The status of Tonga's sea cucumber fishery, including an update on Vava'u and Tongatapu

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by

Kalo M. Pakoa[1], Poasi V. Ngaluafe[2], Talaofa Lotoahea[2], Sione V. Matoto [2] and Ian Bertram[1]

[1] Secretariat of the Pacific Community
[2] Tonga Ministry of Agriculture and Food, Forests and Fisheries

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Summary

Tonga's sea cucumber fishery has gone through a 10-year moratorium on harvesting in order to allow stocks to recover from heavy fishing pressure. Prior to the opening of the fishery in 2008, a national sea cucumber fishery management plan was developed to guide the sustainable management of this important fishery. Some of the main measures included in the plan are: a) separate licenses for processing and exporting beche-de-mer; b) a quota on the number of licenses issued each year; c) a total export quota per season; d) short harvest seasons; and e) a restriction on the use of underwater breathing apparatus. The measures in the plan were not followed after 2008, resulting in increased number of licenses issued and a high production of beche-de-mer.

In 2010, the Secretariat of the Pacific Community (SPC) was requested to assist with assessing the status sea cucumbers and advising on harvest quotas. In response, a sea cucumber resource survey was carried out in Vava'u, and additional surveys were conducted in Tongatapu by officers from Tonga's Fisheries Division, SPC and the Tonga Environment Department. The survey provided information on species presence, abundance and densities, following the previous three annual harvests. Based on preliminary results of the surveys, a re-closure of the fishery for three to five years was recommended to allow stocks to recover. This advice was not adhered to by management authorities; instead, the annual quota was dropped from more than 200 tonnes to 100 tonnes for the 2011 season. However, final 2011 exports fell short of the annual quota, and later opening seasons were implemented in 2012 and 2013. Intense fishing pressure has resulted in the illegal use of scuba gear to access deep-water fishing grounds for white teatfish (especially in the Ha'apai group). In addition, the inappropriate use of underwater breathing apparatus has resulted in several deaths among fishers.

In total, 125 stations were surveyed in Vava'u and Tongatapu by a range of methods, with data collected on the abundance, distribution and size structure of sea cucumber species. The survey produced estimates of the current diversity of sea cucumber species present and, most importantly, the abundance and density of species following the previous three annual harvesting seasons.

Approximately 70–85% of all species were represented by the low-value lollyfish (*Holothuria atra*) in Vava'u and Tongatapu. Poor to critical densities of most other sea cucumber species were also noted. Production records indicate a shift in harvesting strategies from targeting high-value species to harvesting whatever sea cucumber species that fishers can find. These changes in the composition of the catch and exports are early warning signs that the fishery needs more effective management intervention.

The sea cucumber fishery is important to communities in Tonga: 360 tonnes of beche-de-mer were exported in 2009 and 318 tonnes in 2010. The estimated value to fishers and processors from the two seasons is about 7 million US dollars (USD) (or 13 million Tongan pa'anga — TOP) per season.

The authors make the following recommendations:

- Tonga's Fisheries Division should promote the development of the sea cucumber industry, but at present the stock status is such that a complete moratorium is deemed necessary until stocks can recover sufficiently. As part of strengthening the long-term viability of the industry, it is recommended that a review of the current management plan be undertaken based on lessons learned, and that consideration be given to incorporating key elements into legislation.
- Biennial monitoring of selected areas should be undertaken to assess the potential recovery of stocks. A monitoring programme should include a number of permanent stations that can act as reference stations for the whole of Tonga. Ideally, such reference stations should be closed to fishing in any open season or be part of special management areas.
- All possible steps should be taken, including implementing new legislation, to prevent or effectively discourage the use of underwater breathing apparatus for harvesting sea cucumbers. Any Fisheries Division-sponsored development work in this fishery should also provide for the collection of basic production statistics to allow monitoring the way in which sea cucumber resources are being exploited.
- The method of determining harvest, processing or export quotas should be reviewed.

1. Introduction

1.1 Background

Tonga consists of three main island groups — Vava'u, Ha'apai and Tongatapu — that extend in a roughly north-south direction. The main administrative centre and airport is on the island of Tongatapu (Fig. 1). The growing global demand for sea cucumber products[1] and a decline in worldwide sea cucumber resources is exerting unprecedented pressure on global sea cucumber stocks. Tonga made a critical move to impose a moratorium on its sea cucumber fishery towards the end of 1997 after assessments in 1996 recorded a significant decline in the abundance of the main target species in Ha'apai's lagoon (Lokani et al. 1996). The fishery was closed for 10 years and re-opened in 2008; it has been a very lucrative economic activity in recent years.

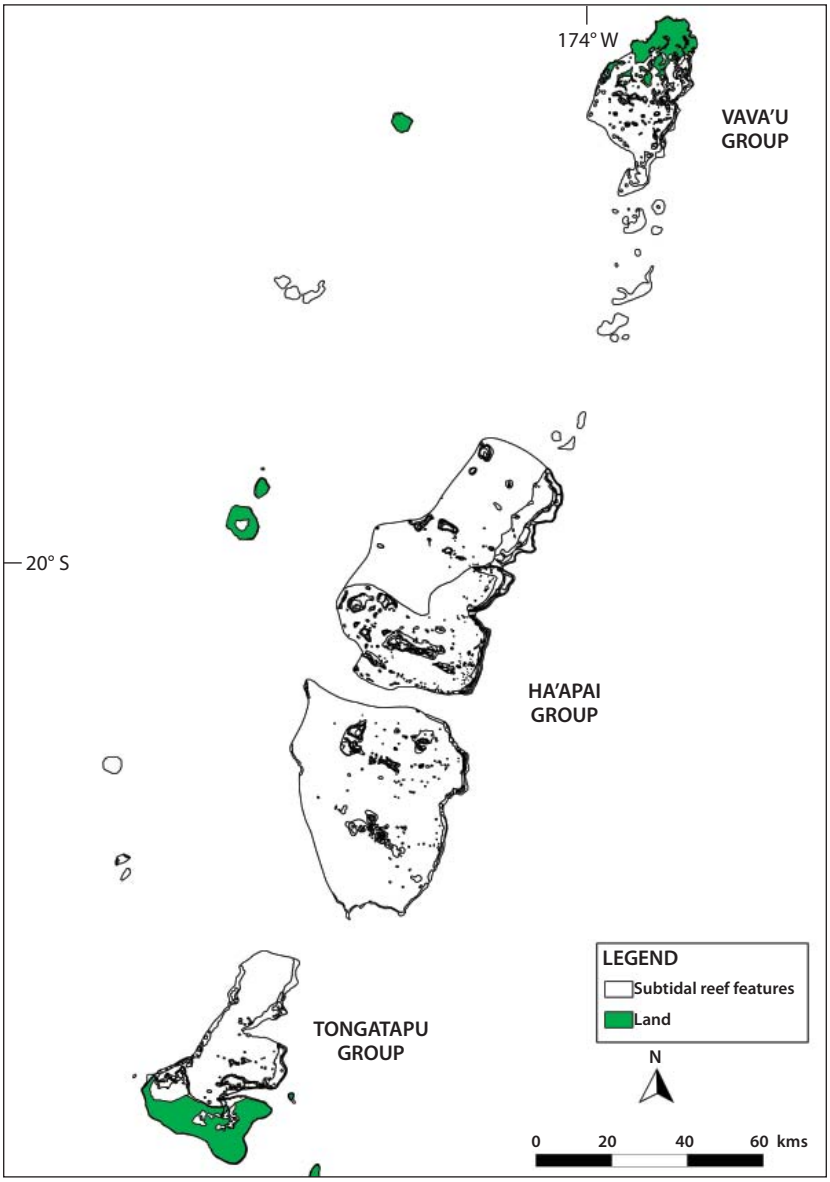

Figure 1. Tonga's three main island groups.

[1] 'Sea cucumber' refers to the live organism, while 'beche-de-mer' refers to the dried product.

The sale of raw and dried products contributes significantly to the income earnings of rural communities in Tonga, and the government generates considerable revenue from sea cucumber export licence fees and other charges. An increase in the number of licences issued after 2008 resulted in heavy fishing activity in the 2009–2010 seasons, including the highest production of beche-de-mer the country has ever recorded: 360 tonnes in 2009. Tonga's Fisheries Division was concerned that increased fishing pressure may have depleted the resource beyond the pre-moratorium level. Fisheries managers asked the question, 'Will the remaining resource support future open seasons?' To answer this question, surveys of current stocks were needed to determine the status of the resource after the recent years of fishing activities.

In 2010, the Tonga Fisheries Division requested the Secretariat of the Pacific Community (SPC) to re-assess sea cucumber resources and provide advice on management measures for the review of the Tonga National Sea Cucumber Fishery Management Plan. SPC provided a capacity building training package that included field surveys and an attachment at SPC. Specific areas covered in the training included species identification, survey methodologies, recording techniques, habitat identification, data analysis and interpretation, safety issues during surveys, and the presentation of results to decision-makers. Follow-up mentoring will be provided in order to strengthen the capacity of fisheries officers from Tonga's Fisheries Division so that they can conduct the surveys themselves, analyse data, and generate advice to managers.

Resource assessments in Vava'u were completed in November 2010 followed by further surveys undertaken by the trained team in Tongatapu in December 2010 and January 2011. Information on export production collected by staff at the Ministry of Agriculture and Food, Forests and Fisheries was assessed to cross-examine fishery and resources status trends. This report presents the results of the surveys undertaken, and provides recommendations on improving the management of sea cucumber resources.

1.2 Sea cucumber resources

Of the 1,200 species within the family Holothuroidea that have been described globally, 22 species are present in Tonga and are important in beche-de-mer production (Friedman et al. 2008). Five sea cucumber species are consumed in Tonga as local food items. Sea cucumbers are slow-moving and inhabit shallow waters. Most sea cucumbers are benthic feeders that ingest sand and detritus to digest bacteria and fungi on sediments. Sea cucumbers recycle organic matter on the lagoon bottom and release nutrients to other organisms for the maintenance of healthy reef systems. Most sea cucumber species reproduce sexually while some of the soft-bodied species belonging to the genus Holothuridae and Stichopidae are capable of undergoing asexual reproduction by splitting into two pieces and forming separate animals. Species such as lollyfish and greenfish, which are known to adopt both reproductive strategies, have a greater ability to recover after fishing and, therefore, can be present in high densities (Friedman et al. 2010). Reproductive maturity is reached at around three to four years of age for most species, and spawning occurs during the summer months. A few species have a second winter spawning (Conand 1993). Fertilised eggs drift for several weeks as plankton before settling to the bottom to begin a permanent benthic life. An updated list of commercial sea cucumbers present in Tonga and their common and local names is provided in Table 1.

1.3 Sea cucumber fisheries

There are three sectors of the sea cucumber fishery in Tonga: 1) the subsistence fishery for home consumption, 2) domestic commercial sales of raw sea cucumber products at local markets, and 3) the commercial export fishery for beche-de-mer products. Tonga is one of a few Pacific Island countries where sea cucumber species are consumed locally. The meat (body wall) and viscera of species such as lollyfish, snakefish, brown sandfish, chalkfish and curryfish are all consumed locally. The growing demand from urban populations has opened the market for the local delicacy and is an increasing source of income for fisherwomen. The subsistence sector is exempt from fishery management measures and the local sale of beche-de-mer enjoys this same exemption.

The commercial processing of beche-de-mer in Tonga began in the 1980s, and there is little available information about the fishery prior to this time. The commercial sea cucumber fishery began in the 1990s after resource assessments found that a small-scale commercial fishery was viable (Okamoto 1984 and undated; Preston and Lokani 1990). Fourteen species were targeted by thirteen registered exporters in the 1990s. These exporters were mostly Asian-owned companies operating in joint venture arrangements with local interests. The Ha'apai region was the main source of the high-value white teatfish and black teatfish, while Tongatapu produced significant quantities of golden sandfish.

Commercial exports of beche-de-mer have varied significantly over the period since records have been kept. Between 1990 and in 1995, peak exports reached 70 tonnes per year (1995) but in the years after 1995, exports dropped to 10 tonnes (1997). In effect, Tonga experienced its first 'boom and bust' cycle in the sea cucumber fishery over these years. A resource assessment conducted in 2006 (Lokani et al. 1996) recommended a 10-year closure of the sea cucumber fishery and this recommendation was approved by the Cabinet starting with the closure of the fishery in the last quarter of 1997. An assessment of the current trend in the sea cucumber fishery and export production in the last five years (2008–2013) is analysed and presented in the Results section as part of this assessment.

Table 1. Sea cucumber species present in Tonga and corresponding value groups.

Abbreviation	Common name	Scientific name	Tongan name	Value
AF	Amberfish	*Thelenota anax*	*Mokohunu saianiti*	M
BTF	Black teatfish	*Holothuria whitmaei*	*Huhuvalu 'uli'uli*	H
BCF	Brown curryfish	*Stichopus vastus*	*Lomu*	L
BSF	Brown sandfish*	*Bohadschia vitiensis*	*Mula*	M
CHF	Chalkfish	*Bohadschia marmorata*	*Finemotua*	M
CF	Curryfish*	*Stichopus herrmanni*	*Lomu*	M
DWRF	Deepwater redfish	*Actinopyga echinites*	*Telehea loloto*	H
DWSRF	Deepwater spiky redfish	*Actinopyga* sp. affn. *flammea*	*Telehea loloto*	H
DF	Dragonfish	*Stichopus horrens*	*Lomu*	M
ETF	Elephant trunkfish	*Holothuria fuscopunctata*	*Elefanite*	L
GSF	Golden sandfish*	*Holothuria lessoni*	*Nga'ito*	VH
GF	Greenfish	*Stichopus chloronotus*	*Holomumu*	H
HBF	Hairy blackfish	*Actinopyga miliaris*	*Lolo fulufulu*	M
LF	Lollyfish*	*Holothuria atra*	*Loli*	L
PKF	Pinkfish	*Holothuria edulis*	*Loli pingiki*	M
PRF	Prickly redfish	*Thelenota ananas*	*Pulukalia*	H
SNF	Snakefish	*Holothuria coluber*	*Te'epupulu*	M
STF	Stonefish	*Actinopyga lecanora*	*Telehea maka*	M
SRF	Surf redfish	*Actinopyga mauritiana*	*Telehea kula*	H
TF	Tigerfish*	*Bohadschia argus*	*Matamata*	M
WSF	White snakefish	*Holothuria leucospilota*	*Te'epupulu*	--
WTF	White teatfish	*Holothuria fuscogilva*	*Huhuvalu hinehina*	VH

VH = Very high; H = High; M = Medium; L = Low.

