefs, Tongatapu shoreline from Finehika beach to Fua'amtu beach, Tonga

relative coastal protection index	0.24
extreme climatic event probability (100 years)	0.45

	Number		Unit	Currency	Total value of avoided damage		Annual value of avoided damage	
	min	*max*			*min*	*max*	*min*	*max*
Houses	229	381	houses	US$	1,765,664	2,942,773	800,067	1,333,444
				T$	3,531,328	5,885,547	1,600,133	2,666,888
Total				US$	1,765,664	2,942,773	800,067	1,333,444
				T$	3,531,328	5,885,547	1,600,133	2,666,888

TABLE 31 • Residential avoided damages costs due to the presence of coral reefs, Tongatapu shoreline from Fua'amotu beach to Ha'atafu beach, Tonga

relative coastal protection index	**0.23**
extreme climatic event probability (100 years)	**0.45**

	Number		Unit	Currency	Total value of avoided damage		Annual value of avoided damage	
	min	*max*			*min*	*max*	*min*	*max*
Houses	21	35	houses	US$	153,563	255,938	69,583	115,972
				T$	307,125	511,875	139,166	231,943
Luxury hotel	2	3	hotels	US$	82,802	138,004	37,520	62,533
				T$	165,604.50	276,007.50	75,039.54	125,065.90
Total				US$	236,365	393,941	107,103	178,505
				T$	472,730	787,883	214,206	357,009

TABLE 32 • Value of potential carbon offsets, sensitivity analysis

	US$ 4.90/tCO_2		US$ 10.00/tCO_2	
	Min	**Max**	**Min**	**Max**
Per hectare	$ 5,154	$ 10,227	$ 10,519	$ 20,871
Total (7.8ha/yr)	$ 40,203	$ 79,770	$ 82,046	$ 162,796

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