PACIFIC REGIONAL OCEANIC AND

COASTAL FISHERIES DEVELOPMENT PROGRAMME

(PROCFish/C/CoFish)

TONGA
COUNTRY REPORT:

PROFILES AND RESULTS FROM SURVEY WORK AT HA'ATAFU, MANUKA, KOULO AND LOFANGA

(November and December 2001; March to June 2002;
April to June, September and October 2008)

by

Kim Friedman, Silvia Pinca, Mecki Kronen, Pierre Boblin, Lindsay Chapman, Franck Magron, Aliti Vunisea and Pierre Labrosse

This document has been produced with the financial assistance of the European Community

Original text: English

Secretariat of the Pacific Community Cataloguing-in-publication data

Tonga country report: profiles and results from survey work at Ha'atafu, Manuka, Koulo and Lofanga (November and December 2001; March to June 2002; April to June, September and October 2008) / by Kim Friedman, Silvia Pinca, Mecki Kronen, Pierre Boblin, Lindsay Chapman, Franck Magron, Aliti Vunisea and Pierre Labrosse

(Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish/C/CoFish) / Secretariat of the Pacific Community)

I. Friedman, Kim. II. Pinca, Silvia. III. Kronen, Mecki. IV. Boblin, Pierre. V. Chapman, Lindsay. VI. Magron, Franck. VII. Vunisea, Aliti. VIII. Labrosse, Pierre. IX. Title. X. Secretariat of the Pacific Community, Reef Fisheries Observatory. XI. Series.
1. Marine resources — Tonga — Statistics. 2. Fisheries — Tonga — Statistics. 3. Fisheries — Economic aspects — Tonga.

338.372 099 612 AACR2

ISBN: 978-982-00-0390-3

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Prepared for publication and printed at
Secretariat of the Pacific Community headquarters
Noumea, New Caledonia, 2009

ACKNOWLEDGEMENTS

The Secretariat of the Pacific Community (SPC) acknowledges with gratitude the funding support provided by the European Commission for the implementation of the Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish, coastal component)[1] and the MacArthur Foundation, who funded the early work in the Kingdom of Tonga in 2001–2002 under "The joint application of demography and ecology in evaluating the role of coastal fisheries resources in Pacific Islands: the DemEcoFish project".

SPC also acknowledges the collaborative support of the staff of the Fisheries Division, Ministry of Agriculture and Food, Forests and Fisheries (formerly the Ministry of Fisheries) and others for their in-country assistance, in particular Dr Sione Vailala Matoto, Secretary for Fisheries; Mr 'Ulunga Fa'anunu, Deputy Secretary for Fisheries; Mr Tala'ofa Loto'ahea, former Officer in Charge at Ha'apai Fisheries and Mr Tevita 'Ahoafi, Officer in Charge at Ha'apai Fisheries; Ms Silika Ngahe, Officer in Charge at Vava'u Fisheries; Mr Siola'a Malimali, Fisheries Officer; Ms Mele Makasini, Community Section; Mr Martini Finau, Aquaculture Section; Mr Poasi Fale Ngaluafe, Aquaculture Section; Ms Fina Vili and Mr Fanueli Tongaonevai, Fisheries Officers Ha'apai; Mr Enelio Liufau, Environment Officer from Wallis assisting the finfish team; the boat operators and guides at all six locations; and the Elders, community members, fishers and people from the survey sites.

The preparation of this report has been a team effort, given the amount of information gathered and the need to present the results in a useable format. SPC staff who assisted with the production of this report were Ms Céline Barré, report compiling, formatting and layout; Ms Sarah Langi, report editing; Ms Youngmi Choi, cover design; and the SPC Translation Section for translating the executive summary; their assistance is acknowledged with thanks.

In addition, thanks are provided to Dr Serge Andrefouet and his team for the provision and analysis of satellite images used in this report for the calculation of reef-habitat surfaces. More information on this project is provided in Appendix 5.

[1] CoFish and PROCFish/C are part of the same programme, with CoFish covering the countries of Niue, Nauru, Federated States of Micronesia, Palau, Marshall Islands and Cook Islands (ACP countries covered under EDF 9 funding) and PROCFish/C countries covered under EDF 8 funding (the ACP countries: Fiji, Tonga, Papua New Guinea, Solomon Islands, Vanuatu, Samoa, Tuvalu and Kiribati, and French overseas countries and territories (OCTs): New Caledonia, French Polynesia, and Wallis and Futuna). Therefore, CoFish and PROCFish/C are used synonymously in all country reports.

PROCFish/C and CoFish staff work (or used to work) for the Secretariat of the Pacific Community, BP D5, 98848 Noumea Cedex, New Caledonia under this EU-funded project. All PROCFish/C and CoFish staff work as a team, so even those not directly involved in fieldwork usually assist in data analysis, report writing, or reviewing drafts of site and country reports.

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EXECUTIVE SUMMARY

The coastal component of the Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish/C) conducted fieldwork in four locations around the Kingdom of Tonga in April to June, September and October 2008. This followed previous work funded by the MacArthur Foundation at six locations in the Kingdom of Tonga in November and December 2001, and March to June 2002 under "The joint application of demography and ecology in evaluating the role of coastal fisheries resources in Pacific Islands: the DemEcoFish project". The Kingdom of Tonga is one of 17 Pacific Island countries and territories being surveyed over a 5–6 year period by PROCFish/C or its associated programme CoFish (Pacific Regional Coastal Fisheries Development Programme)[2].

The aim of the survey work was to provide baseline information on the status of reef fisheries, and to help fill the massive information gap that hinders the effective management of reef fisheries.

Other programme outputs include:

- implementation of the first comprehensive multi-country comparative assessment of reef fisheries (finfish, invertebrates and socioeconomics) ever undertaken in the Pacific Islands region using identical methodologies at each site;
- dissemination of country reports that comprise a set of 'reef fisheries profiles' for the sites in each country in order to provide information for coastal fisheries development and management planning;
- development of a set of indicators (or reference points to fishery status) to provide guidance when developing local and national reef fishery management plans and monitoring programmes; and
- development of data and information management systems, including regional and national databases.

Survey work in the Kingdom of Tonga covered three disciplines (finfish, invertebrate and socioeconomic) in each site, with programme scientists and several local counterparts from the Ministry of Agriculture and Fisheries. The fieldwork included capacity building for the local counterparts through instruction on survey methodologies in all three disciplines, including the collection of data and inputting the data into the programme's database.

In the Kingdom of Tonga, the four sites selected for the survey were Ha'atafu and Manuka on Tongatapu, and Koulo and Lofanga on Ha'apai. These were also sites surveyed under the DemEcoFish project, which provided a unique opportunity to do a comparison of results six years after the initial surveys. These sites were also selected based on specific criteria, which included:

- having active reef fisheries,
- being representative of the country,
- being relatively closed systems (people from the site fish in well-defined fishing grounds),

[2] CoFish and PROCFish/C are part of the same programme, with CoFish covering the countries of Niue, Nauru, Federated States of Micronesia, Palau, Marshall Islands and Cook Islands (ACP countries covered under EDF 9 funding) and PROCFish/C countries covered under EDF 8 funding (the ACP countries: Fiji, Tonga, Papua New Guinea, Solomon Islands, Vanuatu, Samoa, Tuvalu and Kiribati, and French overseas countries and territories (OCTs): New Caledonia, French Polynesia, and Wallis and Futuna). Therefore, CoFish and PROCFish/C are used synonymously in all country reports.

- being appropriate in size,
- possessing diverse habitat,
- presenting no major logistical problems,
- having been previously investigated, and
- presenting particular interest for the Ministry of Agriculture and Fisheries.

Results from fieldwork at Ha'atafu

Tongatapu is a coral atoll with mean coordinates of 21°10' S and 175°10' W, and a lagoon that has the unusual feature of opening to the north, which gives it the shape of a crescent and should classify it in the 'pseudo lagoon' category. Ha'atafu is located on the western side of the lagoon, with no clearly defined fishing areas, as the inhabitants conduct 'open-access' fishing. The fishing surface area of the lagoon is about 18.5 km wide and 37 km long, and is shared with Manuka and other villages. Around Ha'atafu, the coastal reef is mainly made up of seagrass beds and small patches of coral; in the centre, the reef flat is much narrower and is mainly made of coral debris, sand and seagrass beds. Fish traps are placed on this structure.

Socioeconomics: Ha'atafu

Ha'atafu is a rural coastal community with road access to urban and market facilities. The standard of living is relatively high, with electricity and public water supply. People have limited access to agricultural land and depend primarily on marine resources. Therefore, Ha'atafu's population depends heavily on marine resources (finfish and invertebrates), as well as canned fish for home consumption. Revenues obtained from marketing fisheries produce, however, are far less important than income from salaries, money received from remittances and mat weaving done by females. Seafood consumption is highest across all communities studied in Tonga at 92 kg/person/year for finfish and 21 kg/person/year for invertebrates.

Males are the only commercial finfish fishers, while females are in charge of invertebrate collection, although females also catch fish at times. Handlining, cast netting and a combination of gillnetting, handlining, trolling and spear diving are the main fishing techniques used for finfish. Invertebrates are collected using very low-cost equipment, with some male fishers free-diving to collect invertebrates, using mask, snorkel and fins. The invertebrate catch is mainly made up of holothurians, octopus, sea urchins and *Turbo crassus* (wet weight). By comparison, catches of *Strombus* spp., *Dolabella* spp., and other species are low.

Finfish resources: Ha'atafu

The finfish resources in Ha'atafu were poor but slightly better than those in Manuka, with higher biodiversity of species, density and biomass of fish, but smaller average sizes. Coral cover was lower in coastal reefs but higher in back-reefs compared to Manuka, and much higher on the outer reefs. Herbivores, especially Acanthuridae, dominated the fish community, with a total density slightly higher than at Manuka. Other relevant families included Scaridae, although with much lower density and biomass than Acanthuridae and Holocentridae (still in very low values). The mean sizes of several fish families were below 50% of the maximum values, indicating that the fish population was impacted by fishing. As in Manuka, the most representative species for this site in terms of density and biomass were small-sized species of Acanthuridae and Scaridae. In the first assessment in 2002, average sizes and biomass were found to be higher than in the second assessment. Since density slightly increased, the decrease in biomass was mainly due to a serious decrease in average fish sizes and to a replacement of larger species with small species. A more marked decrease in biomass was observed for piscivores.