* Indicates species used as local food items.

1.4 Management arrangements

As is the case with many other sea cucumber fisheries in the Pacific, harvesting sea cucumbers in Tonga in the 1990s was open to everyone. Prior to 1998, there was no formal management plan for the fishery except for certain license conditions. In the 1990s, 13 licenses were issued, and licensees were allowed to fish for sea cucumber as well as buy, process and export sea cucumbers from anywhere within the country. All beche-de-mer exports were accompanied by an export permit issued by the Ministry of Agriculture and Food, Forests and Fisheries. The use of scuba was not restricted in those days and many fishers used it to target deepwater species.

The National Sea Cucumber Fishery Management Plan for Tonga was developed in 2007 prior to the sea cucumber fishery open seasons. Management measures in the plan include six-monthly closed seasons (1 October–31 March), species size limits, a ban on using scuba and hookah apparatus for fishing, export quotas, and limiting the number of export licenses issued. In addition, the plan limited the processing of beche-de-mer to licensed exporters in an effort to improve product quality and improve monitoring of fishing activities. Fishers are free to fish anywhere in Tongan waters but they have to be registered with Tonga Fisheries Division as sea cucumber fishers. These new policies were to improve the management of the fishery through improved monitoring systems, better product quality and improved economic return of the fishery.

1.5 Previous assessments

Tonga's sea cucumber resources are relatively well studied, with the first surveys undertaken in 1984 and 1985 in Vava'u and Ha'apai (Okamoto undated, 1984) and recording substantial sea cucumber populations. In 1990, a joint SPC-Tonga Fisheries Division survey in Ha'apai documented 12 sea cucumber species that were present in sufficient densities for commercial fishing (Preston and Lokani 1990). This survey was followed by a commercial fishery that operated throughout the 1990s. A follow-up assessment in Ha'apai in 1996 revealed a decline in the density of five targeted species (black teatfish, white teatfish, prickly redfish, elephant trunkfish and amberfish) and recommended a 10-year closure of the fishery and for the development of a national sea cucumber fishery management plan (Lokani et al. 1996).

Several sea cucumber resource assessments have been carried out at four sites in Tonga since 2002 (Friedman et al. 2004; Friedman et al. 2009). These assessments documented 22 species of sea cucumbers present at different densities within shallow waters (Friedman et al. 2009). In 2004, another sea cucumber resource survey in the Ha'apai group by SPC and Tonga Fisheries Division documented the recovery of sea cucumber stocks since the moratorium was imposed. Stock densities for five indicator species — white teatfish, prickly redfish, amberfish, elephant trunkfish and curryfish — indicated recoveries of stocks to pre-harvest 1990s levels. However, an exception was the high-value black teatfish, which had not fully recovered after the 10-year closure (Friedman et al. 2010). This is to be expected because black teatfish is slow-growing and takes 10 years to reach sexual maturity, and stocks that are reduced to low density levels will take longer than 10 years to fully recover. Despite several assessments undertaken in Tonga, reliable estimates of fishable stocks by island groups were not available for management use.

1.6 This assessment report

The outcome of the assessment undertaken in 2010 was to be used to assess the status of sea cucumber resources after the last three open seasons, and to decide on future management measures. At the same time, the trained officers can repeat the assessments in the other two island groups and into the future for consistency and comparability of information. Tonga's sea cucumber fishery presents a rare case in the region in that resources have been closely monitored since the 1990s and the effective ban on fishing for 10 years and the development of a sea cucumber management plan present useful lessons. This report presents the results of underwater surveys and cross-checks these results with export information for the open seasons during 2008–2010. The resources and fishery indicators are used to provide updated advice on the way forward for the management of Tonga's sea cucumber fishery. Preliminary advice was provided to the Fisheries Division in March 2011; this advice called for the closing of the fishery in 2011 for three to five years to allow stocks to recover. The completion of this report was delayed to await further resource surveys in Ha'apai by Tonga Fisheries Division; however surveys were not completed in Ha'apai.

2. Methodology

2.1 Fishery assessment

Catch and export data were collected by Tonga Fisheries Division and entered into the sea cucumber exports database developed by the Ministry (Lavenia Vaipuna, Tonga Fisheries Division Statistician, pers. comm.). Data were entered on monthly log forms by processors and exporters as a licensing condition. Data from processers were entered onto logsheets and submitted monthly to the Fisheries Division during the open harvest season. A processor's logsheet provides data on the source location of products, species composition of the catch, and local purchase prices. Export data are provided by exporters each time an export is made. Export data provide information on the quantity of each species, market destination, and export prices per product. Tonga's Ministry of Revenue and Customs collects the final data on export quantity, and these data are submitted to the Fisheries Division on request after each open season. Export permit data and Customs data are cross-checked and verified in the database for compliance. Other summarised data were checked with reports (Friedman et al. 2010; Poasi et al. 2012; Carleton et al. 2013). Relatively good data on export quantity and prices has allowed the assessment of production by the three island groups. Prices paid to fishers were collected by the Fisheries Division and used to provide estimates of the income derived by fishing communities for each island group. To determine income to fishing communities, export data for processed sea cucumber (beche-de-mer) were first converted to wet weight for each species using conversion ratios.

2.2 Resources assessment and reporting

To obtain a complete assessment of sea cucumber resources for Tonga, data are required from all three island groups. Ha'apai was assessed in 1990, 1996 and 2004, and similar assessments are required for Vava'u and Tongatapu for use as baseline information for future monitoring and management. Underwater surveys follow protocols promoted by SPC for Pacific Island countries to use (Friedman et al. 2008, 2010; Pinca et al. 2010; SPC in press). These surveys involve broad-scale assessments over large areas of reef using manta tow, reef front searches, sea cucumber day searches, and fine-scale assessments using reef benthos transects and soft benthos transects in order to provide better coverage of the different sea cucumber habitats.

A manta tow station comprises six replicates of a 300 m x 2 m wide swath, covering 3,600 m^2 (Fig. 2A). For a fine-scale assessment (e.g. a reef benthos transect – RBt, and soft benthos transect – SBt), the station comprises six, 40 m x 1 m transects covering an area of 240 m^2 per station (Fig. 2B). These methods are relatively easy and safe to use to collect counts, species identification and size information. Global positioning system (GPS) coordinates are logged in the general area of a fine-scale station, and for broad-scale manta tows, GPS readings are recorded at the start and end of each 300-m-long replicate. Timed search surveys (reef front swims and deep dive timed searches) were also conducted in a few previously assessed sites in Vava'u in order to determine the condition of the white teatfish stock. (Details of these assessment methods are provided in Friedman et al. 2008, 2010; Pinca et al. 2010; and SPC in press.)

Data were processed and analysed using the Reef Fisheries Integrated Database (RFID) at SPC as part of training attachment for two Tonga Fisheries Officers, Poasi Ngaluafe and Talaofa Lotoahea in February 2011. Analyses of species composition, species densities (individuals per hectare or ind. ha^{-1}), and population size structure were assessed to determine stock health status. Regional reference densities were compared with sea cucumber densities at Vava'u and Tongatapu. The regional reference densities are derived from best densities from sites assessed across the Pacific and can be used to decide on the state of stock health.

A

B

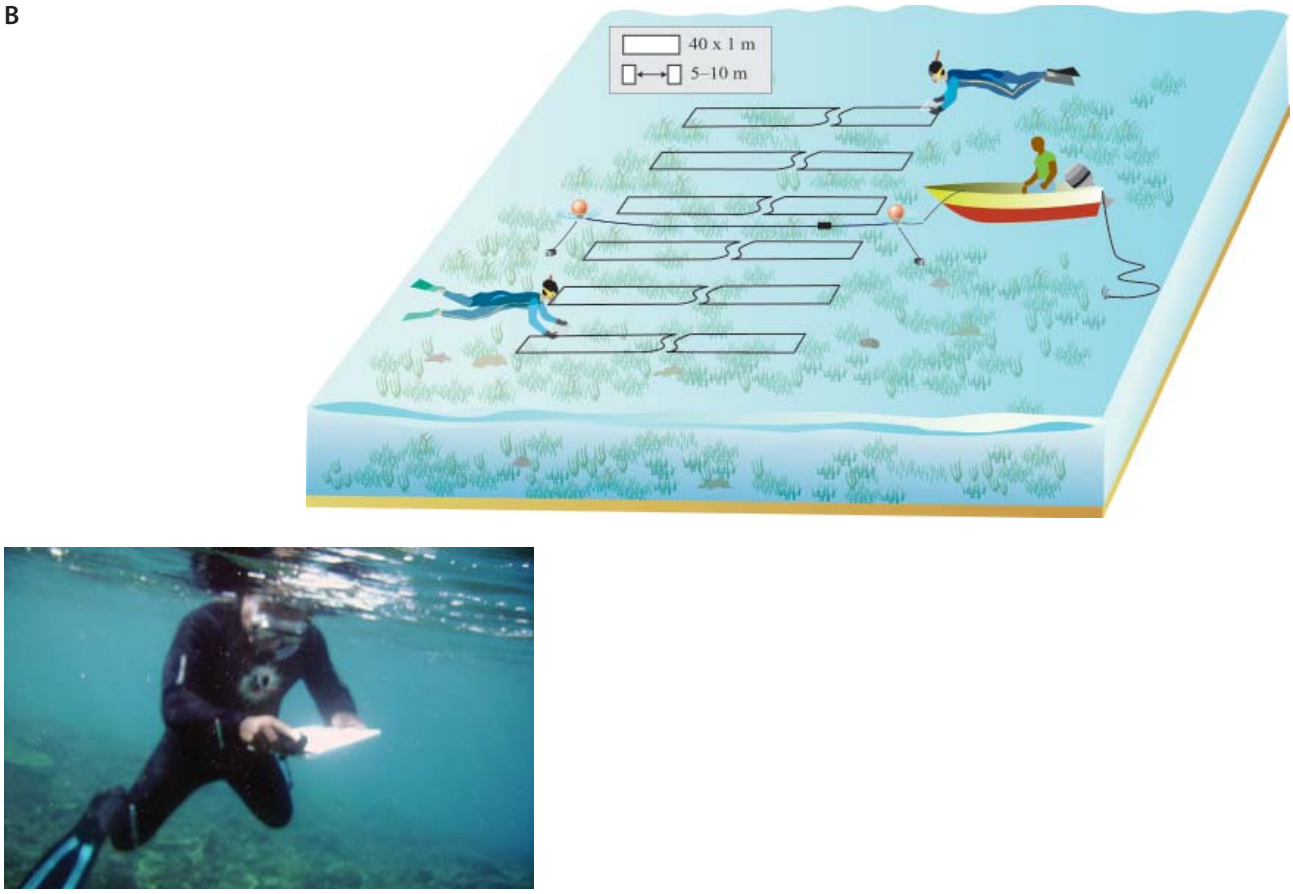

Figure 2. The two main assessment methods used for sea cucumber surveys in Tonga. A: Manta tow surveys; B: reef benthos transects (Illustration by Youngmi Choi, SPC).

3. Results

3.1 Fishery assessment results

3.1.1 Processing and export license and local product prices

Sea cucumber fishers use to dry-process their products and sell directly to exporters, but the processing done by many fishers has been known to produce poor or inconsistent quality of product due to the variability in the ways fishers process their catch. Raw unprocessed sea cucumbers are sold by fishers to licensed processors to be processed to a fully dried product. A licensed processor can be a middleman from an outer island acting as an agent for the licensed export company, or the export company itself can be based in Tongatapu. Selling unprocessed products meant less income for fishers although product quality and consistency has since improved. The minimum buying prices[2] for wet products was set by Tonga Fisheries Division for the 20 commercial species in an attempt to control price fluctuations (Table 2). This, however, was difficult to enforce because of the high competition for products among exporters and the variation of prices and reduced prices for most products. Variation in local product buying prices from 10 processors reflected competition among exporters for products.

Table 2. Mean beach prices of wet (unprocessed) sea cucumbers in Tonga during the 2010 harvest season and average "Melanesian countries + Tonga" prices[3]. TOP = Tonga pa'anga, USD = US dollars.

Common name	Set price (TOP)	Actual price range (TOP)	Mean price (TOP)	Regional price (USD)
White teatfish	2.00	25.00–65.00	41.00	84
Black teatfish	3.00	10.00–25.00	17.57	53
Prickly redfish	22.00	4.00–15.00	9.20	45
Hairy blackfish	20.00	4.00–15.00	8.17	20
Stonefish	40.00	3.00–11.00	6.40	20
Surf redfish	2.00	2.00–6.00	4.80	39
Amberfish	5.00	1.00–5.00	3.14	14
Elephant trunkfish	20.00	1.00–8.00	2.83	11
Curryfish	20.00	2.00–4.00	2.80	20
Tigerfish	2.00	1.00–3.00	2.19	20
Deepwater redfish	3.00	2.00	2.00	45
Brown sandfish	25.00	1.00–1.50	1.17	14
Dragonfish	3.00	1.00	1.00	14
Greenfish	3.00	0.06–0.16	0.11	50
Lollyfish	30.00	0.10–0.12	0.10	11
Snakefish	10.00	0.09–0.10	0.09	16
Chalkfish	10.00	0.05–0.06	0.06	14
Flowerfish	3.00	n/a	n/a	14
Pinkfish	3.00	n/a	n/a	6
Golden sandfish	20.00	n/a	n/a	60

[2] Minimum prices were set however they were not followed.

[3] Average Melanesian countries + Tonga prices were determined by Carleton et al. 2013, they are the average prices paid to fishers for well processed, high grade beche-de-mer from Papua New Guinea, Solomon Islands, Vanuatu, Fiji and Tonga.

The number of export licences allocated per fishing sea season was capped at nine licenses in the Tonga National Sea Cucumber Fishery Management Plan. In 2008, seven licenses were issued at an annual license fee of TOP 2,000 per license. Export licenses increased to 27 in 2009 and 23 in 2010, and in 2011 the number of export licenses issued dropped to 11 (Fig. 3). Annual license fees were raised in 2010 to TOP 30,000, with the intention of forcing a reduction in the number of exporters by limiting licenses to those who could afford the high fees. This did not deter interest, however, and 23 licenses were issued. The increased license fee disadvantaged some companies, particularly those owned by Tongan nationals, because they could not afford the high license fees. Export operators were then dominated by foreigners, mainly Chinese nationals who could afford the high license fees, and many of these are in joint venture arrangements with local partners (Poasi Ngaluafe, Tonga Fisheries Officer, pers. comm.).

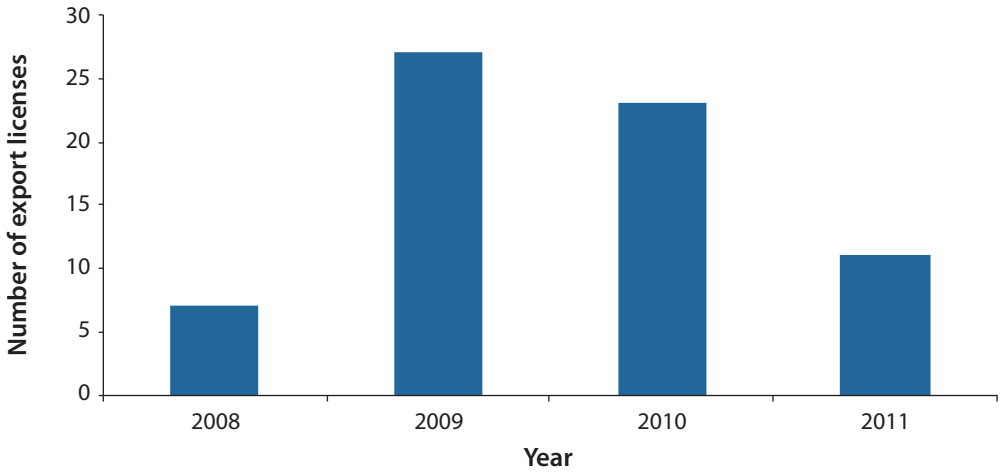

Figure 3. Trends in the number of export license issued over the period 2008–2011 (Tonga Fisheries Division).

3.1.2 Export production trend

Catch and export production information from 2008 to 2011 indicates a decline in catch after 2009 (Fig. 4). Tonga has gone through its second 'boom and bust' cycle, the first boom production peaked at 70 tonnes in 1995 before the introduction of the moratorium during the last quarter of 1997. Tonga later experienced a major boom production in the 2009 and 2010 seasons, with a recorded production of 360 tonnes, and by 2011 exports declined to 79 tonnes (Fig. 4). Modest productions in the 1990s allowed healthy stocks to replenish during the 10-year moratorium. The high production in 2009 and 2010 could be due to the strong recovery of stocks and the harvest for more species, including species that were of no commercial interest in the past. For example snakefish was not harvested during the early 90's, but has occured in recent catch and exports in 2013. These species with no previous commercial value were harvested in the 2008–2010 period.

The 2008 harvest season was modest, resulting in 15 tonnes of exports from a quota allocation of 189 tonnes, and actual harvesting occurred over a shorter time frame, between one and two months (Siola'a. Malimali, Deputy Secretary for Fisheries, pers. comm.). In addition, the low production was due to a lack of knowledge about the open season, and licensed operators targeting mainly high-value species in Hapa'ai. Growing interest in 2009 resulted in an increase in the number of licenses issued; exports of 360 tonnes (with a quota over-run of 156 tonnes) were recorded for the 2009 season, and 318 tonnes (over-run of 106 tonnes) were recorded for the 2010 season (Fig. 5). Scientific advice provided in March 2011 recommended that the fishery be closed for another three to five years to allow stocks to recover. This advice, however, was not accepted and another fishing season was allowed to proceed in 2011 but with a reduced export quota of 100 tonnes; however, 79 tonnes were exported despite extending the open season by two weeks. Open seasons continued in 2012 and in 2013 although export data have not been made available for these assessments. Table 3 summarises the status of these management measures for the six harvest seasons.

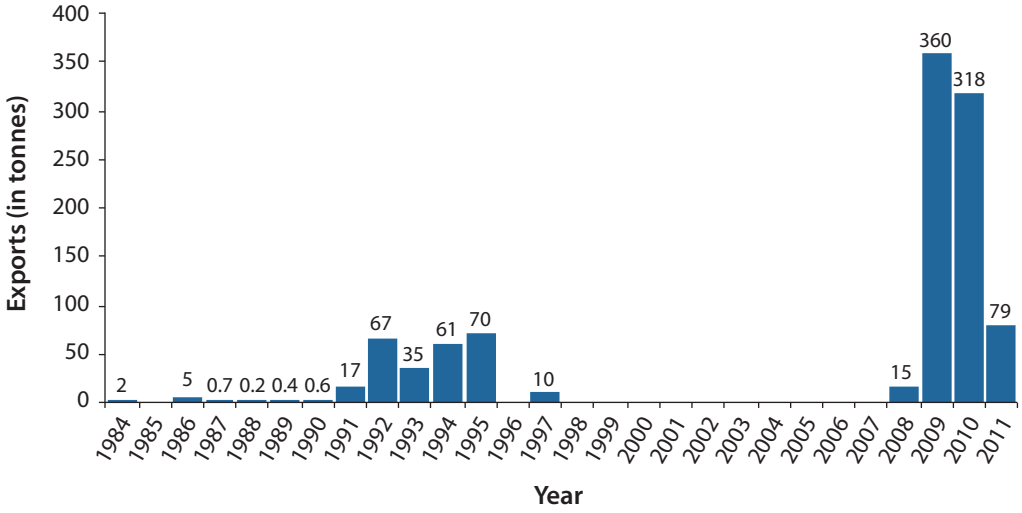

Figure 4. Historical beche-de-mer exports from Tonga.

Table 3. Fishery management measures prescribed in the management plan (*in italics*) and actual number of licences, period of open seasons, and quantity of exports for the Tonga sea cucumber fishery.

	2008	2009	2010	2011	2012	2013
Export license permitted	*9*	*9*	*9*	*9*	*9*	*9*
Export licenses issued	5	27	23	11	10	9
Open season (months)	*6*	*6*	*6*	*6*	*6*	*6*
Actual open season (months)	3 (August–October)	9 (March–December)	7 (March–September)	4 (June–October)	7 (April–October)	2 (August–October)
BdM export quota (tonnes)	*189*	*204*	*212*	*100*	*103*	*No quota*
BdM exports (tonnes)	15	360	318	79	68	63
Export license fees (TOP)	2,000	2,000	30,000	30,000	30,000	27,000

Changes over time in the composition of species harvested are common in multi-species sea cucumber fisheries. Usually, higher-value species groups are targeted in the early years of exploitation, followed by the lower-value species groups as the formerly higher-value species become depleted. Often, the higher-value species occur at lower relative densities to the less valued species, leading to rapid reductions in density across fishing grounds. Beche-de-mer data from Tonga's three main island groups follow this pattern as indicated by catch composition data from each island group for 2008, 2009 and 2010 (Fig. 6).

For Ha'apai, the dominance of harvested species shifts to lollyfish in the latter two seasons when high-value white teatfish were fished to low levels in the 2008 season. The same trend is evident in Tongatapu and in Vava'u where medium- and low-value species dominated production as high-value species decreased in catches. For Vava'u, catches of low- and medium-value species increased from 79% to 84% and to 92% for 2008, 2009 and 2010, and for Tongatapu from 88% to 91% and to 92% for 2008, 2009 and 2010, respectfully.

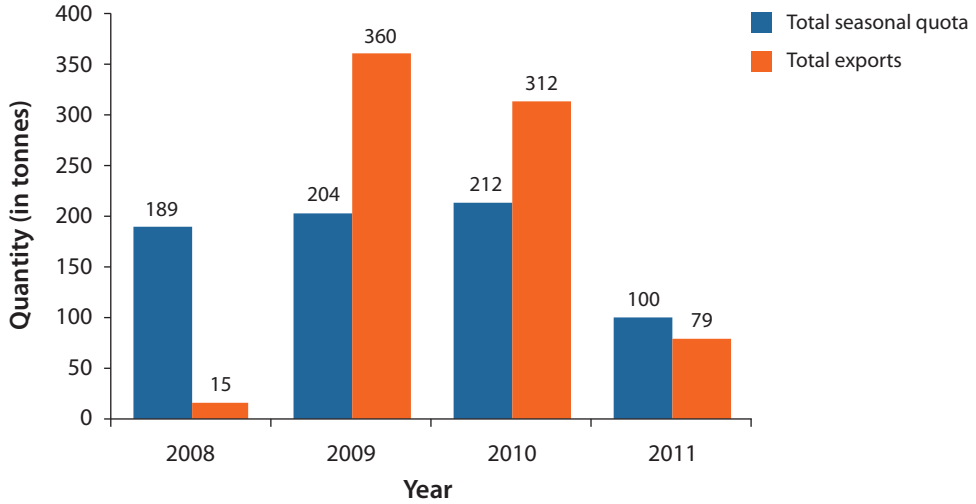

Figure 5. Beche-de-mer export quota and actual exports from Tonga.

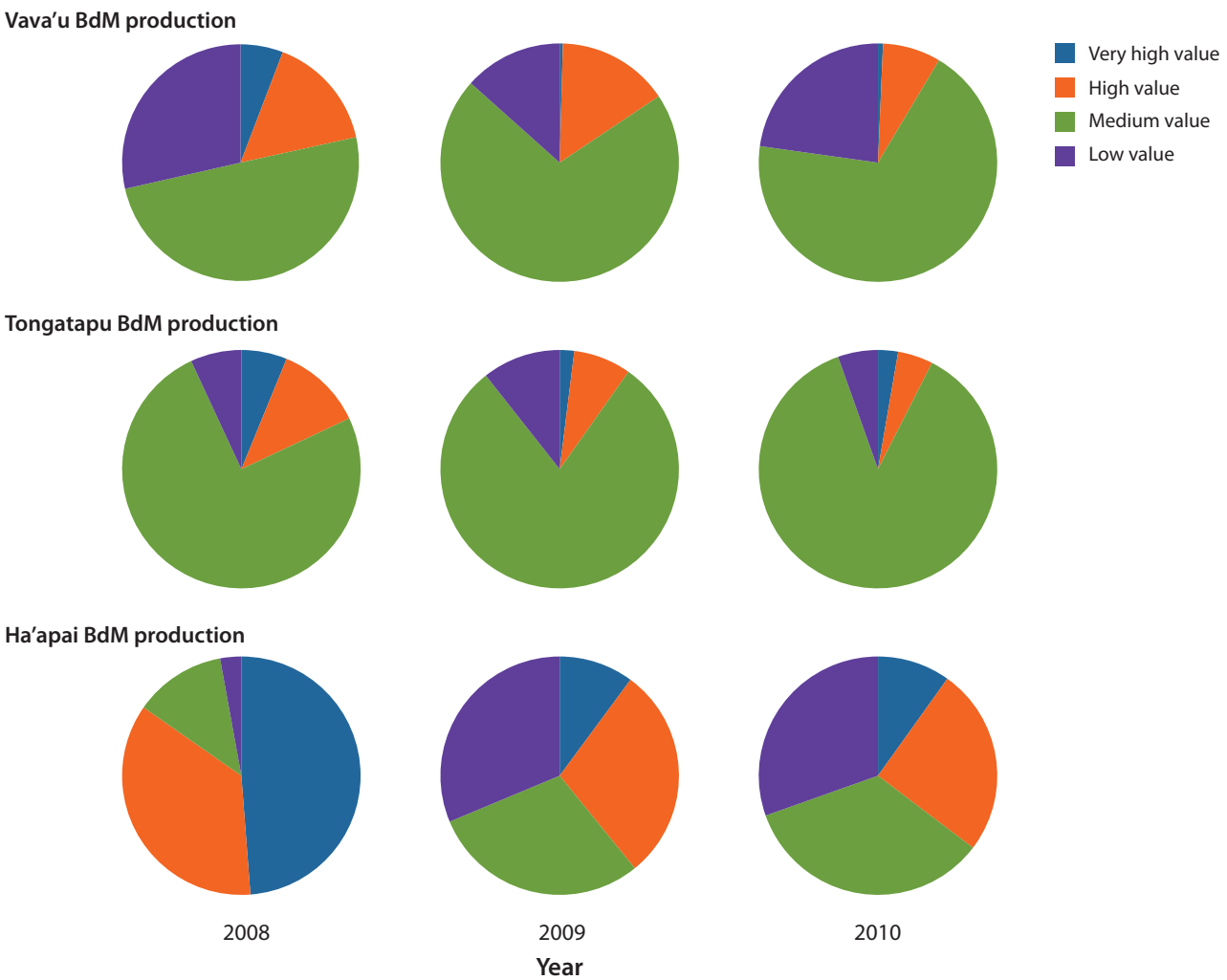

Figure 6. Trends in catch composition (proportion of dry weight exports) for 2008, 2009 and 2010 from Tonga's three main island groups — Vava'u, Tongatapu and Ha'apai.
Very high value: white teatfish; High value: black teatfish, deepwater redfish, greenfish, prickly redfish, surf redfish; Medium value: hairy blackfish, amberfish, brown sandfish, chalkfish, curryfish, dragonfish, flowerfish, snakefish, stonefish, tigerfish; Low value: elephant trunckfish, lollyfish, pinkfish.

3.1.3 Production value

Due to the lack of export price information, the value of the sea cucumber fishery to the country is difficult to estimate. However, prices paid to fishers for fresh unprocessed sea cucumber are available (Table 2) and the average prices for species were used to provide an estimate of the income fishers derived from this fishery. For the 2009 and 2010 seasons the fishery has provided earnings of approximately TOP 9.9 million and 8.5 million, respectively, to households that collect sea cucumbers (Fig. 7). A breakdown of the income to fishing communities by island group is provided in Figure 8.