Invertebrate resources: Ha'atafu

The reef at Ha'atafu had extensive areas of limestone and coral benthos, with a range of shallow-water lagoon habitat that was suitable for many of the giant clam species. However, only two species of giant clam were recorded at Ha'atafu (the elongate clam *Tridacna maxima* and the fluted clam *T. squamosa*). The smooth clam (*T. derasa*) and the devil's clam (*T. tevoroa*) are present in Tonga but were not noted in these surveys. Tongatapu is one area that supported the bear's paw clam (*Hippopus hippopus*) until the mid 1970s, although the species is extinct in Tonga now. Giant clam coverage across the study area was noticeably disrupted, and there was only a small number of clams close to Ha'atafu. In fact, the total number of clams recorded in both broad-scale and reef-benthos transects was not high. The densities of clams recorded at Ha'atafu are indicative of an impacted clam fishery.

The reefs at Ha'atafu are outside the natural range for the commercial topshell, *Trochus niloticus*, but now support this species after successful translocations were made. Introductions have included the movement of both adults (from Fiji) and juveniles (from the hatchery on Tongatapu). A similar situation exists for green snail, *Turbo marmoratus*, which was also introduced as juveniles from hatchery rearing. Trochus coverage and density was indicative of a stock that was successfully colonising local reefs. Coverage was good in most relevant surveys, and the density of shells at the better locations reached an average of over 300 /ha. In the case of MOPt surveys, the average density recorded was 772.6 /ha. No green snail was recorded. The blacklip pearl oyster, *Pinctada margaritifera*, was not uncommon at Ha'atafu.

The range of sea cucumber species present at Ha'atafu was high, despite biogeographical influences (the easterly location of Tonga and its relatively isolated position in the Pacific). Densities of sea cucumbers were most substantial in semi-enclosed, depositional environments – fine-sediment, semi-enclosed lagoonal areas. This was the case to the east of Ha'atafu, where moderate numbers of some species (e.g. leopardfish *Bohadschia argus*) were noted. On the other hand, despite the complete ban on commercial harvesting of holothurians being in place for seven to ten years, some species had not re-built strongly (e.g. black teatfish *Holothuria nobilis* and golden sandfish *H. scabra versicolor*). Surf redfish (*Actinopyga mauritiana*) were noted at low density. The deep-water white teatfish (*H. fuscogilva*) and lower-value amberfish (*Thelonata anax*) were also noted, but at low density.

Recommendations for Ha'atafu

- Ha'atafu and neighbouring communities on Tongatapu be included in the ongoing community-based fisheries management programme.

- Protected zones or no-take marine parks be established to help recovery and maintenance of finfish and invertebrate resources and habitat condition, with appropriate monitoring and enforcement to ensure compliance.

- A monitoring system be set in place to follow any further changes in finfish resources.
- For successful stock management, a percentage of large clams of each species needs to be maintained at high density, to ensure there is sufficient successful spawning taking place to produce new generations of clams for the fishery.
- Ongoing protection be provided to the trochus stocks for at least another five years to enable them to benefit from the increased spawning activity that the high-density base population will provide, thus allowing stocks to rebuild to a minimum of 500–600 shells/ha before commercial harvests are considered.
- The high-value black teatfish (*Holothuria nobilis*) and the golden sandfish (*H. scabra versicolor*) require careful management to ensure they recover to 'healthy' densities.
- The potential of the Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

Results from fieldwork at Manuka

Manuka is located on the eastern side of the crescent-shaped lagoon in Tongatapu. Fishing areas are not clearly defined, as the inhabitants conduct 'open-access' fishing. The fishing surface area of the lagoon is about 18.5 km wide and 37 km long and is shared with Ha'atafu and other villages. Around Manuka, a sort of tidal pond bordered by mangroves penetrates the island in an upside-down Y shape. This water is completely filled with microalgae, which indicate poor circulation and give it a greenish hue. Out to sea, a large barrier reef bordered by a few *motu* small islets orms an upside-down L over a length of some 22.2 km.

Socioeconomics: Manuka

Manuka is a rural coastal community with good road access to urban and market facilities. The standard of living is relatively high, with electricity and public water supply; however, a considerable amount of income is generated by finfish fisheries and complemented by remittances received from overseas. People have limited access to agricultural land and depend primarily on marine resources. Finfish consumption is high at 78 kg/person/year, while invertebrates and canned fish are consumed much less than the average rate across all communities studied in Tonga.

Males are the only commercial finfish fishers, while females are in charge of invertebrate collection, although females also catch fish at times. Spearfishing, handlining and deep-bottom lining are the most common techniques used; cast netting and trolling are rarely used for finfish. Invertebrates are collected using very low-cost equipment, with some male fishers free-diving to collect invertebrates using mask, snorkel and fins. The invertebrate catch is mainly made up of holothurians; *Strombus* spp. account for most of the annual harvest (wet weight). By comparison, catches of lobsters, sea urchins, *Turbo* spp., *Dolabella* spp. and all other species are of low importance.

Finfish resources: Manuka

The status of finfish resources at Manuka at the time of surveys was very poor. Density was low in terms of the regional average, but sizes and biomass values were especially low. Biodiversity was also very poor, poorer than in countries to the east of Tonga, therefore suggesting a response not only to the distance from the centre of biodiversity but also an impact from heavy fishing. The most important families were the herbivores Acanthuridae and Scaridae, while carnivores were present in very scarce abundance. Some carnivorous families, such as Serranidae and Lethrinidae, were practically absent. The most representative fish in terms of density and biomass were small-sized fish displaying average sizes much lower than the maximum reported from the literature. We suggest that this overall poverty is due to high fishing impact. Back-reefs were the poorest habitats, with the lowest density, small sizes, very poor biomass and poor biodiversity. Outer reefs displayed a higher number of species, but also very low density and biomass. In 2002, the finfish resources were found to be better than in 2008, with higher biodiversity, density, size, size ratio and biomass.

Invertebrate resources: Manuka

The reef at Manuka had extensive areas of limestone and coral benthos, with shallow-water, sheltered lagoon habitats that were suitable for a range of giant clam species. However, only two species of giant clam were recorded at Manuka (the elongate clam *Tridacna maxima* and the fluted clam *T. squamosa*). The smooth derasa clam (*T. derasa*) and the devil's clam (*T. tevoroa*) are present in Tonga but were not noted in these surveys. Giant clam coverage across the study area was noticeably disrupted, and there was only a small number of clams close to Manuka. In fact, the total number of clams recorded in both broad-scale and reef-benthos transects was not high. The densities of clams recorded at Manuka indicate an impacted clam fishery.

The reefs at Manuka are outside the natural range for the commercial topshell, *Trochus niloticus*, but now support this species after successful introductions. Introductions have included the movement of both adults (from Fiji) and juveniles (from the hatchery on Tongatapu). A similar situation exists for green snail, *Turbo marmoratus*, which was also introduced as juveniles from hatchery rearing. Trochus were recorded at Manuka. Coverage was good in most relevant surveys, and the density of shells at the better locations reached an average of over 300 /ha. Only a single green snail was recorded. The false trochus or green topshell (*Tectus pyramis*) was noted in Manuka, and the blacklip pearl oyster (*Pinctada margaritifera*) was not uncommon.

Densities of sea cucumbers were highest in fine-sediment, semi-enclosed lagoonal areas. This was the case south of Onevai and east of Toke Toke, where large numbers of *Holothuria atra* and *H. coluber*, both low-value species, were recorded. Otherwise, the open lagoon had a more oceanic influence and held lower densities of commercial holothurians. The complete ban on commercial harvesting of holothurians has been in place for long enough to allow stocks of some species to re-build strongly (tigerfish, *Bohadschia argus*), while others do not seem to have recovered much (black teatfish, *Holothuria nobilis*). Surf redfish (*Actinopyga mauritiana*) were noted at low density. No deeper-water white teatfish (*Holothuria fuscogilva*) were recorded, although the lower-value amberfish (*Thelonata anax*) were found at moderate density.

Recommendations for Manuka

- Manuka and neighbouring communities on Tongatapu be included in the ongoing community-based fisheries management programme.

- Protected zones or no-take marine parks be established to help the recovery and maintenance of finfish and invertebrate resources and habitat condition, with appropriate monitoring and enforcement to ensure compliance.

- Spearfishing be controlled in the Manuka area, with a ban on night spearfishing imposed.

- Regulations be put in place to control the mesh size of nets.

- A monitoring system be set in place to follow any further changes in finfish resources.

- For successful stock management, a percentage of large clams of each species needs to be maintained at high density, to ensure there is sufficient successful spawning taking place to produce new generations of clams for the fishery.

- Ongoing protection be provided to the trochus stocks for at least another five-to-ten years to enable them to benefit from the increased spawning activity that the high-density base population will provide, thus allowing stocks to rebuild to a minimum of 500–600 shells/ha before commercial harvests are considered.

- The high-value black teatfish (*Holothuria nobilis*) and the golden sandfish (*H. scabra versicolor*) require careful management to ensure they recover to 'healthy' densities.

- The potential of the Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

Results from fieldwork at Koulo

Koulo is a village located at the northern end of the coral island of Lifuka at the mean coordinates of 19°46' S; 174°20' W. Lifuka is the main island of the Ha'apai Island group. In the eastern part, a barrier reef exposed to the prevailing winds is not accessible by sea, whereas the northern part of the island is linked to the island of Foa by backfill and a road. The back-reef, which is very shallow, can only be fished on foot and does not seem to be very rich. The west coast is bordered by a beach and reef flat, a small part of which is made up of a seagrass bed and the rest of coral patches, sand and coral debris. Further out to sea, coral structures of various sizes are fished by fishers using poles and lines or diving. The fishing system is open-access.

Socioeconomics: Koulo

The Koulo community inhabits an urbanised coastal area with access to modern infrastructure, as well as cash income. People have good access to agricultural land and also to coastal and more distant marine resources. However, people at Koulo have little dependency on marine resources for income but are more dependent on seafood for home consumption. Salaries and mat weaving are the main source for income generation. Seafood consumption is considerable (47 kg/person/year for finfish and 7 kg/person/year for invertebrates), but fresh fish and invertebrates are consumed less than elsewhere, while canned fish is consumed at a much higher rate (18.6 kg/person/year) as compared to all other sites studied in Tonga.

Males are the only commercial finfish fishers while females are in charge of invertebrate collection, although females also catch fish at times. Handlining and spear diving are the dominant fishing techniques used for finfish, while gillnetting and cast netting are much less often used. Invertebrates are collected using very low-cost equipment. The invertebrate catch is mainly made up of *Holothuria* spp., octopus and giant clams, while all other species caught are of minor importance only. Males also harvest invertebrates but their production is much less than the total amount of invertebrates harvested per year by females in the community.