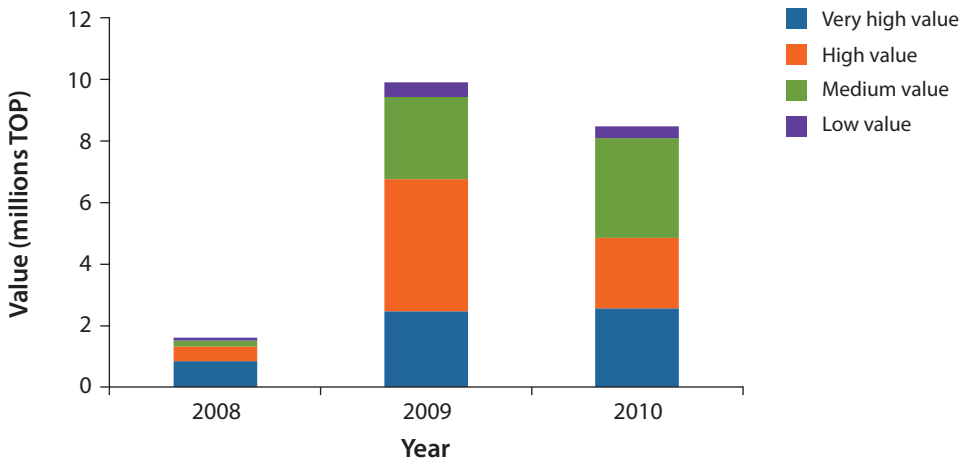

Figure 7. Total estimated earnings for Tonga sea cucumber fishers for 2008, 2009 and 2010.

A study in Tonga, Fiji, Papua New Guinea, Solomon Islands and Vanuatu estimated the average prices paid by species level for well processed, high grade beche-de-mer in these countries (Carleton et al. 2013) (Table 2). In the absence of export prices for beche-de-mer, these regional average prices were used to try and provide an estimate of the value of Tonga's sea cucumber fishery to producers and processors. The average prices determined by Carleton et al. (2013) are for well processed, high quality beche-de-mer. For the 2009 and 2010 seasons 360 tonnes and 318 tonnes of beche-de-mer, respectively, were exported. The estimated value to fishers and processors from the two seasons is on the order of USD 7 million or TOP 13 million per season. This estimate could be slightly overestimated and should be treated with some caution because prices for beche-de-mer within these five countries vary considerably due to species value groups, size of the product, quality of the processing, and location of sales.

Income generated directly by the government through licensing fees and fines are provided in Table 4. In the first two seasons, license fees totalled TOP 2,000 and increased to TOP 30,000 in 2010. Income generated from export license fees and fines from illegally possessing sea cucumber products totalled more than TOP 1.2 million for 2008, 2009 and 2011 combined (Table 4). In addition, the Tonga Fisheries Division estimates the total value of the fishery to be TOP 2 million for 2008 and TOP 12 million for 2009 and 2010 combined.

Table 4. Sea cucumber license fees, fines and estimated value of the fishery for the period 2008–2011 (Tonga Fisheries Division 2011).

Year	Fee (TOP)	Export license	Total fees (TOP)	Fines (TOP)	Total estimated value (TOP)
2008	2,000	7	14,000	98,792	2,000,000
2009	2,000	27	54,000		12,000,000
2010	30,000	23	690,000	14,025	12,000,000
2011	30,000	11	330,000		

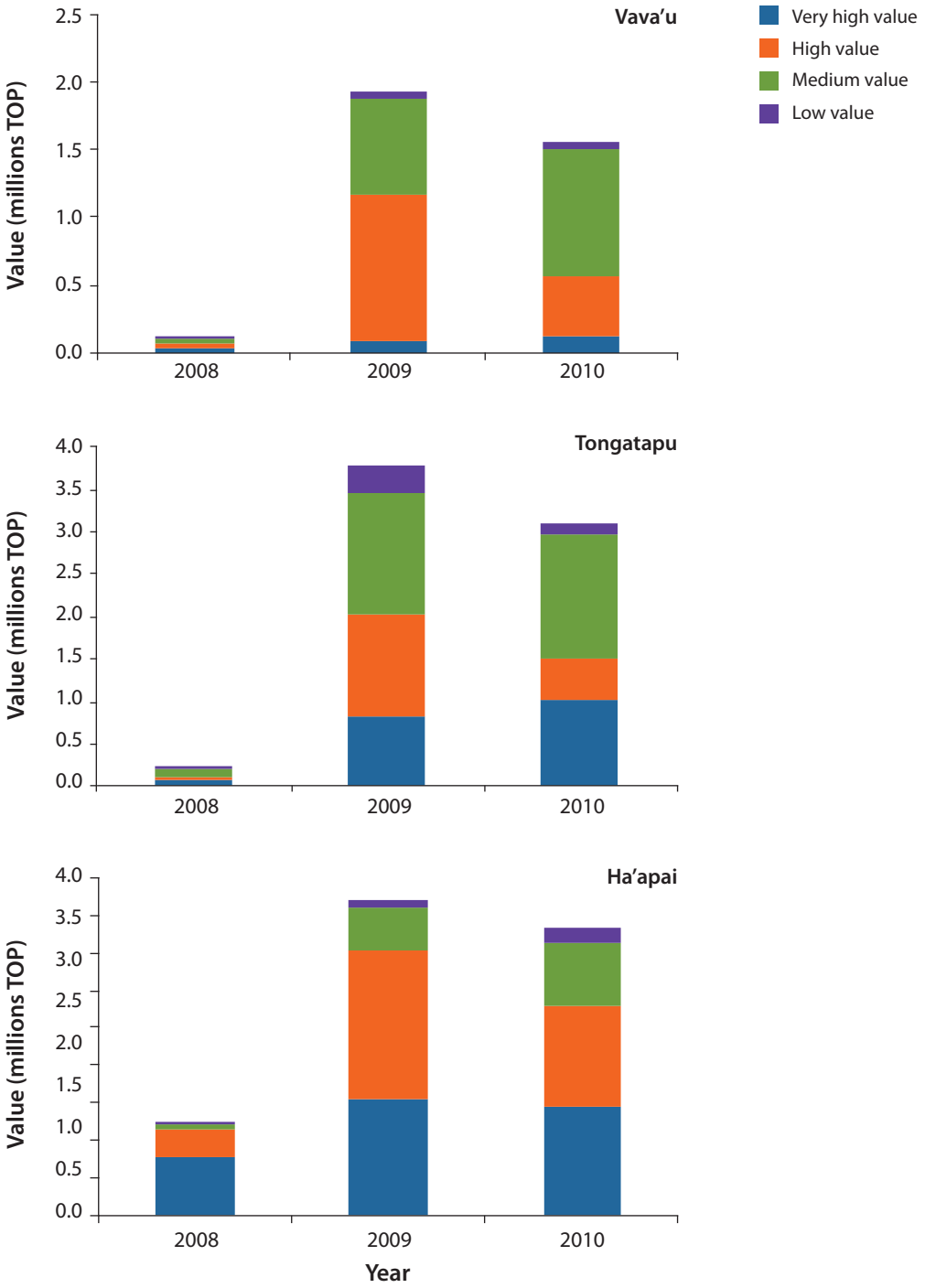

Figure 8. Estimated earnings for sea cucumber fishers in each of Tonga's three main island groups.

3.2 Resource assessment results

3.2.1 Survey coverage

In total, 78 survey stations were completed in Vava'u, covering an area of 17 ha, and in Tongatapu, 47 stations were completed, covering 16.5 ha of reef and lagoon habitat (Table 5). The majority of assessments using reef transects and manta tow surveys (16 ha) targeted shallow waters from 0 to 10 m. Deep lagoon assessments by scuba were not emphasised in the survey although scuba was used in specific areas already surveyed by the Tonga Fisheries Division team to investigate the status of white teatfish species. Distributions of sampling stations by sites assessed are displayed in Figure 9.

Table 5. Survey coverage in Vava'u and Tongatapu, 2010–2011.

Survey methods	Tongatapu		Vava'u	
	Number	Area (m^2)	Number	Area (m^2)
Manta tow (Manta)	10	36,000	16	57,600
Reef benthos transect (RBt)			29	6,960
Reef front search (RFS)	23	66,010	12	34,440
Sea cucumber daysearch (Deep dive)	14	63,336	15	67,860
MOP_transect			4	6,384
Soft_benthos_transect (SBt)			2	480
Total area (m^2)		**165,346**		**173,724**
Total area (ha)		**16.5**		**17.4**

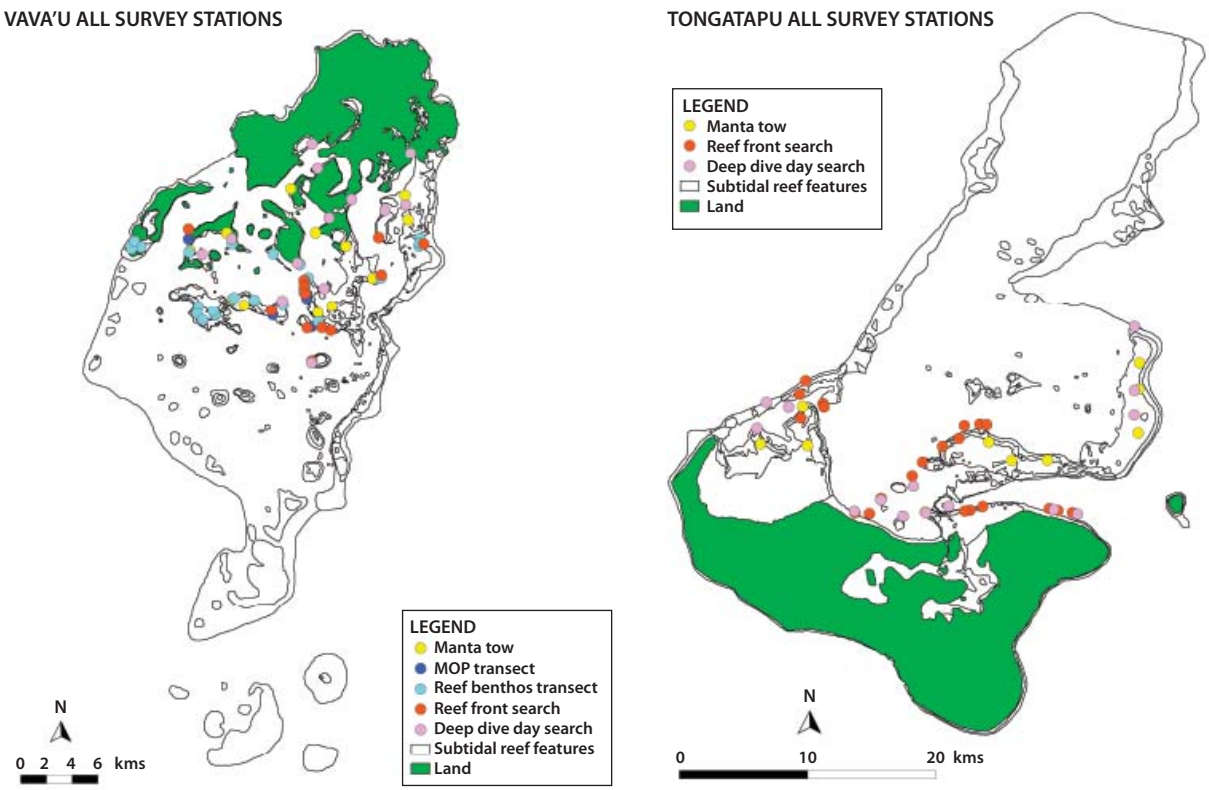

Figure 9. Distribution of sampling stations in Vava'u (left) and Tongatapu (right). Note; large proportion of the reef complex was not surveyed towards the southern end of the Vava'u and northern end of Tongatapu.

3.2.2 Species presence

Recent surveys recorded 16 sea cucumber species in Vava'u. Two species — black teatfish and chalkfish — that featured in the catch data were not recorded in underwater surveys, which brings the total number to 18 species for Vava'u (Table 6). Black teatfish production for Vava'u was low overall with 60 kg in 2008, 999 kg for 2009, and 344 kg for 2010. Significant production of chalkfish was exported from Vava'u in 2009 and 2010 with 7,642 kg and 5,599 kg, respectively, which indicated relatively good stock levels. The current surveys did not adequately target typical habitat areas (soft bottom seagrass bed) for chalkfish.

In this survey, 19 sea cucumbers species were recorded, including deepwater spiky redfish, a previously unrecorded species, which adds a new record for Tonga. Three species, hairy blackfish, deepwater blackfish and white snakefish were not recorded in this survey; however, they were recorded in export records in past surveys. In the catch record, hairy blackfish was traded at 51 kg for 2008; 3,195 kg for 2009; and 2,252 kg for 2010, while deepwater blackfish was rare and only exploited in the subsistence fishery sector.

Table 6. Sea cucumber species present (shown by + symbol) by island group in Tonga (Ha'apai records are from the 2004 surveys).

Common name	Vava'u	Tongatapu	Ha'apai
Amberfish	+	+	+
Black teatfish	+	+	+
Brown sandfish	+	+	+
Chalkfish	+	+	+
Curryfish	+	+	+
Deepwater blackfish			+
Deepwater redfish	+	+	+
Deepwater spiky redfish		+	+
Dragonfish	+	+	+
Elephant trunkfish	+	+	+
Golden sandfish	+	+	+
Greenfish	+	+	+
Lollyfish	+	+	+
Pinkfish	+	+	+
Prickly redfish	+	+	+
Snakefish	+	+	+
Stonefish	+	+	+
Surf redfish	+	+	+
Tigerfish	+	+	+
White snakefish			+
White teatfish	+	+	+
Total species recorded	**18**	**19**	**21**

3.2.3 Species abundance and densities

Relative abundance (expressed as the density of individuals per hectare) describes how many species are present in relation other species. The relative abundance of species can be a result of natural population dynamics (growth, mortality, recruitment), in addition to the effect of certain management measures, and/or fishing pressure. Expressing mean density for all survey stations explains the overall abundance in a given area, and the value can be relatively low because of the inclusion of stations with zero records. However, this estimate is the most accurate for estimating the overall density of sea cucumbers for a complete fishing area. In contrast, calculating mean density (or present mean) by only including stations where at least one individual was recorded (i.e. excluding zero presence records), is the best description of a species' relative abundance because it only uses stations where individuals are present. This is especially important in invertebrates such as sea cucumbers where distributions are extremely patchy or aggregated.

Figure 10 and Table 4 shows that lollyfish is the most abundant species, with relatively lower densities recorded from manta stations in Vava'u than in Tongatapu. Pinkfish, snakefish, and greenfish are also relatively more abundant throughout the two island groups compared with other species. The exceptions were chalkfish, which were the second most abundant species in manta surveys in Tongatapu, and surf redfish which were the most abundant species in reef belt transects surveys in Vava'u. The latter result from reef benthos transect surveys is most likely due to the surveys being concentrated in more exposed surf habitats where manta tows do not cover areas as efficiently, and where this species is often dominant. Figure 11 shows the distribution of relative densities for all sea cucumber species in Vava'u and Tongatapu. The pattern of relative abundance is patchy and may be related to habitat preferences as well as harvest pressures.

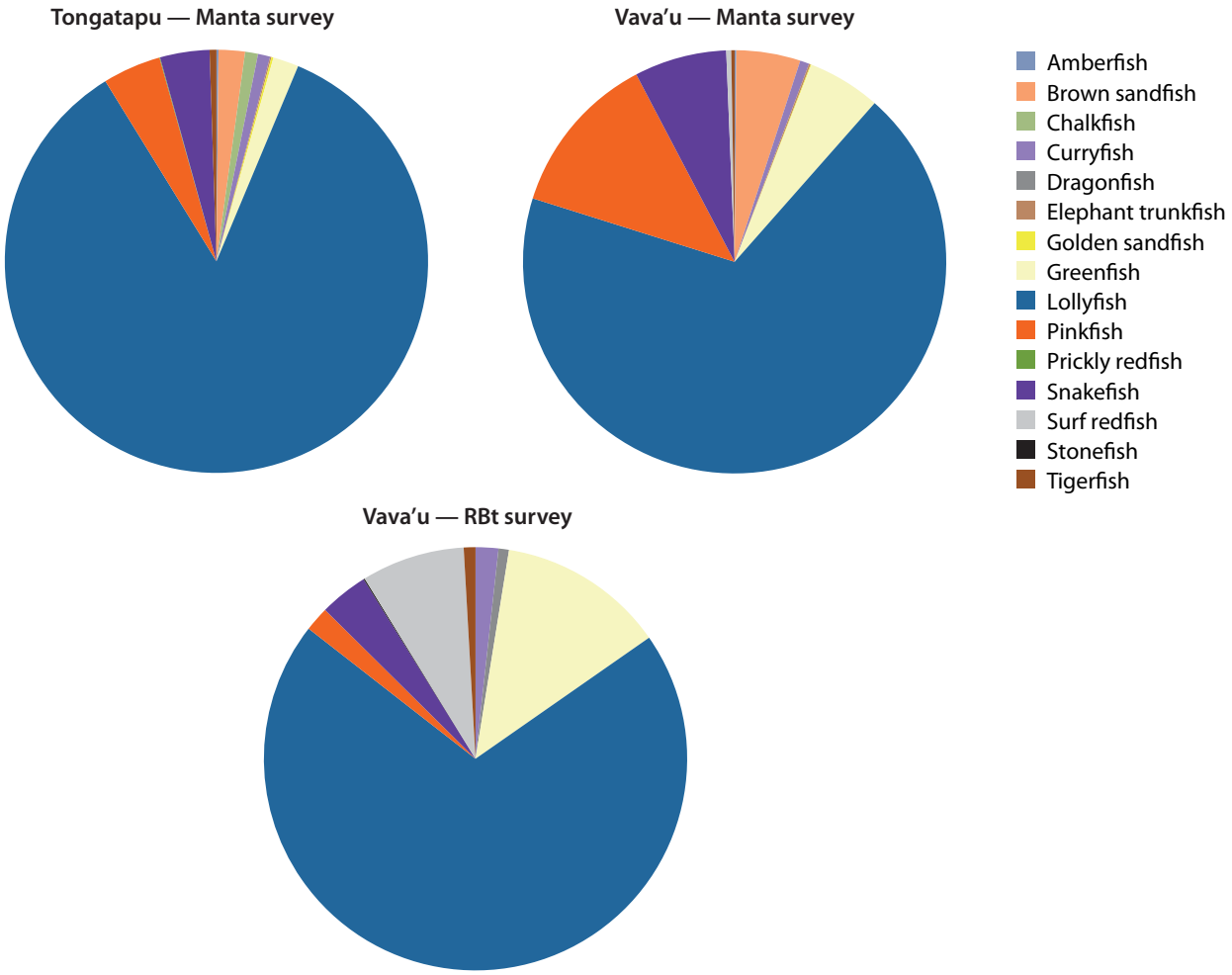

Figure 10. Pie charts showing the relative abundance of sea cucumber species recorded in manta and reef benthos transects in 2010 and 2011 for Vava'u and Tongatapu.

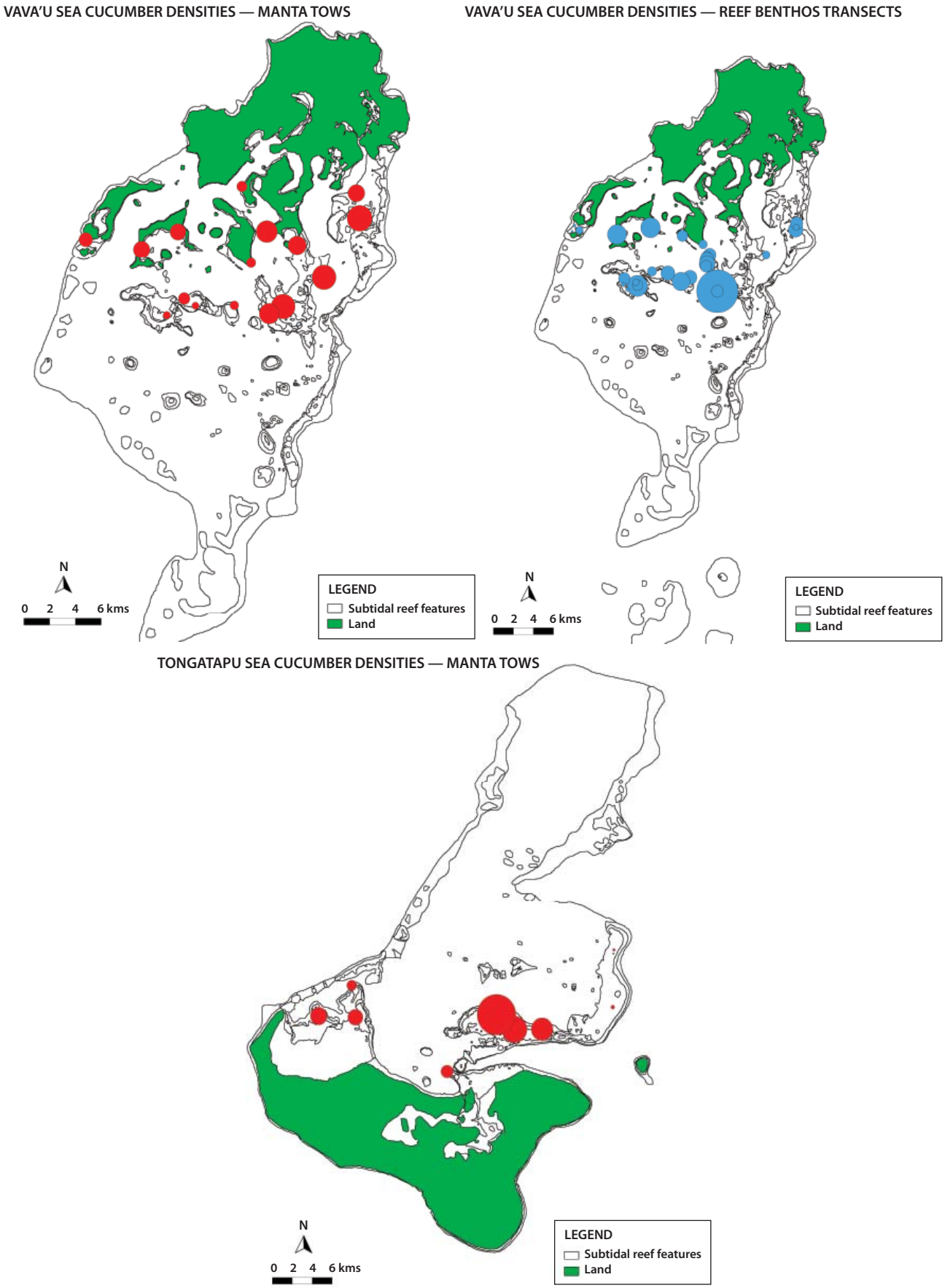

Figure 11. Distribution of sea cucumber relative densities for all sea cucumber species in manta tow (red circles) and reef benthos transect (blue circles) survey stations in Vava'u and Tongatapu. The size of the circles represents the relative densities of all species of sea cucumbers recorded.

3.2.4 Density comparison with Pacific reference densities

Overall mean densities for species were compared against Pacific mean reference densities for 16 species (Table 7). Regional reference densities for sea cucumbers are mean densities for the upper 25% of densities taken from 90 sites assessed across the Pacific Islands region. These regional mean densities are used as reference points for healthy stock abundance based on a 'rule of thumb' as a management decision-making tool. All of the species assessed in Vava'u and Tongatapu had mean densities lower than Pacific-wide reference densities for manta assessments, indicating the impact of recent fishing activities in Vava'u and Tongatapu (Fig. 12). Mean densities for species assessed are listed in Appendix 1.

Table 7. Species densities (ind. ha^{-1}) from manta tow and reef benthos transect assessments compared with regional mean densities for sea cucumbers.

Survey type	Common name	Vava'u	Tongatapu	Pacific reference density
Manta	Lollyfish	1,075	1,641	2,400
	Chalkfish	n.a.	19	1,400
	Greenfish	88	38	1,000
	Golden sandfish	1	3	700
	Snakefish	111	73	350
	Pinkfish	196	86	250
	Brown sandfish	77	39	130
	Curryfish	11	18	130
	Tigerfish	4	10	50
	Surf redfish	6	n.a.	20
	Amberfish	2	3	20
	Black teatfish	n.a.	n.a.	10
	White teatfish	n.a.	n.a.	10
	Prickly redfish	n.a.	1	10
	Elephant trunkfish	2	2	10
RBt-SBt	Lollyfish	1,496	n.a.	5,600
	Greenfish	272	n.a.	3,500
	Snakefish	79	n.a.	1,100
	Pinkfish	40	n.a.	260
	Surf redfish	168	n.a.	200
	Tigerfish	19	n.a.	120
	Curryfish	37	n.a.	100
	Stonefish	2	n.a.	10
	Dragonfish	17	n.a.	n.a.

RBt = Reef benthos transect; SBt = Soft benthos transect; n.a. = sample insufficient to determine relative density (no SBt and RBt surveys conducted in Tongatapu).

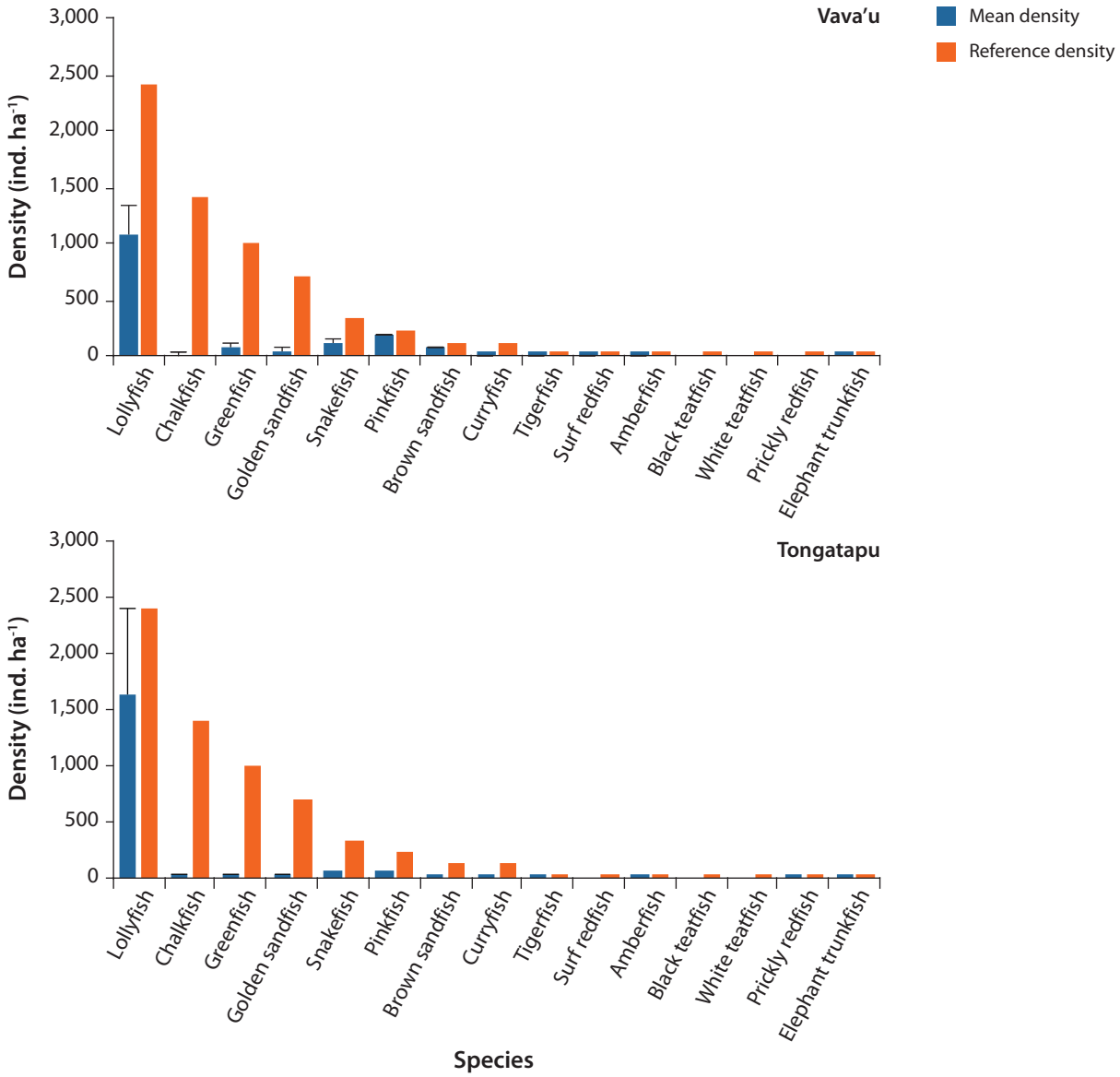

Figure 12. Regional mean density comparison with recent Tonga densities for manta surveys (Vava'u and Tongatapu densities = blue bar; regional reference density = red bar).