Finfish resources: Koulo

The status of finfish resources at Koulo at the time of survey was an average between the very poor conditions at Tongatapu and the relatively healthy conditions at Lofanga. However, compared to regional values, fish biomass and sizes were low. Fish density at Koulo was comparable to Lofanga and Ha'atafu values, but size and biomass were more similar to those at Lofanga. Resources were overall in average-to-poor condition. The back-reefs were poorer than the outer reefs, with low density, size, biomass and biodiversity. At a detailed analysis at family level, Acanthuridae consistently displayed the highest abundance and biomass, while Scaridae were rather poor. Carnivores were particularly poor, with the slight exception of Mullidae, which were only relatively important in terms of biomass in the outer reefs. Sizes of Scaridae, Lethrinidae and Holocentridae were much lower than the maximum size recorded for the relative species, indicating an impact from fishing on these favourite species. Conditions did not show much change between the two survey seasons, except for a slight decrease in average biomass and a decrease in the most important species, *Ctenochaetus striatus*, in the more recent survey.

Invertebrate resources: Koulo

Four species of giant clam were recorded at Koulo: the elongate clam *Tridacna maxima*, the fluted clam *T. squamosa*, the smooth clam *T. derasa* and the devil's clam *T. tevoroa*. *T. tevoroa* is a rare species that has only been recorded in Tonga, Fiji Islands and New Caledonia. Giant clam coverage across the study area was not noticeably disrupted (There was no major decline around main settlement areas.), although larger species were not recorded in shallow-water locations. On the other hand, the total number of clams recorded was not high. The densities recorded at Koulo were at best moderate for an exposed oceanic environment such as that found at Koulo (and Ha'apai as a whole) and such a low density is indicative of an impacted clam fishery.

Trochus (*Trochus niloticus*) and green snail (*Turbo marmoratus*) were recorded at Koulo, but only in small numbers and at low density. In Koulo, two of three reef-front searches and two of 14 reef-benthos transect stations held trochus. These species were introduced to different locations in Tonga, including Koulo. Size measures of both trochus and green snail suggest that growth and reproduction of these species still occur despite the lack of widespread colonisation of local reefs. The blacklip pearl oyster (*Pinctada margaritifera*) was not uncommon at Koulo.

Sea cucumbers were relatively common around Koulo, despite the overall oceanic influence of the lagoon system. The densities of medium- and high-value species offered some potential for the development of commercial fishing, although other species had not recovered noticeably since the moratorium was imposed. The medium-value leopardfish or tigerfish (*Bohadschia argus*) and the lower-value lollyfish (*Holothuria atra*) were recorded at reasonable coverage and density. The high-value black teatfish (*H. nobilis*) was one species that had not recovered markedly around Koulo, although other species, such as the surf redfish (*Actinopyga mauritiana*), were noted at high density on the eastern reef platform of Lifuka Island. Deeper-water white teatfish (*H. fuscogilva*) stocks were common and at moderate density. Other deep-water species, e.g. the lower-value amberfish (*Thelonata anax*), was at high density at Ha'apai.

Recommendations for Koulo

- Koulo and neighbouring communities on Ha'apai be included in the ongoing community-based fisheries management programme.

- Protected zones or no-take marine parks be established to help the recovery and maintenance of finfish and invertebrate resources and habitat condition, with appropriate monitoring and enforcement to ensure compliance.

- Regulations be put in place to control the mesh size of nets and their use.

- A monitoring system be set in place to follow any further changes in finfish resources.

- For successful stock management, a percentage of large clams of each species be maintained at high density, to ensure there is sufficient successful spawning taking place to produce new generations of clams for the fishery.

- Ongoing protection be provided to the trochus stocks for at least another five-to-ten years to enable them to benefit from the increased spawning activity that the high-density base population will provide, thus allowing stocks to rebuild to a minimum of 500–600 shells/ha before commercial harvests are considered.

- The potential of Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

Results from fieldwork at Lofanga

The volcanic island of Lofanga, located at the coordinates 19°49' S and 174°33' W, is a slightly elevated island (maximum altitude 15 m), about 1.9 km long by 0.9 km wide. It has no lagoon and is inhabited by a community of about 300 people. The village is only accessible by sea from the west or southeast coast. The fishing area, excluding the island itself, includes, to the north and northwest, the lagoon reef complexes of Hakau Houa'ulu (5.6 km x 1.5 km, the *motu* of Niniva included) and Hakau Lahi (4.8 km x 1.9 km, the *motu* of Nukupule and Meama included). Southeast of Lofanga, fishers also use the reefs on the small islands of Makauata and Luangahu along with about a dozen other reef microstructures, each no more than 200 m in diameter. There are only two types of habitat at the site, outer reefs and back-reefs. In reality, this fishing area is not exclusive (open-access), although preferred by the Lofanga community as it is closer and has more fish.

Socioeconomics: Lofanga

The Lofanga community inhabits an isolated, rural coastal area with limited access to agricultural land. The Lofanga population depends heavily on its marine resources for home consumption, and finfish fisheries provide the main source of income. Revenues obtainable from marketing fisheries produce, however, are limited due to the distance to the Ha'apai mainland, the lack of electricity (ice and cooling) and the cost of fuel and boat transport. Seafood consumption is high (65 kg/person/year for finfish and 16.8 kg/person/year for invertebrates). The community also consumes rather high amounts of canned fish (21.2 kg/person/year).

Males are the only commercial finfish fishers, while females are in charge of invertebrate collection, although females also catch fish at times. Handlining and spear diving are the dominant fishing techniques used, while trolling and cast netting are used much less. Invertebrates are collected using very low-cost equipment. The invertebrate catch is mainly made up of giant clams, octopus and sea urchins, while all other species caught are of minor importance only. In contrast to finfish fishing, significant differences were found in the average annual catch by invertebrate fishery. Average annual catches reported for the gleaning of reeftops were less than those obtained by free-diving for selected, reef-associated invertebrate species.

Finfish resources: Lofanga

The status of finfish resources in Lofanga was better than at the other three sites but only mediocre when compared to the regional values. Density, sizes and biomass were the highest recorded among the four sites, however, still quite low compared to the regional values. At a detailed analysis at family level, Acanthuridae was the dominant fish family but was represented by small-sized species; Scaridae was much less abundant. This is already a sign of impact from heavy fishing. Carnivores were rare and only in the outer reef did they represent one-third of the herbivore biomass, a higher value than in the back-reefs. There were some good-sized fish but these were very rare. However, species of piscivores belonging to the families Lutjanidae and Serranidae were extremely rare. The existence of *Siganus niger*, endemic to Tonga, was confirmed. Large predators were rare, particularly sharks and Epinephelidae.

Invertebrate resources: Lofanga

Three species of giant clam were recorded at Lofanga: the elongate clam *Tridacna maxima*, the fluted clam *T. squamosa* and the devil's clam *T. tevoroa*. The smooth clam *T. derasa* was also noted in Ha'apai, but not in the shallow-water surveys assigned to the Lofanga study area. Giant clam coverage across the study area was not noticeably disrupted, although the larger species were not recorded in shallow-water locations. On the other hand, the total number of clams recorded was low. The densities recorded at Lofanga were at best moderate for an exposed oceanic environment such as that found at Lofanga and such a low density is indicative of an impacted clam fishery.

The reefs at Lofanga are outside the natural range of the commercial topshell, *Trochus niloticus*, but now support this species after successful introductions. Introductions have included the movement of both adults (from Fiji) and juveniles (from the hatchery on Tongatapu). A similar situation exists for the green snail, *Turbo marmoratus*, which was also introduced as juveniles from hatchery rearing. *T. niloticus* and *Turbo marmoratus* were recorded at Lofanga, but only in very small numbers and at low densities. Size measures of both trochus and green snail suggested that growth and reproduction of these species was still occurring despite the lack of widespread colonisation of local reefs. The blacklip pearl oyster *Pinctada margaritifera* was not common at Lofanga.

Sea cucumbers were relatively common around Lofanga. The densities of medium- and high-value species offered some potential for the development of commercial fishing, although other species had not recovered noticeably since the moratorium was imposed. The medium-value leopardfish or tigerfish (*Bohadschia argus*) and the lower-value lollyfish (*Holothuria atra*) were recorded at reasonably high coverage and density, and there was some recovery of greenfish numbers. The high-value black teatfish (*H. nobilis*) was one species that had not recovered markedly around Lofanga as, too, was the golden sandfish (*H. scabra versicolor*). Surveys targeting deeper-water white teatfish stocks (*H. fuscogilva*) revealed that this high-value species was common and at moderate density. Other deep-water species, e.g. the lower-value amberfish (*Thelonata anax*) was at high density at Ha'apai.

Recommendations for Lofanga

- Lofanga and neighbouring communities on Ha'apai be included in the ongoing community-based fisheries management programme.

- Protected zones or no-take marine parks be established to help recovery and maintenance of finfish and invertebrate resources and habitat condition, with appropriate monitoring and enforcement to ensure compliance.

- Regulations be put in place to control the mesh size of nets and their use.

- A monitoring system be set in place to follow any further changes in finfish resources.

- For successful stock management, a percentage of large clams of each species be maintained at high density, to ensure there is sufficient successful spawning taking place to produce new generations of clams for the fishery.

- Ongoing protection be provided to the trochus stocks for at least another five-to-ten years to allow them to benefit from the increased spawning activity that the high-density base population will provide, thus allowing stocks to rebuild to a minimum of 500–600 shells/ha before commercial harvests are considered.

- The high-value black teatfish (*Holothuria nobilis*) and the golden sandfish (*H. scabra versicolor*) require careful management to ensure they recover to 'healthy' densities.

- The potential of the Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

RÉSUMÉ

Les agents de la composante côtière du Programme régional de développement des pêches océaniques et côtières dans les PTOM français et pays ACP du Pacifique (PROCFish/C) ont conduit des travaux de terrain sur quatre sites du Royaume des Tonga, d'avril à juin, et de septembre à octobre 2008. Ces activités s'inscrivaient dans le prolongement de travaux financés par la *MacArthur Foundation* et conduits en six endroits des Tonga en novembre et en décembre 2001, et de mars à juin 2002, dans le cadre du projet DemEcoFish (application conjointe de la démographie et de l'écologie à l'évaluation des ressources halieutiques côtières du Pacifique). Le Royaume des Tonga est l'un des dix-sept États et Territoires insulaires du Pacifique visés, sur une période de 5 à 6 ans, par le projet PROCFish ou le projet CoFish qui lui est associé (Projet de développement de la pêche côtière)[3].

Les enquêtes réalisées visaient à recueillir des données de référence sur l'état des ressources récifales, afin de combler l'énorme déficit d'informations qui fait obstacle à la bonne gestion de ces ressources.