3.2.5 Population size structure

Some sea cucumber species vary in size by different geographical locations across the Pacific. Size variation is observed in greenfish, sandfish, dragonfish, brown curryfish and lollyfish, which are not well studied. Generally length information of sea cucumbers obtained from reasonable sample sizes provides information on stock structure and an indication of recruitment, mature proportion of the population and the impact of fishing on stock structure. Here, mean sizes for the majority of sea cucumbers in Vava'u (81%) and Tongatapu (85%) were smaller than their respective common sizes recorded elsewhere in the Pacific (Figs. 13 and 14), which indicate young populations due to recent extraction of larger, more valuable specimens from sea cucumber populations. Appendices 2 and 3 list the mean size and associated statistics for sea cucumbers assessed in Vava'u and Tongatapu.

Size frequency distributions for lollyfish (Fig. 15) and greenfish (Fig. 16) from Vava'u were sufficient to assess stock condition. The majority of the populations of both species are less than their common size of 230 mm. The maximum size of lollyfish recorded in Vava'u was 385 mm, which is 40% smaller than the maximum length (650 mm) of lollyfish. For green fish the maximum length recorded in Vava'u was 255 mm while the

maximum size recorded for the species was 385 mm. The absence of larger greenfish is due to the recent extraction of larger, more valuable specimens leaving behind smaller specimens in the population.

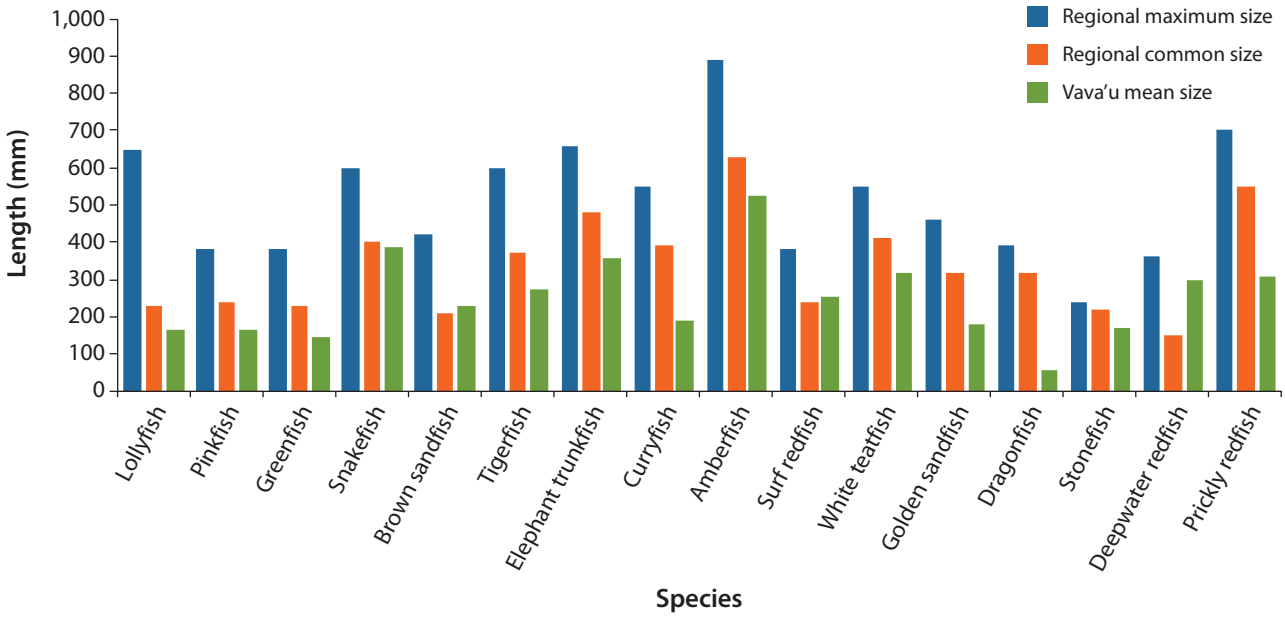

Figure 13. Mean sea cucumber size (mm) for Vava'u in comparison with regional common and maximum sizes (regional maximum size = blue bar; regional common size = orange bar; Vava'u mean size = green bar).

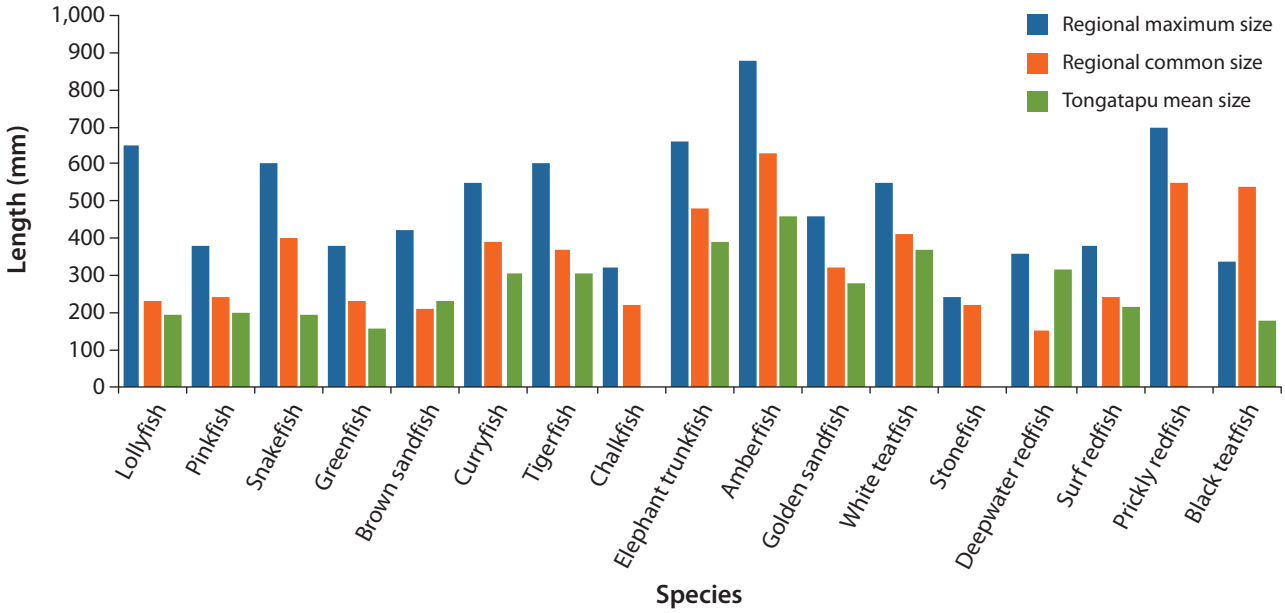

Figure 14. Mean sea cucumber size (mm) in Tongatapu compared with regional common and maximum sizes (regional maximum size = blue bar; regional common size = orange bar; Tongatapu mean size = green bar). Note: chalkfish, stonefish and prickly redfish were recorded in the assessment but no specimens were measured.

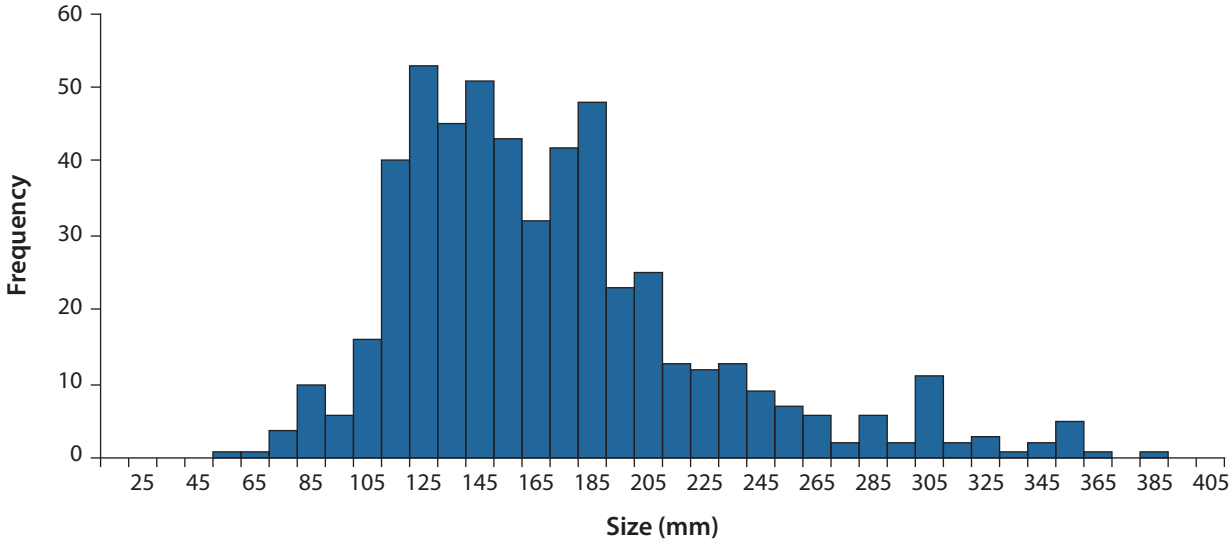

Figure 15. Size distribution for lollyfish in Vava'u (mean size 166 mm).

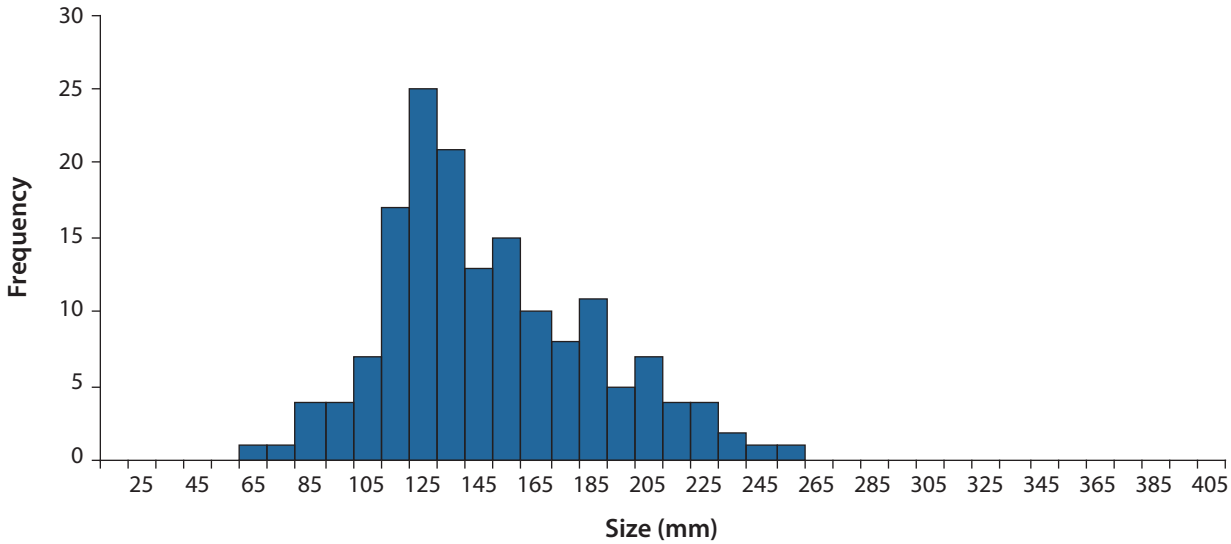

Figure 16. Size distribution for greenfish in Vava'u (mean size 144 mm).

3.2.6 Stock estimation for Vava'u

The reef habitat areas of Vava'u and Tongatapu were calculated using geographical information system (GIS) tools and using LandSat maps from Millennium Project maps (Andréfouët et al. 2006). Shallow reef zones (down to 10 m) covered by the surveys and which are important for stock estimation purposes are presented in Table 8. The total reef area for Vava'u and Tongatapu can be used in calculating stock estimates from which catch or export quotas can be determined. Estimates of stocks were not performed in this reporting because status indicators showed a declining resource trend in terms of density and population mean sizes, which require management intervention more than further exploitation of the resource.

Table 8. Habitat surface areas for Vava'u, Ha'apai and Tongatapu, which have been calculated by QGIS (an open source GIS system), using map projection WGS84/UTM-2S and using habitat maps generated by Andréfouët et al. (2006). Refer to Appendix 4 for geomorphological classification.

Habitat attribute	Surface area (ha)		
	Vava'u	Tongatapu	Ha'apai
Barrier reef / pinnacle patch	-	50	36
Channel	-	19	-
Deep drowned reef flat	820	6,237	3,825
Deep terrace	-	-	9,304
Deep terrace with constructions	-	-	11,755
Diffuse fringing reef	341	5,199	373
Enclosed basin	-	82	-
Enclosed lagoon	563	535	-
Forereef	3,288	2,619	10,671
Forereef or terrace	-	399	-
Pinnacle	23	-	-
Reef flat	3,156	3,872	10,573
Shallow terrace	2,982	2,487	1,925
Shallow terrace with constructions	382	3,735	2,871
Shelf slope	-	-	100,127
Shelf terrace with constructions	-	-	257,956
Subtidal reef flat	1,454	1,575	4,646
Total habitat area	**13,009**	**26,808**	**414,062**

4. Discussions

While sea cucumber species diversity in Vava'u and Tongatapu remain unaffected by fishing activities, their abundance is affected. Densities of all species in Vava'u and Tongatapu were lower than regional reference densities for healthy abundance. The decision taken in 2009 to prohibit the commercial fishing of golden sandfish was a sound one to protect this important subsistence species form further depletion. The same species is also of interest for aquaculture development, and so preserving existing stocks is important to support future breeding programmes. Heavy fishing in the latter two seasons (2009 and 2010) has reduced sea cucumber stocks in Vava'u and Tongatapu. Densities in Tongatapu were lower than Vava'u. Overall mean sizes were smaller than their common sizes. Closing the fishery would allow stocks to recover to full maturity potential for high-grade products, and in addition improve stronger recruitment capacity.

Tonga was ahead of other Pacific Island countries in successfully enforcing a 10-year moratorium on its sea cucumber fishery. The 10-year closure allowed recovery of most sea cucumbers species, which were closely monitored until the fishery opened in 2008. In the 1990s, fishing was relatively modest with production below 70 tonnes. The current high exploitation has reduced the breeding population to the extent that another moratorium will be needed for existing stocks to recover to healthy levels.

The Tonga sea cucumber fishery management plan contains many measures for sustainably managing the fishery. The separation of processing licences from exporting licences, restricting processing to licence holders only, setting local prices of wet products, establishing a product tracing system from fishing ground to export exit points, are all sound management measures. It is the implementation of, and adherence to, the plan in the later seasons that was not maintained, resulting in escalating numbers of export licences, the extension of the open season and non-compliance to the catch quota limits, and subsequently low catches and exports.

The development of separate licenses for processing and exporting beche-de-mer was a good management decision that enabled the monitoring and generation of catch data by area, as well traceability of product to fishing grounds, and an evaluation of economic returns to rural communities. In addition, the policy opened opportunities for local citizens to participate in the sea cucumber industry in terms of processing and selling products, and ensures improved product quality. The minimum prices set would have benefited the fishers had the quota on the number of licenses and annual exports been effectively enforced. Competition by the many licensed operators allowed fluctuations in prices, which are driven mainly by exporters making it impossible to enforce these minimum price measures.

Fishing for sea cucumbers in Tonga was concentrated in shallow waters from 0 m to 10 m (apart from those illegally collected by fishers using UBA gear in deeper areas). While the use of scuba gears is illegal, many fishers have used the gear to harvest deep-water sea cucumbers such as white teatfish. Scuba diving for sea cucumbers was practiced illegally in the three island groups which have resulted in several dive related paralysis and deaths (Siola'a. Malimali, Deputy Secretary for Fisheries pers. comm.). The increase in white teatfish catches in Ha'apai may have been from scuba diving operators.

The shift in species composition from high-value to low-value species in the catches from Tonga's three main island groups demonstrates that fishers turn to targetting the more abundant low-value species as a result of diminishing stocks of high-value species. The pressure to opportunistically harvest higher-value species that is low in density continues at the same time as fishers are harvesting the low-value snakefish and lollyfish. The overcapacity within the fishery, reduction of the abundance of high-value species, and the need for income resulted in the increase of snakefish and lollyfish catches in the later seasons as fishers and sea cucumber processing and export companies strive to make sufficient profit margins to offset expenditure and putting more pressure on what species are available to be harvested.

5. Recommendations for improved management

1. ***Moratoria:*** Tonga's sea cucumber fishery experienced another 'boom and bust cycle', with high production in 2009 and 2010 followed by falling production. The advice in 2011 to let the fishery rest for three to five years was timely, and if this advice had been followed it would have helped maintain resources at a healthy abundance, which would have supported a quicker stock recovery. However, open harvest seasons have occurred in 2011, 2012 and 2013, which will reduce existing breeding populations, thereby prolonging the time needed for stocks to recover. Therefore, to achieve stock levels prior to 2008, another 10 or more years of allowing the fishery to rest would be required.
2. ***Annual export quota:*** The annual export quota allocation was set too high in the first four open seasons. Harvest and export productions in the 1990s were modest and peaked at 70 tonnes. This modest production ensured sufficient stocks, which supported recovery in the last 10-year closure of the fishery. Considering Tonga's relatively limited sea cucumber habitat, past production levels provide a good bench-mark for setting annual export quotas. It is recommended that after stocks have recovered from a moratorium on harvesting and exports, any future harvest quota should be set at a more conservative level (less than 70 tonnes), and should be set at the species level. Effective monitoring systems to track harvest, processing and exports by island group should be maintained. Any quota over-runs[4] for an open season should be subtracted from the following year's quota.
3. ***Prescribed species:*** The more valuable species were harvested at the start of an opening season of the fishery and when these high-value stocks were reduced, effort shifted to whatever species remained. The pressure to opportunistically harvest higher-value species at the same time as fishers are harvesting the low-value snakefish and lollyfish is not sustainable. A permissible list of species for harvest, processing and exports can be prescribed as a management measure. Species deemed to be in low abundance should not be included in the prescribed list of permissible species for harvest, processing and export. The measure should allow for flexibility to amend the list on an annual or biannual basis so that species with improved abundance can be added to the list and those species with poor stock levels can be removed from the list.
4. ***Density and size distribution:*** The declining state of resource abundance is in line with declining trends in beche-de-mer production. Many species assessed at Vava'u and Tongatapu were well below sustainable densities for stronger stock recovery. Further harvesting will continue to deplete resources and, therefore, impact recruitment. Small sized sea cucumbers within a population demonstrate young, immature stock structures that are yet to achieve full productive capacity. Closing the fishery is the best solution to allow these young stocks to reach maturity and higher market quality.
5. ***Underwater breathing apparatus, or UBA:*** UBA gear has been used illegally to access deeper fishing grounds in order to harvest white teatfish. If this practice is left un-checked divers will continue to use UBA to target sea cucumbers in deeper waters as resources in shallow fishing areas become depleted. Deeper water areas can protect breeding populations of some species, but only if prohibiting the use of UBA gear is enforced. Increases in incidences of diving-related accidents and related deaths associated with the use of UBA gear will continue as stocks become depleted. Fishers will increase the number of dives per day with minimal rest periods between dives, thereby leading to accidents. To save human lives and the remaining breeding stocks of sea cucumbers in deeper waters, regulating the use of UBA gear should be effectively enforced.
6. ***Limits on gear:*** Fishing practices and gear such as 'sea cucumber bombs', night fishing, trawls and submersible equipment are destructive to sea cucumbers and need to be outlawed.

[4] Quota over-runs are quantities of sea cucumber harvested or exported in excess of the declared quota.

7. ***Sea cucumber management plan:*** The Tonga National Sea Cucumber Fishery Management Plan contains many necessary measures to ensure a sustainable fishery; it is the lack of adherence to some of these measures that have allowed implementation to derail, resulting in the issuing of more licenses, quota over-runs, and increasing pressure for more resources. The current management plan should be reviewed with the objective of developing a more rigid management framework. It is further recommended that associated regulations be drafted and once approved the regulations are enforced and adhered to.
8. ***Monitoring and compliance:*** Monitoring and compliance is a common weakness in sea cucumber fisheries. It is recommended a coastal fisheries monitoring and compliance program be established and management regulations for sea cucumber and coastal fisheries in general enforced. Central export exit points can be designated which all products intended for exports must past through. This eases the burden of inspections.
9. ***Licensing system:*** Implementing separate licenses for the exporting and processing of sea cucumbers facilitate the efficient monitoring and compliance of operators. The approach should continue to be implemented. The quota on the number of licenses should be respected and enforced effectively. Additional management measures are needed to ensure that processors and exporters do not participate in or have influence on fishing activities that should to be undertaken by local fishers.
10. ***Improving resource rent:*** The sea cucumber fishery is a lucrative industry that can be managed effectively. Rising demand and price, and falling production are attractive to traders and, therefore, there are opportunities to raise the value of resource rent such as through an auctioning scheme. There is a need to review existing management plans to facilitate this development.
11. ***Local participation in the industry:*** The beche-de-mer export industry was dominated by foreigners (mainly Asian nationals) through joint venture arrangements. Incidences of unfair treatment of local partners in joint venture arrangements has prevented or created an uncompetitive climate for aspiring local entrepreneurs. Opportunities for localising the industry should be assessed with necessary regulatory changes in favour of local interests.
12. ***Aquaculture and ranching:*** The preservation of golden sandfish (*H. lessoni*) in Tongatapu is a sound management decision, and will conserve a breeding stock for aquaculture development. Considering the declining stock status of golden sandfish and sandfish in other fisheries, Tonga should ensure there is a locally sufficient stock of golden sandfish to support potential aquaculture development by prohibiting the harvest of this species for export. A dedicated assessment of golden sandfish should be undertaken to determine their status. Furthermore, where necessary, opportunities for the introduction of sandfish (*H. scabra*) should be explored to expand the resource base. In addition, golden sandfish is now listed as endangered on the International Union for the Conservation of Nature Red List of species; therefore, any translocation should follow strict procedures.
13. ***Protect food resources:*** Lollyfish (*H. atra*), snakefish (*H. coluber*), brown sandfish (*B. vitiensis*), chalkfish (*S. marmorata*) and curryfish (*S. herrmanni*) are used for domestic consumption. Like golden sandfish, consideration should be given for protecting these species that are important local food items.
14. ***Aggregation of broodstock:*** Aggregating stocks to encourage breeding and improved gamete fertilisation must be given careful consideration. Collecting mature specimens and restocking these in defined areas to encourage improved fertilization may be detrimental due to the commercial temptation to harvest stocks. Any attempt to aggregate adult sea cucumber species in Tonga should be undertaken in effectively enforced protected areas, and with regular monitoring.
15. ***Area closure:*** Tonga has established special management areas for marine resource conservation. These areas, if effectively monitored and enforced, can protect portions of the sea cucumber population from exploitation. Consideration should be given to protecting other areas from fishing where sea cucumber stocks are not protected. Establishing and enforcing no-fishing areas for sea cucumbers is a tool to protect sea cucumber species (and other marine resources) from fishing pressure. Each no-fishing area

should comprise between 25 ha and 1,000 ha. As a guide, networks of no-fishing areas encompassing between 15% and 30% of suitable sea cucumber habitats are recommended. The goal is to avoid large-scale depletion and to protect mature breeding populations that will contribute to the production of new recruits that may settle in nearby areas. A secondary goal is to rebuild stocks of reproductively mature sea cucumbers. No-take areas should comprise habitats with healthy densities of several species of mature sea cucumbers and areas where enforcement is easy to carry out. No-fishing areas should be clearly marked and made known to communities and enforced.

16. ***Price controls:*** The implementation of set prices was an issue that needed effective enforcement. The increasing demand for beche-de-mer and the rising trend in sea cucumber prices justify an assessment of the potential to increase the value of products to fishers through the auctioning of licenses and/or products. These improved valuations are best implemented when there is healthy stock abundance in the fishery following sufficient rest periods and recovery of the resources, and improved processing of product. Setting a minimum price is designed to control unnecessary price fluctuation and improve local income. It is, however, difficult to enforce the minimum price due to strong competition from the increased number of operators. Minimum product prices are best used with effective control on the number of exporters and processors. Price fluctuations are related to the strong influence of exporters on processors and fishers.

17. ***Monitoring product chain:*** To gain more precise information on the value of the sea cucumber fishery to Tonga's economy, it is recommended that as a license condition, beche-de-mer exporters be required to submit a commercial invoice as part of documentation they need to submit Tonga's Fisheries Division to gain export permission. It is also recommended that the monitoring of prices paid to fishers and processors is maintained. This will allow a better understanding of the value chain of the fishery.

18. ***Using same resources assessment method:*** Using the same resource assessment protocols over time enables comparable results and the delivery of effective management advice. It is recommended that the same method be used in future assessments in order to maintain consistency and comparability. Further information on in-water assessment methods are found in the *Manual for assessing tropical marine invertebrate resources for management purposes in the Pacific islands* (SPC in press). Due to resource (both staff and finance) limitations, major sea cucumber assessments can only be carried out every three to five years. In the interim period, smaller or scaled down surveys can be conducted on a one to two year basis. These scaled down surveys should include a combination of stations that are assessed during each survey (permanent survey stations) and stations that are randomly selected.

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Appendix 1.

Mean sea cucumber density (ind. ha^{-1}) by assessment types at Vava'u and Tongatapu

Species are ranked with respect to their mean relative density for stations where they are present (Mean_P)

Vava'u

Survey	Common name	Mean	SE	n	Mean_P	SE	n_P	%_P
Manta	Lollyfish	1,074.5	275.4	16	1,074.5	275.4	16	100
	Pinkfish	196.4	82.2	16	285.6	110.4	11	69
	Snakefish	110.9	39.3	16	136.5	45.7	13	81
	Greenfish	87.9	41.6	16	127.9	57.1	11	69
	Brown sandfish	76.9	24.1	16	94.7	27.4	13	81
	Surf redfish	5.7	5.7	16	91.7		1	6
	Curryfish	11.1	6.2	16	29.6	13.9	6	38
	Sandfish	1.2	1.2	16	19.4		1	6
	Golden sandfish	0.9	0.9	16	13.9		1	6
	Elephant trunkfish	2.1	1.7	16	11.1	8.3	3	19
	Tigerfish	3.6	1.4	16	9.7	2.1	6	38
	Amberfish	1.9	1	16	7.6	2.1	4	25
RBt	Surf redfish	180.1	172.5	28	2,520.8	2,312.5	2	7
	Lollyfish	1,495.5	431.2	28	1,550.9	443.8	27	96
	Greenfish	278.3	57.4	28	389.6	65.3	20	71
	Snakefish	59.5	36.6	28	277.8	147	6	21
	Pinkfish	26.8	18.6	28	187.5	108.3	4	14
	Tigerfish	19.3	8.7	28	77.4	24.8	7	25
	Stonefish	1.5	1.5	28	41.7		1	4

RBt = Reef benthos transect; Mean = Mean density (ind. ha^{-1}); Mean_P = Mean density for stations where species is present; n = Number of stations; SE = Standard error; n_P = Number of stations where species is present; % _P = Percentage of stations when a record is present.

Mean sea cucumber density (ind. ha^{-1}) by assessment types at Vava'u and Tongatapu

Species are ranked with respect to their mean relative density for stations where they are present (Mean_P)

Tongatapu

Survey	Common name	Mean	SE	n	Mean_P	SE	n_P	%_P
	Lollyfish	1,641.4	778.2	10	1,641.4	778.2	10	100
	Chalkfish	19.2	19.2	10	191.7		1	10
	Pinkfish	86.1	36	10	172.2	46.2	5	50
	Snakefish	73.1	32.2	10	121.8	43.8	6	60
	Greenfish	37.8	16.7	10	54	21.3	7	70
	Brown sandfish	38.9	14.1	10	43.2	15	9	90
Manta	Curryfish	18.3	11.4	10	36.7	20.4	5	50
	Tigerfish	9.7	5	10	24.3	8.5	4	40
	Amberfish	3.3	2.8	10	16.7	11.1	2	20
	Elephant trunkfish	1.9	1.4	10	9.7	4.2	2	20
	Golden sandfish	2.8	1.5	10	9.3	2.4	3	30
	Stonefish	0.8	0.8	10	8.3		1	10
	Prickly redfish	0.6	0.6	10	5.6		1	10

Mean = Mean density (ind. ha^{-1}); Mean_P = Mean density for stations where species is present; n = Number of stations; SE = Standard error; n_P = Number of stations where species is present; % _P = Percentage of stations when a record is present.

Appendix 2.