Les autres résultats attendus du projet sont les suivants :

- Première évaluation exhaustive et comparative des pêcheries récifales (poissons, invertébrés et paramètres socioéconomiques de leur exploitation) de plusieurs pays de la région océanienne, suivant une méthode normalisée, appliquée sur chaque site d'étude ;
- Diffusion de rapports nationaux comprenant un ensemble de « descriptifs des ressources halieutiques récifales » pour les sites étudiés dans chaque pays, servant de base au développement de la pêche côtière et à la planification de sa gestion ;
- Élaboration d'un jeu d'indicateurs (ou points de référence pour l'évaluation de l'état des stocks), qui serviront de guide à l'élaboration de plans de gestion des ressources récifales à l'échelle locale et nationale, et de programmes de suivi ; et
- Élaboration de systèmes de gestion des données et de l'information, dont des bases de données régionales et nationales.

Les enquêtes conduites aux Tonga comprenaient trois volets (poissons, invertébrés et aspects socioéconomiques) sur chaque site. L'équipe était composée de huit chercheurs et de plusieurs agents du Ministère de l'agriculture et des pêches. Durant les travaux de terrain, l'équipe a formé les agents des Tonga aux méthodes d'enquête et d'inventaire utilisées dans chaque discipline, notamment la collecte de données et leur saisie dans la base de données du Projet.

[3] Les projets CoFish et PROCFish/C font partie du même programme d'action, CoFish ciblant Niue, Nauru, les États fédérés de Micronésie, Palau, les Îles Marshall et les Îles Cook (pays ACP bénéficiant d'un financement au titre du 9e FED) et PROCFish/C les pays bénéficiant de fonds alloués au titre du 8e FED (pays ACP : Îles Fidji, Tonga, Papouasie-Nouvelle-Guinée, Îles Salomon, Vanuatu, Samoa, Tuvalu et Kiribati, et collectivités françaises d'outre-mer : Nouvelle-Calédonie, Polynésie française, Wallis et Futuna).

Au Royaume des Tonga, les quatre sites sélectionnés pour l'enquête étaient Ha'atafu et Manuka à Tongatapu, et Koulo et Lofanga à Ha'apai. Il s'agissait aussi de sites étudiés dans le cadre du projet DemEcoFish offrant une occasion unique de comparer les résultats obtenus six ans après les enquêtes initiales. Ces sites ont également été sélectionnés selon des critères spécifiques, notamment :

- être le siège d'une pêche récifale active,
- être représentatifs du pays,
- constituer des systèmes relativement fermés (les populations environnantes pêchent dans des zones bien définies),
- couvrir une superficie appropriée,
- présenter une grande diversité d'habitats,
- ne pas poser de problèmes logistiques majeurs,
- avoir été étudiés auparavant, et
- présenter un intérêt particulier pour le Ministère de l'agriculture et des pêches.

Résultats des études de terrain à Ha'atafu

Tongatapu est une île corallienne à la position moyenne de 21° 10' Sud et 175° 10' Ouest, dont le lagon possède la particularité d'être ouvert au Nord ce qui lui donne l'aspect d'un croissant et le classerait plutôt dans une catégorie de pseudolagon. Ha'atafu est situé du côté Ouest du lagon. Les aires de pêche ne sont pas clairement définies et les habitants pratiquent la pêche en « accès libre ». L'aire de pêche dans le lagon s'étend sur 18,5 km de large et 37 km de long, et les ressources halieutiques sont exploitées conjointement avec Manuka et d'autres villages. Autour de Ha'atafu, le récif côtier est surtout formé d'herbier et de petites étendues de corail ; au centre, le platier est beaucoup moins large et se compose essentiellement de débris corallien de sable et d'herbiers. C'est sur cette structure que sont disposés les pièges à poissons.

Enquêtes socioéconomiques : Ha'atafu

Ha'atafu est une communauté côtière rurale reliée à la ville et au marché par une route. Le niveau de vie est relativement élevé. Les habitants ont l'électricité et l'eau courante. Toutefois ils n'ont qu'un accès limité aux terres arables et sont en grande partie tributaires des ressources marines (poissons et invertébrés), notamment de poissons en conserve pour leur consommation personnelle. Les revenus tirés de la commercialisation des produits de la pêche sont cependant nettement inférieurs à ceux provenant d'activités rémunérées, de transferts de fonds de l'étranger (salaires) ou de la confection de tapis réalisée par les femmes. La consommation annuelle de produits de la mer est la plus élevée parmi les populations étudiées aux Tonga, avec 92 kilos de poissons et 21 kilos d'invertébrés par personne.

Seuls les hommes pêchent le poisson à l'échelle commerciale. Les femmes pêchent aussi occasionnellement, mais elles sont avant tout chargées de la collecte d'invertébrés. La pêche à la palangrotte et à l'épervier, ou la pêche alliant le filet maillant, la palangrotte, le fusil à harpon et la traîne sont autant de techniques utilisées pour pêcher le poisson. Les invertébrés sont collectés à l'aide d'un matériel très économique, puisque les hommes utilisent simplement un masque, un tuba et des palmes. Les prises d'invertébrés sont principalement constituées d'holothuries, de poulpes, d'oursins et de *Turbo crassus* (poids frais). Par comparaison, les prises de *Strombus* spp., *Dolabella* spp. et d'autres espèces, sont nettement moins importantes.

Ressources en poissons : Ha'atafu

Les ressources en poissons à Ha'atafu sont maigres, mais légèrement supérieures à celles de Manuka. Elles se caractérisent par une biodiversité des espèces, une densité et une biomasse plus importantes, mais des tailles inférieures à la moyenne. La couverture de corail est plus fine sur les récifs côtiers, mais plus épaisse sur l'arrière-récif en comparaison à Manuka, et nettement plus épaisse sur le tombant récifal externe. Les herbivores, en particulier les Acanthuridés, dominent avec une densité totale légèrement supérieure à celle de Manuka. Parmi les autres familles, citons les scaridés dont la densité et la biomasse totales sont nettement inférieures à celles des acanthuridés et des holocentridés (très faibles valeurs). Les tailles moyennes de plusieurs familles de poissons étaient inférieures de 50 pour cent aux valeurs maximales, élément révélateur des effets de la pêche sur les stocks. Comme à Manuka, les espèces les plus représentatives pour ce site sur le plan de la densité et de la biomasse étaient les acanthuridés et les scaridés de petite taille. Lors de la première évaluation conduite en 2002, les tailles et la biomasse moyennes étaient supérieures à celles de la deuxième évaluation. Comme la densité a légèrement augmenté, la diminution de la biomasse est due principalement à une réduction sensible de la taille moyenne des poissons et au remplacement de grandes espèces par des espèces plus petites. Une diminution plus marquée de la biomasse a été observée chez les piscivores.

Ressources en invertébrés : Ha'atafu

Le récif à Ha'atafu abrite de vastes étendues calcaires et de benthiques coralliennes, avec un habitat lagonaire peu profond particulièrement adapté aux espèces de bénitier. Toutefois, seules deux espèces de bénitier ont été observées à Ha'atafu, le bénitier allongé (*Tridacna maxima*) et le grand tridacne gaufré *(Tridacna squamosa)*. Le grand tridacne brillant (*T. derasa*) et le bénitier de Tevoro (*T. tevoroa*) sont présents aux Tonga, mais n'ont pas été consignés dans le cadre de ces enquêtes. Tongatapu est une zone qui a abrité le bénitier tacheté (*Hippopus hippopus*) jusqu'au milieu des années 70, mais cette espèce n'existe plus aujourd'hui aux Tonga. La couverture de bénitier sur l'ensemble de la zone d'étude était sérieusement perturbée, et seul un petit nombre de bénitiers a été observé à proximité d'Ha'atafu. En réalité, le nombre total de bénitiers consignés dans l'évaluation à grande échelle et sur les transects tirés dans les stations du benthos récifal était faible. Les densités de bénitier enregistrées à Ha'atafu témoignent de l'impact de la pêche sur cette ressource.

Les récifs de Ha'atafu sont situés au-delà de l'aire naturelle propice au troca d'importance commerciale *Trochus niloticus*, mais des translocations concluantes ont permis à cette espèce de s'implanter sur ces récifs. Les introductions ont porté à la fois sur des adultes (des Îles Fidji) et des juvéniles (de l'écloserie située à Tongatapu). Le burgau *Turbo marmoratus* a lui aussi été introduit en tant que juvénile issu d'un élevage en écloserie. La couverture et la densité de trocas indiquent qu'une ressource colonise avec succès les récifs locaux. La couverture était de bonne qualité dans la plupart des enquêtes les plus pertinentes, et la densité de coquillages, aux meilleurs endroits, atteignait une moyenne supérieure à 300 unités par hectare. Dans le cas des enquêtes MOPt, la densité moyenne enregistrée était de 772,6 unités par hectare. Aucun burgau n'a été observé. L'huître perlière à lèvres noires *Pinctada margaritifera* a été observée à Ha'atafu.

Une grande diversité d'holothuries a été observée à Ha'atafu malgré les influences biogéographiques (la position orientale des Tonga et son isolement relatif dans le Pacifique).

Les densités d'holothuries étaient particulièrement élevées dans les habitats sédimentaires semi-fermés – zones lagonaires semi-fermées, aux sédiments fins. C'était notamment le cas à l'est de Ha'atafu où un certain nombre d'espèces a été observé (ex. : l'holothurie léopard *Bohadschia argus*). D'un autre côté, malgré l'interdiction totale de la pêche commerciale d'holothuries qui est en vigueur depuis sept à dix ans, certaines espèces n'ont pas pu se reconstituer pleinement [comme c'est le cas de l'holothurie noire à mamelles (*Holothuria nobilis*) et de l'holothurie de sable *H. scabra. versicolor*]. L'holothurie brune des brisants *Actinopyga mauritiana* a été observée en faible densité de même que l'holothurie blanche à mamelles (*H. fuscogilva*) et l'holothurie géante (*T. anax*) qui est moins recherchée.

Recommandations pour Ha'atafu

- Inclure Ha'atfu et les populations voisines de Tongatapu dans le programme national de gestion communautaire des ressources halieutiques.
- Établir des aires protégées et des réserves marines où la pêche est interdite afin de reconstituer et de pérenniser les ressources en poissons et en invertébrés ainsi que les conditions d'habitat, et adopter des dispositifs de surveillance afin de veiller à ce que ces zones soient respectées.
- Instaurer un système de surveillance afin de suivre l'évolution des ressources en poissons.
- Maintenir, dans le cadre d'une gestion concluante des stocks, un pourcentage de bénitiers de chaque espèce à haute densité afin d'assurer un taux de reproduction suffisant.
- Assurer la protection continue des stocks de trocas pendant une nouvelle période de cinq ans minimum afin qu'ils puissent profiter de l'activité de reproduction accrue engendrée par la population mère à haute densité, permettant ainsi aux stocks de se reconstituer à un minimum de 500 à 600 coquillages par hectare avant de pouvoir envisager leur exploitation commerciale.
- Gérer soigneusement l'holothurie noire à mamelles *Holothuria nobilis*, de forte valeur marchande, et l'holothurie de sable *H. scabra. versicolor* afin qu'elles puissent recouvrer des densités « saines ».
- Le potentiel d'exploitation de l'holothurie aux Tonga est probablement restreint, en général, et toute réintroduction d'un quota commercial doit être envisagée avec la plus grande prudence.