Sea cucumber mean sizes (mm) for Vava'u from 2010 surveys

Common name	Maximum length	Common length	Mean length	SE	n	Total records
Lollyfish	650	230	166	2.4	526	7,279
Pinkfish	380	240	163	5.8	77	1,409
Greenfish	380	230	144	3	159	813
Snakefish	600	400	389	39.8	11	784
Brown sandfish	420	210	229	7.7	18	470
Tigerfish	600	370	274	12	47	111
Elephant trunkfish	660	480	357	25.7	20	107
Curryfish	550	390	188	12	23	101
Amberfish	890	630	524	30.6	14	56
Surf redfish	380	240	252	10.2	5	27
White teatfish	550	410	317	11	14	24
Golden sandfish	460	320	180		1	13
Dragonfish	390	320	57	2.8	12	12
Stonefish	240	220	170	50	2	2
Deepwater redfish	360	150	300		1	1
Prickly redfish	700	550	310		1	1

Note:
Some species sample sizes were low. Total records are the number of specimens encountered during assessment, not all specimens encountered were measured. SE = Standard error; n = Number of specimens measured.

Appendix 3.

Sea cucumber means sizes (mm) for Tongatapu 2011 surveys

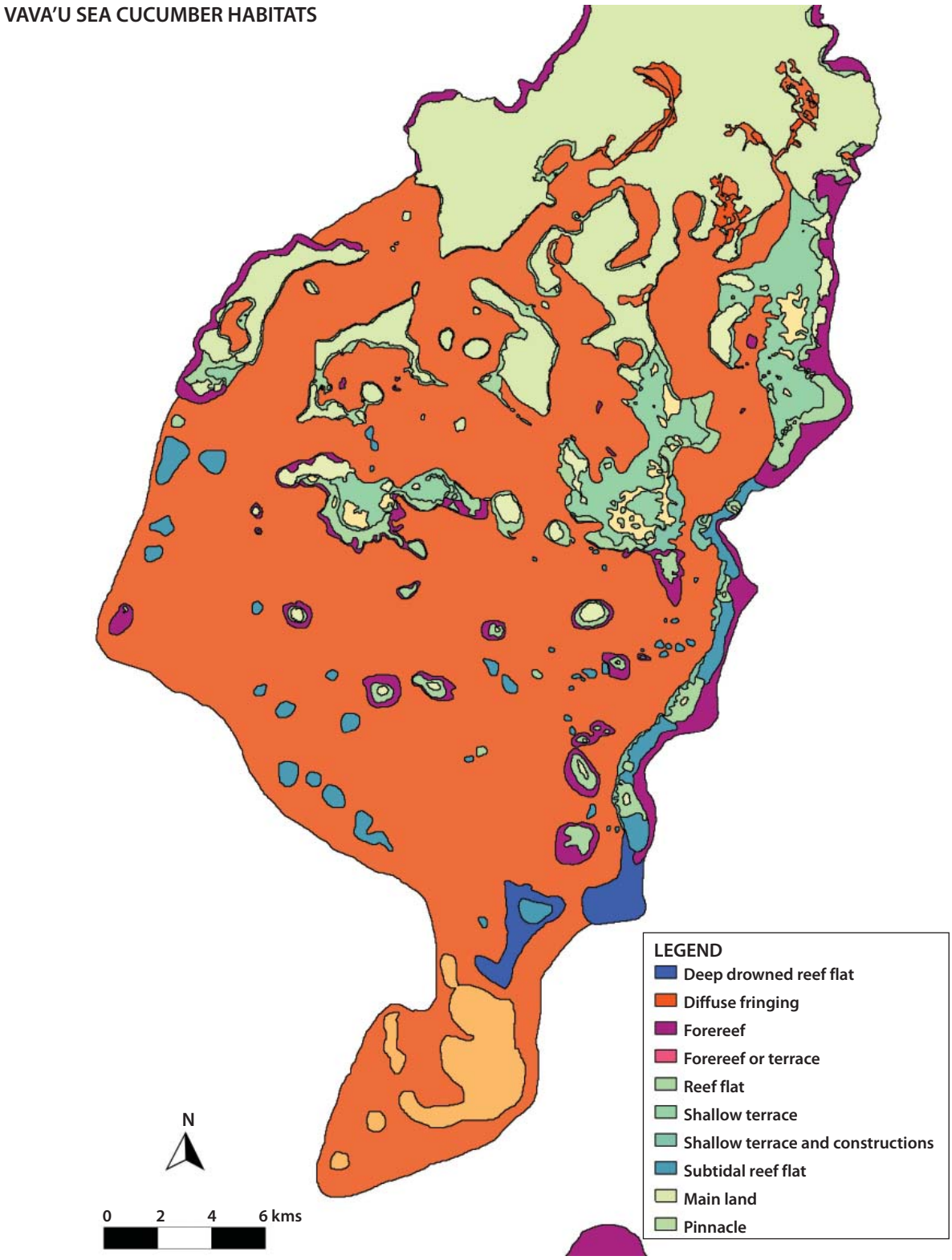
Common name	Maximum length	Common length	Mean length	SE	n	Total records
Lollyfish	650	230	196	8	101	6,250
Pinkfish	380	240	198	6	77	559
Snakefish	600	400	193	21	14	364
Greenfish	380	230	155	6	49	304
Brown sandfish	420	210	233	11	40	169
Curryfish	550	390	306	7	38	104
Tigerfish	600	370	303	16	50	93
Chalkfish	320	220	n.a.	n.a.	n.a.	69
Elephant trunkfish	660	480	390	10	49	69
Amberfish	880	630	458	32	23	31
Golden sandfish	460	320	281	13	8	18
White teatfish	550	410	368	31	13	13
Stonefish	240	220	n.a.	n.a.	n.a.	3
Deepwater redfish	360	150	315	15	2	2
Surf redfish	380	240	215	15	2	2
Prickly redfish	700	550	n.a.	n.a.	n.a.	2
Black teatfish	340	540	180		1	1

Note:
Some species sample sizes were low. Total records are the number of specimens encountered during assessment, not all specimens encountered were measured. SE = Standard error; n = Number of specimens measured; n.a. = Not available.

Appendix 4.

Geomorphological classification of Tonga's three main island groups

Habitat map of Vava'u including all habitat attributes that are expected to contain sea cucumber stocks

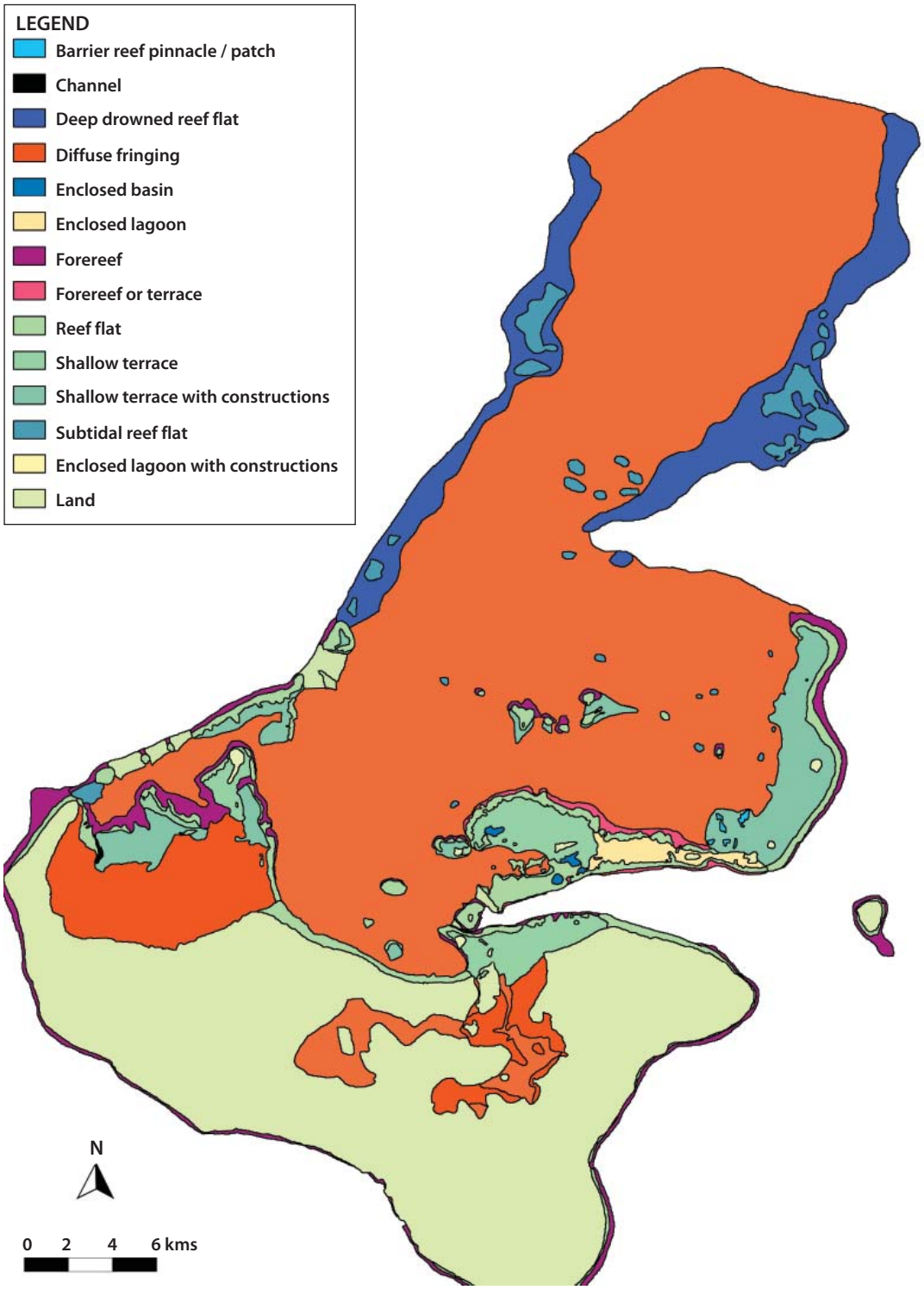


Appendix 4.

Geomorphological classification of Tonga's three main island groups

Habitat map of Tongatapu, including all habitat attributes that are expected to contain sea cucumber stocks

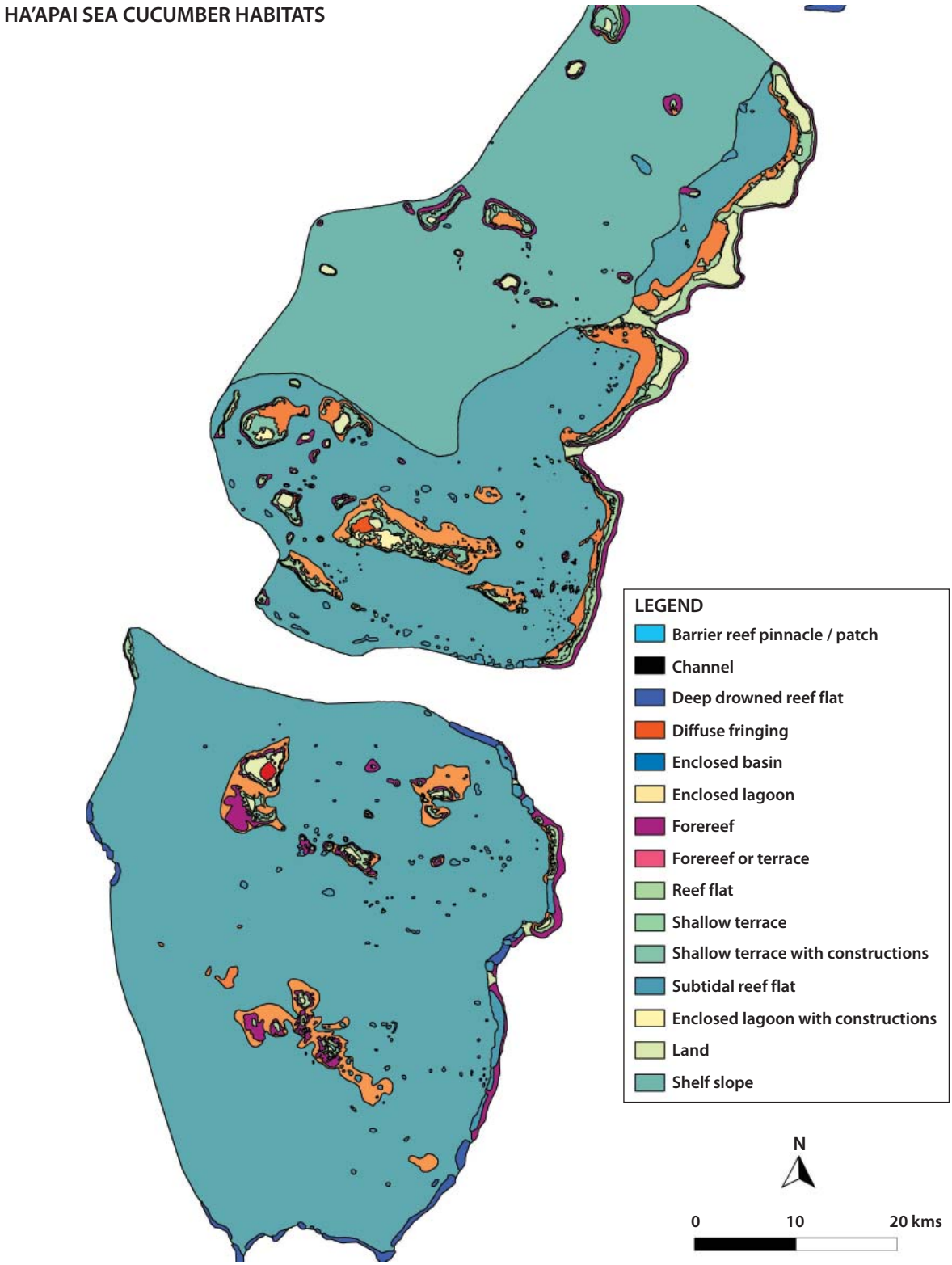
TONGATAPU SEA CUCUMBER HABITATS



Appendix 4.

Geomorphological classification of Tonga's three main island groups

Habitat map of Ha'apai, including all habitat attributes that are expected to contain sea cucumber stocks



Secretariat of the Pacific Community (SPC)

BP D5 • 98848 Noumea Cedex • New Caledonia

Phone: +687 26 20 00 • Fax: +687 26 38 18

www.spc.int/fame • cfpinfo@spc.int