Résultats des études de terrain à Manuka

Manuka est situé sur le flanc est du lagon en forme de croissant à Tongatapu. Les aires de pêche ne sont pas clairement définies et les habitants pratiquent la pêche en « accès libre ». L'aire de pêche dans le lagon s'étend sur 18,5 km de large et 37 km de long, et les ressources halieutiques sont exploitées conjointement avec Ha'atafu et d'autres villages. À proximité de Manuka, une sorte de lagune bordée de mangroves pénètre dans l'île par un Y inversé. Cette eau est saturée en microalgues, ce qui indique un manque de circulation et lui donne un aspect verdâtre. Au large, un grand récif barrière bordé de quelques motus forme un L inversé sur une longueur de 22,2 km.

Enquêtes socioéconomiques : Manuka

Manuka est une communauté côtière rurale reliée à la ville et au marché par une bonne route. Le niveau de vie est relativement élevé. Les habitants ont l'électricité et l'eau courante. Ils tirent des revenus substantiels des activités de pêche de poissons ainsi que des transferts de fonds provenant de l'étranger. Ils n'ont qu'un accès limité aux terres arables et sont en grande partie tributaires des ressources marines. La consommation annuelle de poisson atteint 78 kilos par personne, mais celle d'invertébrés et de poissons en conserve est nettement inférieure à la moyenne sur l'ensemble des communautés étudiées aux Tonga.

Seuls les hommes pêchent le poisson à l'échelle commerciale. Les femmes pêchent aussi occasionnellement, mais elles sont avant tout chargées de la collecte d'invertébrés. Le harpon, la palangrotte et la palangre sont les techniques privilégiées contrairement à l'épervier et à la traîne plus rarement utilisés pour pêcher le poisson. Les invertébrés sont pêchés à l'aide d'un matériel très économique, puisque les hommes utilisent simplement un masque, un tuba et des palmes. Les prises d'invertébrés sont principalement constituées d'holothuries. *Strombus* spp représente la majeure partie de la récolte annuelle (poids frais). Par comparaison, les prises de langoustes, d'oursins, de *Turbo* spp., de *Dolabella* spp. ainsi que des autres espèces sont dérisoires.

Ressources en poissons : Manuka

À l'époque des enquêtes, les stocks de poissons à Manuka étaient très bas. La densité était faible par rapport à la moyenne régionale, mais les valeurs relatives aux tailles et à la biomasse étaient particulièrement basses. La biodiversité était également très faible, beaucoup plus que dans les pays situés à l'est des Tonga. L'état de la zone ne s'explique donc pas uniquement par la distance par rapport au centre de biodiversité, mais aussi par les effets d'une pêche intensive. Les acanthuridés et les scaridés représentaient les familles d'herbivores les plus importantes tandis que les carnivores étaient très peu abondants. Certaines familles carnivores, tels que les serranidés et les lethrinidés, étaient pratiquement absentes. Sur le plan de la densité et de la biomasse, les petits poissons étaient les plus représentatifs, leurs tailles moyennes étant nettement inférieures aux tailles maximales figurant dans les ouvrages scientifiques. Nous pensons que cette pauvreté générale s'explique par une intense activité de pêche. Les arrières-récifs abritent les habitats les plus pauvres, caractérisés par la densité la plus faible, les tailles les plus petites, et une biomasse et une biodiversité très pauvres. Les tombants récifaux externes abritent un plus grand nombre d'espèces, mais se caractérisent par une densité et une biomasse très faibles. En 2002, les stocks de poissons étaient plus importants qu'en 2008 et la situation était également meilleure dans les domaines de la biodiversité, de la densité, des tailles, des rapports de taille et de la biomasse.

Ressources en invertébrés : Manuka

Le récif à Manuka abrite de vastes étendues calcaires et de benthiques coralliennes, avec un habitat lagonaire peu profond particulièrement adapté aux espèces de bénitier. Toutefois, seules deux espèces de bénitier ont été observées à Manuka, le bénitier allongé (*Tridacna maxima*) et le grand tridacne gaufré (*Tridacna squamosa*). Le grand tridacne brillant (*T. derasa*) et le bénitier de Tevoro (*T. tevoroa*) sont présents aux Tonga, mais n'ont pas été consignés dans le cadre de ces enquêtes. La couverture de bénitier sur l'ensemble de la zone d'étude était sérieusement perturbée et seul un petit nombre de bénitiers a été observé à proximité de Manuka. En réalité, le nombre total de bénitiers consignés dans l'évaluation à grande échelle et sur les transects tirés dans les stations du benthos récifal était faible. Les densités de bénitier enregistrées à Manuka témoignent de l'impact de la pêche sur la ressource.

Les récifs de Manuka sont situés au-delà de l'aire naturelle propice au troca d'importance commerciale *Trochus niloticus*, mais des introductions concluantes ont permis à ces espèces de s'implanter sur ces récifs. Les introductions ont porté à la fois sur des adultes (des Îles Fidji) et des juvéniles (de l'écloserie située à Tongatapu). Le burgau *Turbo marmoratus* a lui aussi été introduit en tant que juvénile issu d'un élevage en écloserie. La présence de trocas a été consignée à Manuka. La couverture était de bonne qualité dans la plupart des enquêtes les plus pertinentes, et la densité de coquillages, aux meilleurs endroits, atteignait une moyenne supérieure à 300 unités par hectare. Un seul burgau *Turbo marmoratus* a été observé. La troque obélisque (*Tectus pyramis*) a été observée à Manuka au même titre que l'huître perlière à lèvres noires *Pinctada margaritifera*.

Les densités d'holothuries étaient particulièrement élevées dans les zones lagonaires semi-fermées aux sédiments fins. C'était notamment le cas au Sud d'Onevai et à l'est de Toke Toke où un grand nombre d'*Holothuria atra* et d'holothuries serpents (*H. coluber)*, toutes deux de faible valeur commerciale, a été observé. Le lagon ouvert subit une influence plus océanique et abrite des densités plus faibles d'holothuries commerciales. L'interdiction totale de la pêche d'holothuries commerciales a été en place suffisamment longtemps pour permettre une reconstitution énergique des stocks de certaines espèces (holothurie léopard *Bohadschia argus*) alors que d'autres ne semblent pas s'être reconstituées suffisamment (holothurie noire à mamelles *Holothuria nobilis*). L'holothurie brune des brisants *Actinopyga mauritiana* a été observée à faible densité. Aucune holothurie blanche à mamelles (*H. fuscogilva*) n'a été consignée, mais l'holothurie géante (*Thelonata anax*), moins recherchée, a été observée à une densité modérée.

Recommandations pour Manuka

- Inclure Manuka et les populations voisines de Tongatapu dans le programme national de gestion communautaire des ressources halieutiques.

- Établir des aires protégées et des réserves marines où la pêche est interdite afin de reconstituer et de pérenniser les ressources en poissons et en invertébrés ainsi que les conditions d'habitat, et adopter des dispositifs de surveillance afin de veiller à ce que ces zones soient respectées.

- Encadrer la pêche au harpon à Manuka et l'interdire de nuit.

- Réglementer la largeur de maille des filets.

- Mettre en place un système de surveillance de l'évolution des ressources en poissons.

- Maintenir, dans le cadre d'une gestion concluante des stocks, un pourcentage de bénitiers de chaque espèce à haute densité afin d'assurer un taux de reproduction suffisant.

- Assurer la protection continue des stocks de trocas pendant une nouvelle période de cinq ans minimum afin qu'ils puissent profiter de l'activité de reproduction accrue engendrée par la population mère à haute densité, permettant ainsi aux stocks de se reconstituer à un minimum de 500 à 600 coquillages par hectare avant de pouvoir envisager leur exploitation commerciale.

- Gérer soigneusement l'holothurie noire à mamelles *Holothuria nobilis*, de forte valeur marchande et l'holothurie de sable *H. scabra. versicolor* afin qu'elles puissent recouvrer des densités « saines ».

- Le potentiel d'exploitation de l'holothurie aux Tonga est probablement restreint, en général, et toute réintroduction d'un quota commercial doit être envisagée avec la plus grande prudence.

Résultats des études de terrain à Koulo

Koulo est un village situé sur l'extrémité Nord de l'île corallienne de Lifuka à la position moyenne de 19° 46' Sud et174° 20' Ouest. Lifuka est l'île principale du groupe Ha'apai. Sur la partie est un récif barrière exposé aux vents dominant reste inaccessible par voie de mer puisque la partie Nord de l'île est reliée à l'île de Foa par un remblai et une route. L'arrière-récif peu profond n'est exploitable qu'à pied et ne semble pas très riche. Le coté Ouest est bordé par une plage et par un platier dont une petite partie est composée d'herbier et le reste de patch de corail, de sable et de débris corallien. Plus au large, des structures de corail plus ou moins importantes sont exploitées par les pêcheurs à la ligne ou en plongée. Le système de pêche est « open access ».

Enquêtes socioéconomiques : Koulo

La population de Koulo habite une zone côtière urbanisée et dispose d'infrastructures modernes et de revenus en espèces. Elle a accès à des terres arables ainsi qu'à des ressources marines côtières et hauturières. Alors que les habitants de Koulo dépendent peu des ressources marines aux fins de revenus, ils sont plus tributaires des produits de la mer pour leur consommation personnelle. Les activités salariées et la confection de tapis constituent les principales sources de revenus. La consommation annuelle de produits de la mer est considérable (47 kilos par personne pour le poisson et sept kilos par personne pour les invertébrés), mais les invertébrés et le poisson frais sont consommés moins qu'ailleurs, tandis que le poisson en conserve est particulièrement prisé (16,8 kilos par personne par an) par rapport à tous les autres sites étudiés aux Tonga.

Seuls les hommes pêchent le poisson à l'échelle commerciale. Les femmes pêchent aussi occasionnellement, mais elles sont avant tout chargées de la collecte d'invertébrés. La palangrotte et le fusil-harpon sont les deux techniques de pêche prédominantes pour le poisson, le filet maillant et l'épervier étant nettement moins utilisés. Les invertébrés sont collectés à l'aide d'un matériel très économique. Les prises d'invertébrés sont principalement constituées d'holothuries, de poulpes et de bénitiers, tandis que les autres espèces capturées revêtent uniquement une importance mineure. Les hommes pêchent également des invertébrés mais leur production est nettement inférieure à la quantité totale d'invertébrés collectés chaque année par les femmes à l'échelon local.

Ressources en poissons: Koulo

L'état des stocks de poissons à Koulo, à l'époque de l'enquête, s'établissait dans une moyenne située entre des conditions particulièrement médiocres à Tongatapu et des conditions relativement saines à Lofanga. Toutefois, les tailles et la biomasse de poissons étaient faibles par rapport au reste de la région. La densité de poisson à Koulo était comparable à celle observée à Lofanga et à Ha'atafu, mais les tailles et la biomasse étaient plus proches de celles consignées à Lofanga. Globalement, les ressources étaient dans un état pouvant être qualifié de moyen à mauvais. Les arrières-récifs étaient plus pauvres que les tombants récifaux externes, avec une densité, des tailles, une biomasse et une biodiversité faibles. Une analyse détaillée des différentes familles a révélé que les acanthuridés se caractérisaient systématiquement par l'abondance et la biosécurité la plus élevée, alors que les scaridés avaient plutôt des caractéristiques opposées. Les carnivores étaient particulièrement pauvres à l'exception des mullidés qui, sur le plan de la biomasse, n'étaient que relativement importants sur les tombants récifaux externes. La taille des scaridés, des lethrinidés et des holocentridés était nettement inférieure à la taille maximale consignée pour ces espèces particulières, ce qui traduit un impact de la pêche sur ces espèces recherchées. La situation n'a pratiquement pas évolué entre les deux périodes d'enquête, à l'exception d'une faible diminution de la biomasse moyenne et d'une réduction de l'espèce la plus importante, *Ctenochaetus striatus*, lors de l'enquête la plus récente.

Ressources en invertébrés : Koulo

Quatre espèces de bénitiers ont été observés à Koulo: le bénitier allongé (*Tridacna maxima*), le grand tridacne gaufré (*Tridacna squamosa*), le grand tridacne brillant (*T. derasa*) et le bénitier de Tevoro (*T. tevoroa*). Le bénitier de Tevoro est une espèce rare dont la présence n'a été observée qu'aux Tonga, aux Îles Fidji et en Nouvelle-Calédonie. La couverture de bénitier sur l'ensemble de la zone d'étude ne semblait pas particulièrement perturbée (aucune diminution majeure n'a été observée à proximité des principales zones de fixation), bien que des espèces plus grandes n'aient pas été constatées dans les eaux peu profondes. Par ailleurs, le nombre total de bénitiers enregistrés était faible. Les densités consignées à Koulo étaient, dans le meilleur des cas, modérées pour un environnement océanique exposé comme celui de Koulo (Ha'apai dans son ensemble), et une densité aussi faible indique que les stocks de bénitier ont subi les effets de la pêche.

Des trocas (*Trochus niloticus*) et des burgaux (*Turbo marmoratus*) ont été observés à Koulo, mais seulement en petit nombre et à faible densité. À Koulo, deux des trois recherches sur le front récifal et deux des quatorze évaluations (en station) sur les transects tirés dans le benthos récifal ont révélé la présence de trocas. Ces espèces ont été introduites à différents endroits aux Tonga, y compris à Koulo. Les mesures des tailles des trocas et des burgaux indiquent que la croissance et la reproduction de ces espèces se poursuivent malgré l'absence d'une colonisation massive des récifs locaux. L'huître perlière à lèvres noires *Pinctada margaritifera* a été observée à Koulo.

Les holothuries sont relativement répandues autour de Koulo malgré l'influence océanique globale du système lagonaire. Les densités des espèces prisées et très prisées offrent des débouchés potentiels sur le plan commercial, même si les stocks d'autres espèces ne se sont pas encore reconstitués suffisamment depuis que le moratoire a été imposé. L'holothurie léopard (*Bohadschia argus*), de valeur moyenne, et *Holothuria atra*, de faible valeur, ont été observées, avec une assez bonne couverture et une densité raisonnable. L'holothurie noire à mamelles (*Holothuria nobilis*), particulièrement prisée, est une espèce qui n'est pas parvenue à se reconstituer pleinement aux alentours de Koulo alors que d'autres espèces telles que l'holothurie brune des brisants *Actinopyga mauritiana* ont été observées à haute densité sur la plate-forme récifale orientale de l'île Lifuka. L'holothurie blanche à mamelles (*H. fuscogilva*), qui évolue en eau profonde, était répandue à des densités modérées. D'autres espèces d'eau profonde comme, par exemple, l'holothurie géante (*T. anax*) ont été observées à haute densité à Ha'apai.

Recommandations pour Koulo

- Inclure Koulo et les populations voisines de Ha'apai dans le programme national de gestion communautaire des ressources halieutiques.

- Établir des aires protégées et des réserves marines où la pêche est interdite afin de reconstituer et de pérenniser les ressources en poissons et en invertébrés ainsi que les conditions d'habitat, et adopter des dispositifs de surveillance afin de veiller à ce que ces zones soient respectées.

- Réglementer la largeur de maille des filets et leur utilisation.

- Mettre en place un système de surveillance de l'évolution des ressources en poissons.

- Maintenir, dans le cadre d'une gestion concluante des stocks, un pourcentage de bénitiers de chaque espèce à haute densité afin d'assurer un taux de reproduction suffisant.

- Assurer la protection continue des stocks de trocas pendant une nouvelle période de cinq ans minimum afin qu'ils puissent profiter de l'activité de reproduction accrue engendrée par la population mère à haute densité, permettant ainsi aux stocks de se reconstituer à un minimum de 500 à 600 coquillages par hectare avant de pouvoir envisager leur exploitation commerciale.

- Le potentiel d'exploitation de l'holothurie aux Tonga est probablement restreint, de manière générale, et toute réintroduction d'un quota commercial doit être envisagée avec la plus grande prudence.

Résultats des études de terrain à Lofanga

L'île volcanique de Lofanga, située à la position 19°49,2' Sud et 174°33,3' Ouest, est une terre légèrement surélevée (altitude max15 mètres) de 1,9 km de long sur 0,9 km de large. Elle est dépourvue de lagon et habitée par une communauté d'environ 300 âmes. Le village n'est accessible que par voie de mer du coté Ouest ou Sud/Est. L'aire de pêche outre l'île elle-même, comprend au Nord- Ouest et au Nord les ensembles récifaux lagonaires de Hakau Houa'ulu (5,6 x 1,5 km, *motu* de Niniva compris) et de Hakau Lahi (4,8 km x 1,9 km, motu de Nukupule et de Meama compris). Au Sud-Est de Lofanga les pêcheurs exploitent aussi les récifs des ilots Makauata et Luangahu ainsi qu'une dizaine d'autres microstructures récifales n'excédant pas 200 mètres de diamètre chacune. Il n'existe que deux types d'habitats sur ce site : les tombants récifaux externes et les arrières-récifs. En réalité, cette zone de pêche n'est pas exclusive (« libre accès »), mais elle est assez fréquentée par les habitants de Lofanga car elle est plus proche et abrite davantage de poissons.

Enquêtes socioéconomiques : Lofanga

Les habitants de Lofanga habitent une zone rurale côtière isolée et ont un accès limité aux terres agricoles. Ils sont largement tributaires des ressources marines pour leur consommation personnelle et la pêche représente leur principale source de revenus. Les revenus perçus au titre de la vente de produits de la mer sont cependant limités en raison de la distance qui sépare Lofanga de Ha'apai, l'absence d'électricité (glace et refroidissement) et le coût du carburant et du transport par bateau. La consommation annuelle de produits de la mer est élevée (65 kilos de poissons et 16,8 kilos d'invertébrés par personne). La communauté consomme également d'importantes quantités de poissons en conserve (21,2 kilos par personne et par an).

Seuls les hommes pêchent le poisson à l'échelle commerciale. Les femmes pêchent aussi occasionnellement, mais elles sont avant tout chargées de la collecte d'invertébrés. La palangrotte et le harpon sont les techniques de pêche privilégiées contrairement à la traîne et à l'épervier. Les invertébrés sont pêchés à l'aide d'un matériel très économique. Les prises d'invertébrés sont principalement constituées d'holothuries, de poulpes et d'oursins, toutes les autres espèces étant moins importantes. Contrairement aux prises de poissons, les prises annuelles moyennes d'invertébrés se caractérisent par d'importantes différences. Celles issues du ramassage sur les sommets récifaux étaient inférieures à celles obtenues en plongée libre pour des espèces d'invertébrés récifaux donnés.

Ressources en poissons : Lofanga

L'état des stocks de poissons à Lofanga était meilleur que sur les trois autres sites, mais médiocre par rapport aux valeurs régionales. La densité, les tailles et la biomasse comptaient parmi les plus importantes sur les quatre sites, mais restaient particulièrement faibles par rapport aux valeurs régionales. Une analyse détaillée au niveau de la famille indique que les acanthuridés constituent la famille de poissons la plus importante mais représentée par des espèces de petite taille. Les scaridés étaient nettement moins abondants. Cette situation témoigne des effets d'une pêche intensive. Les carnivores observés étaient rares et, sur le tombant récifal externe, ils ne représentaient qu'un tiers de la biomasse d'herbivores, un nombre plus important que dans les arrières-récifs. Des poissons de bonne taille ont été observés, mais en infime quantité. Néanmoins, les espèces piscivores appartenant aux familles des lutjanidés et des serranidés étaient extrêmement rares. La présence de *Siganus Niger*, endémique à Tonga, a été confirmée. Les gros prédateurs, en particulier les requins et les épinephelidés, ont été observés en très petits nombres.

Ressources en invertébrés : Lofanga

Trois bénitiers ont été observés à Lofanga : le bénitier allongé (*Tridacna maxima*), le grand tridacne gaufré *(Tridacna squamosa)* et le bénitier de Tevoro (*T. tevoroa*). Le grand tridacne brillant (*T. derasa*) a également été repérée à Ha'apai, mais pas dans le cadre des enquêtes dans les eaux de faible profondeur associées à la zone d'étude de Lofanga. La couverture de bénitier sur l'ensemble de la zone d'étude n'était pas sérieusement perturbée même si les espèces de grande taille n'ont pas été observées dans les eaux peu profondes. Par contre, le nombre total de bénitiers consigné était faible. Les densités enregistrées à Lofanga étaient, dans le meilleur des cas, modérées pour un environnement océanique exposé tel qu'on le trouve à Lofanga, et une densité aussi faible est symptomatique de l'effet des activités de pêche sur les stocks.

Les récifs à Lofanga sont situés au-delà de l'aire naturelle propice au troca d'importance commerciale *Trochus niloticus*, mais des translocations concluantes ont permis à cette espèce de s'implanter sur ces récifs. Les introductions ont porté à la fois sur des adultes (des Îles Fidji) et des juvéniles (de l'écloserie située à Tongatapu). Le burgau Turbo marmoratus a lui aussi été introduit en tant que juvénile issu d'un élevage en écloserie. *T. niloticus* et *Turbo marmoratus* ont été consignés à Lofanga, mais seulement en petit nombre et à faible densité. Les mesures des tailles des trocas et des burgaux indiquent que la croissance et la reproduction de ces espèces se poursuivent malgré l'absence d'une colonisation massive des récifs locaux. L'huître perlière à lèvres noires *Pinctada margaritifera* n'est pas répandue à Lofanga.

Les holothuries sont relativement répandues autour de Lofanga. Les densités des espèces prisées et très prisées offrent des débouchés potentiels sur le plan commercial, même si les stocks d'autres espèces ne se sont pas encore reconstitués suffisamment depuis que le moratoire a été imposé. L'holothurie léopard (*Bohadschia argus*), de valeur moyenne, et *Holothuria atra*, de faible valeur, ont été observées, avec une assez bonne couverture et une densité raisonnable. Le stock de *Stichopus chloronotus* a commencé à se reconstituer. L'holothurie noire à mamelles (*Holothuria nobilis*), particulièrement prisée, est une espèce qui n'est pas parvenue à se reconstituer pleinement aux alentours de Lofanga au même titre que l'holothurie de sable *H. scabra. versicolor*. Les enquêtes consacrées aux stocks d'holothuries blanches à mamelles *H. fuscogilva*, qui vivent en eaux plus profondes, indiquent que cette espèce particulièrement prisée était répandue, à une densité modérée. D'autres espèces d'eau profonde comme, par exemple, l'holothurie géante (*T. anax*) ont été observées à haute densité à Ha'apai.

Recommandations pour Lofanga

- Inclure Lofanga et les populations voisines de Ha'apai dans le programme national de gestion communautaire des ressources halieutiques.

- Établir des aires protégées et des réserves marines où la pêche est interdite afin de reconstituer et de pérenniser les ressources en poissons et en invertébrés ainsi que les conditions d'habitat, et adopter des dispositifs de surveillance afin de veiller à ce que ces zones soient respectées.

- Réglementer la largeur de maille des filets et leur utilisation.

- Mettre en place un système de surveillance de l'évolution des ressources en poissons.

- Maintenir, dans le cadre d'une gestion concluante des stocks, un pourcentage de bénitiers de chaque espèce à haute densité afin d'assurer un taux de reproduction suffisant.

- Assurer la protection continue des stocks de trocas pendant une nouvelle période de cinq ans minimum afin qu'ils puissent profiter de l'activité de reproduction accrue engendrée par la population mère à haute densité, permettant ainsi aux stocks de se reconstituer à un minimum de 500 à 600 coquillages par hectare avant de pouvoir envisager leur exploitation commerciale.

- L'holothurie noire à mamelles (*Holothuria nobilis*), très recherchée, et l'holothurie de sable *H. scabra. versicolor* doivent faire l'objet d'une gestion attentive afin de s'assurer que leur densité redevienne normale.

- Le potentiel d'exploitation de l'holothurie aux Tonga est probablement restreint, de manière générale, et toute réintroduction d'un quota commercial doit être envisagée avec la plus grande prudence.

ACRONYMS

ACIAR	Australian Centre for International Agricultural Research
ACP	African, Caribbean and Pacific Group of States
AusAID	Australian Agency for International Development
BdM	bêche-de-mer (or sea cucumber)
CMT	customary marine tenure
CoFish	Pacific Regional Coastal Fisheries Development Programme
COTS	crown of thorns starfish
CPUE	catch per unit effort
Ds	day search
DSFDP	Deep Sea Fisheries Development Project
D-UVC	distance-sampling underwater visual census
EDF	European Development Fund
EEZ	exclusive economic zone
FAD	fish aggregating device
FAO	Food and Agricultural Organization (UN)
FFA	Forum Fisheries Agency
FL	fork length
GDP	gross domestic product
GIS	Geographic Information Systems
GPS	global positioning system
ha	hectare
HACCP	Hazard Analysis and Critical Control Points
HH	household
ICFMaP	Integrated Coastal Fisheries Management Project (SPC)
JICA	Japan's International Cooperation Agency
MCRMP	Millennium Coral Reef Mapping Project
MIRAB	Migration, Remittances, Aid and Bureaucracy (model explaining the economies of small island nations)
MOP	mother-of-pearl
MOPs	mother-of-pearl search
MOPt	mother-of-pearl transect
MPA	marine protected area
MRM	marine resource management
MSA	medium-scale approach
MSY	maximum sustainable yield
NASA	National Aeronautics and Space Administration (USA)
Ns	night search
OCT	Overseas Countries and Territories
PICTs	Pacific Island countries and territories

PROCFish	Pacific Regional Oceanic and Coastal Fisheries Development programme
PROCFish/C	Pacific Regional Oceanic and Coastal Fisheries Development programme (coastal component)
RBt	reef-benthos transect
RFID	Reef Fisheries Integrated Database
RFs	reef-front search
RFs_w	reef-front search by walking
SBq	soft-benthos quadrat
SCUBA	self-contained underwater breathing apparatus
SE	standard error
SMC	Sopu Mariculture Centre
SO	southern oscillation
SPC	Secretariat of the Pacific Community
SSFC	Sea Star Fishing Company
TOP	Pa'anga
UNCDF	United Nations Capital Development Fund
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USD	United States dollar(s)
VMS	vessel monitoring system(s)
WHO	World Health Organization

1. INTRODUCTION AND BACKGROUND

Pacific Island countries and territories (PICTs) have a combined exclusive economic zone (EEZ) of about 30 million km^2, with a total surface area of slightly more than 500,000 km^2. Many PICTs consider fishing to be an important means of gaining economic self-sufficiency. Although the absolute volume of landings from the Pacific Islands coastal fisheries sector (estimated at 100,000 tonnes per year, including subsistence fishing) is roughly an order of magnitude less than the million-tonne catch by the industrial oceanic tuna fishery, coastal fisheries continue to underpin livelihoods and food security.

SPC's Coastal Fisheries Management Programme provides technical support and advice to Pacific Island national fisheries agencies to assist in the sustainable management of inshore fisheries in the region.

1.1 The PROCFish and CoFish programmes

Managing coral reef fisheries in the Pacific Island region in the absence of robust scientific information on the status of the fishery presents a major difficulty. In order to address this, the European Union (EU) has funded two associated programmes:

1. The Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish); and
2. The Coastal Fisheries Development Programme (CoFish).

These programmes aim to provide the governments and community leaders of Pacific Island countries and territories with the basic information necessary to identify and alleviate critical problems inhibiting the better management and governance of reef fisheries and to plan appropriate future development.

The PROCFish programme works with the ACP countries: Fiji Islands, Kiribati, Papua New Guinea, Vanuatu, Samoa, Solomon Islands, Tonga, Tuvalu, and the OCT French territories: French Polynesia, Wallis and Futuna, and New Caledonia, and is funded under European Development Fund (EDF) 8.

The CoFish programme works with Cook Islands, Federated States of Micronesia, Marshall Islands, Nauru, Niue and Palau, and is funded under EDF 9.

The PROCFish/C (coastal component) and CoFish programmes are implementing the first comprehensive multi-country comparative assessment of reef fisheries (including resource and human components) ever undertaken in the Pacific Islands region using identical methodologies at each site. The goal is to provide baseline information on the status of reef fisheries, and to help fill the massive information gap that hinders the effective management of reef fisheries (Figure 1.1).

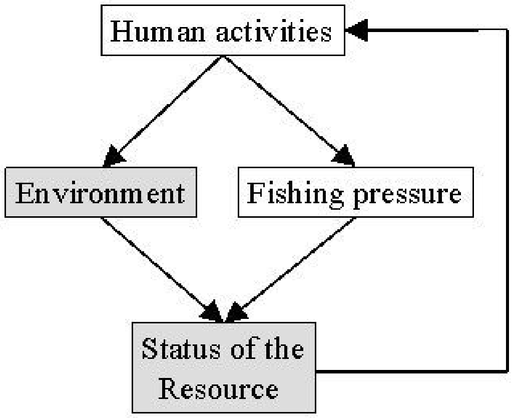

Figure 1.1: Synopsis of the PROCFish/C* multidisciplinary approach.
PROCFish/C conducts coastal fisheries assessment through simultaneous collection of data on the three major components of fishery systems: people, the environment and the resource. This multidisciplinary information should provide the basis for taking a precautionary approach to management, with an adaptive long-term view.

* PROCFish/C denotes the coastal (as opposed to the oceanic) component of the PROCFish project.

Expected outputs of the project include:

- the first-ever region-wide comparative assessment of the status of reef fisheries using standardised and scientifically rigorous methods that enable comparisons among and within countries and territories;
- application and dissemination of results in country reports that comprise a set of 'reef fisheries profiles' for the sites in each country, in order to provide information for coastal fisheries development and management planning;
- development of a set of indicators (or fishery status reference points) to provide guidance when developing local and national reef fishery management plans and monitoring programmes;
- toolkits (manuals, software and training programmes) for assessing and monitoring reef fisheries, and an increase in the capacity of fisheries departments in participating countries in the use of standardised survey methodologies; and
- data and information management systems, including regional and national databases.

1.2 PROCFish/C and CoFish methodologies

A brief description of the survey methodologies is provided here. These methods are described in detail in Appendix 1.

1.2.1 Socioeconomic assessment

Socioeconomic surveys were based on fully structured, closed questionnaires comprising:

1. **a household survey** incorporating demographics, selected socioeconomic parameters, and consumption patterns for reef and lagoon fish, invertebrates and canned fish; and
2. **a survey of fishers** (finfish and invertebrate) incorporating data by habitat and/or specific fishery. The data collected addresses the catch, fishing strategies (e.g. location, gear used), and the purpose of the fishery (e.g. for consumption, sale or gift).

Socioeconomic assessments also relied on additional complementary data, including:

3. **a general questionnaire targeting key informants**, the purpose of which is to assess the overall characteristics of the site's fisheries (e.g. ownership and tenure, details of fishing

gear used, seasonality of species targeted, and compliance with legal and community rules); and

4. **finfish and invertebrate marketing questionnaires** that target agents, middlemen or buyers and sellers (shops, markets, etc.). Data collected include species, quality (process level), quantity, prices and costs, and clientele.

1.2.2 Finfish resource assessment

The status of finfish resources in selected sites was assessed by distance-sampling underwater visual census (D-UVC) (Labrosse *et al.* 2002). Briefly, the method involves recording the species name, abundance, body length and distance to the transect line of each fish or group of fish observed; the transect consists of a 50 m line, represented on the seafloor by an underwater tape (Figure 1.2). Mathematical models were then used to infer fish density (number of fish per unit area) and biomass (weight of fish per unit area) from the counts. Species surveyed included those reef fish of interest for marketing and/or consumption, and species that could potentially act as indicators of coral reef health (See Appendix 1.2 for a list of species.).

The medium-scale approach (MSA; Clua *et al.* 2006) was used to record habitat characteristics along transects where finfish were counted by D-UVC. The method consists of recording substrate parameters within twenty 5 m x 5 m quadrats located on both sides of the transect (Figure 1.2).

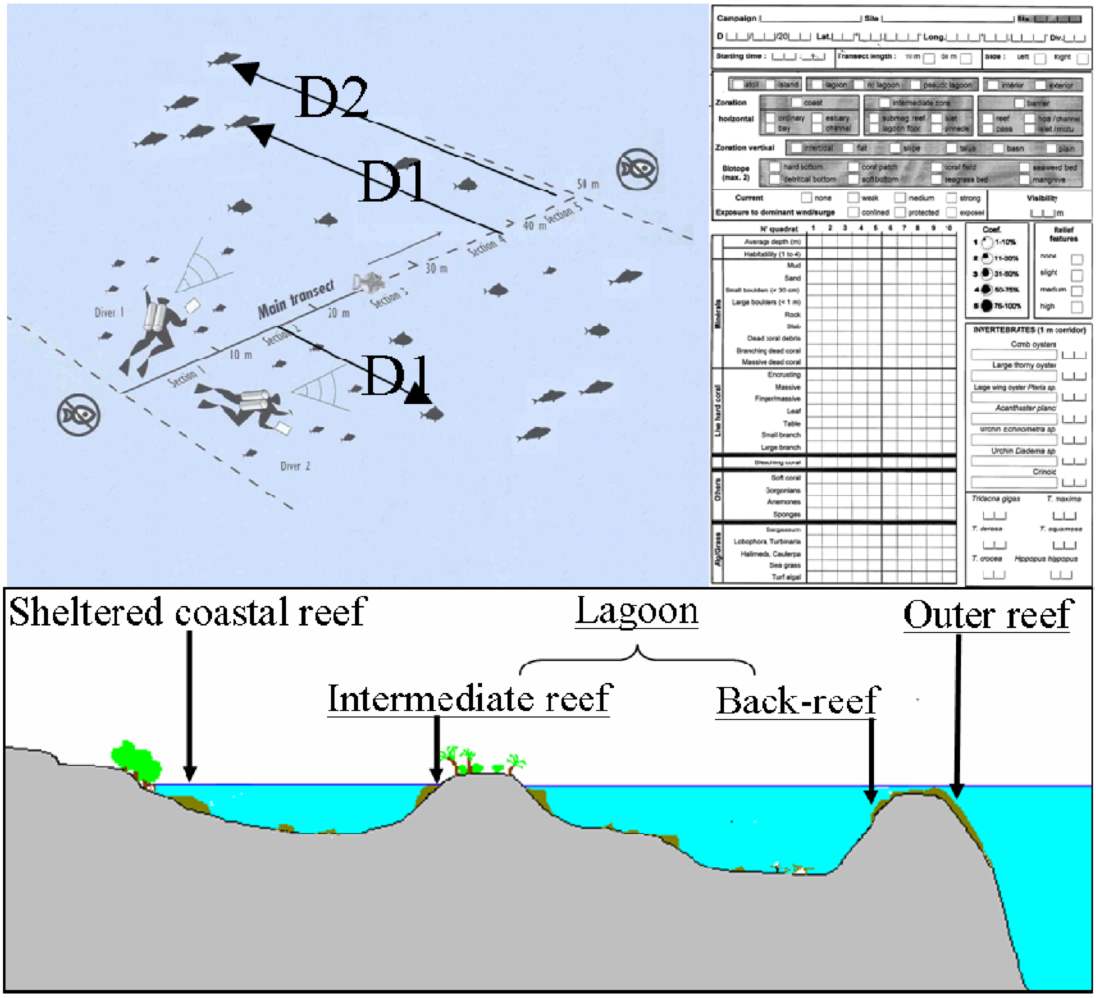

Figure 1.2: Assessment of finfish resources and associated environments using distance-sampling underwater visual censuses (D-UVC).
Each diver recorded the number of fish, fish size, distance of fish to the transect line, and habitat quality, using pre-printed underwater paper. At each site, surveys were conducted along 24 transects, with six transects in each of the four main geomorphologic coral reef structures: sheltered coastal reefs, intermediate reefs and back-reefs (both within the grouped 'lagoon reef' category used in the socioeconomic assessment), and outer reefs.

Fish and associated habitat parameters were recorded along 24 transects per site, with an equal number of transects located in each of the four main coral reef geomorphologic structures (sheltered coastal reef, intermediate reef, back-reef, and outer reef). The exact position of transects was determined in advance using satellite imagery; this assisted with locating the exact positions in the field and maximised accuracy. It also facilitated replication, which is important for monitoring purposes.

Maps provided by the NASA Millennium Coral Reef Mapping Project (MCRMP) were used to estimate the area of each type of geomorphologic structure present in each of the studied sites. Those areas were then used to scale (by weighted averages) the resource assessments at any spatial scale.

1.2.3 Invertebrate resource assessment

The status of invertebrate resources within a targeted habitat, or the status of a commercial species (or a group of species), was determined through:

1. resource measures at scales relevant to the fishing ground;
2. resource measures at scales relevant to the target species; and
3. concentrated assessments focussing on habitats and commercial species groups, with results that could be compared with other sites, in order to assess relative resource status.

The diversity and abundance of invertebrate species at the site were independently determined using a range of survey techniques, including broad-scale assessment (using the ‘manta-tow’ technique) and finer-scale assessment of specific reef and benthic habitats.

The main objective of the broad-scale assessment was to describe the large-scale distribution pattern of invertebrates (i.e. their relative rarity and patchiness) and, importantly, to identify target areas for further fine-scale assessment. Broad-scale assessments were used to record large sedentary invertebrates; transects were 300 m long × 2 m wide, across inshore, midshore and more exposed oceanic habitats (See Figure 1.3 (1).).[4]

Fine-scale assessments were conducted in target areas (areas with naturally higher abundance and/or the most suitable habitat) to specifically describe resource status. Fine-scale assessments were conducted of both reef (hard-bottom) and sandy (soft-bottom) areas to assess the range, size, and condition of invertebrate species present and to determine the nature and condition of the habitat with greater accuracy. These assessments were conducted using 40 m transects (1 m wide swathe, six replicates per station) recording most epi-benthic resources (those living on the bottom) and potential indicator species (mainly echinoderms) (See Figure 1.3 (2) and (3).).

In soft bottom areas, four 25 cm × 25 cm quadrats were dug at eight locations along a 40 m transect line to obtain a count of targeted infaunal molluscs (molluscs living in bottom sediments, which consist mainly of bivalves) (See Figure 1.3 (4).).

For trochus and bêche-de-mer fisheries, searches to assess aggregations were made in the surf zone along exposed reef edges (See Figures 1.3 (5) and (6).); and using SCUBA (7). On occasion, when time and conditions allowed, dives to 25–35 m were made to determine the availability of deeper-water sea cucumber populations (Figure 1.3 (8)). Night searches were conducted on inshore reefs to assess nocturnal sea cucumber species (See Appendix 1.3 for complete methods.).

[4] In collaboration with Dr Serge Andrefouet, IRD-Coreus Noumea and leader of the NASA Millennium project: http://imars.usf.edu/corals/index.html/.

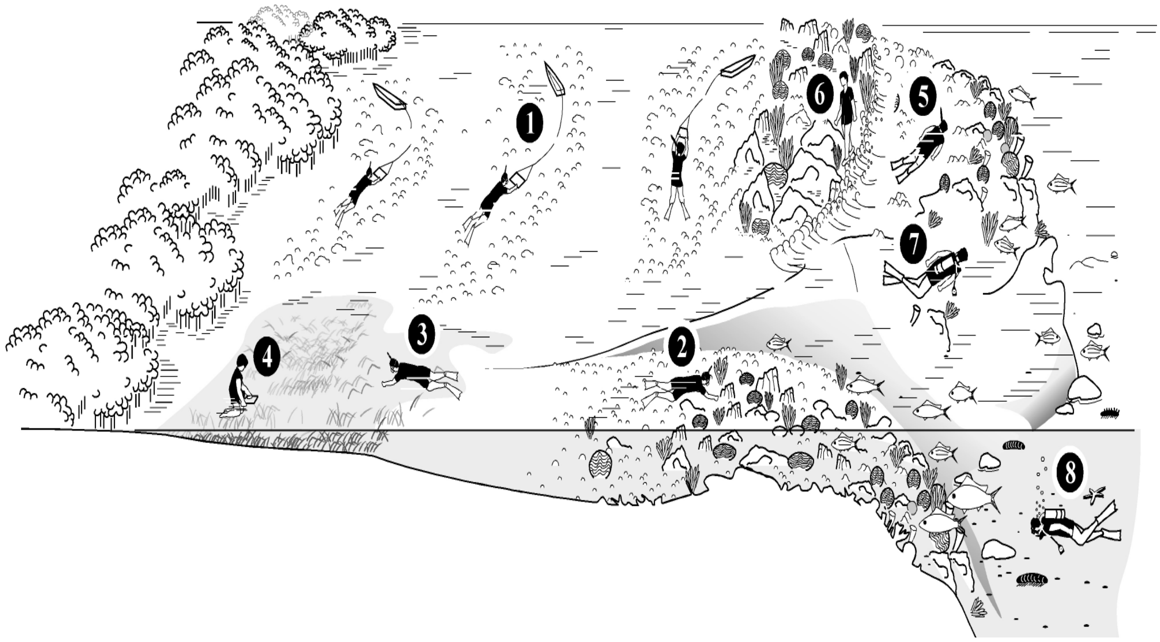

Figure 1.3: Assessment of invertebrate resources and associated environments.
Techniques used include: broad-scale assessments to record large sedentary invertebrates (1); fine-scale assessments to record epi-benthic resources and potential indicator species (2) and (3); quadrats to count targeted infaunal molluscs (4); searches to determine trochus and bêche-de-mer aggregations in the surf zone (5), reef edge (6), and using SCUBA (7); and deep dives to assess deep-water sea cucumber populations (8).

1.3 Tonga

1.3.1 General

The Kingdom of Tonga is an archipelago that consists of 170 islands of which only 36 are inhabited. The islands are scattered in three main island groups, Vava'u, Ha'apai, and Tongatapu, and make up an estimated total land area of 747 km^2 (Gillett 2002). The islands are mainly elevated coral reefs some of which have volcanic origin. The coralline and limestone islands in the Tongatapu, Ha'apai and Vava'u groups, are immediately west of the Tonga Trench, while further west is a line of small volcanic islands, some of which are still active. The area of the inshore fishing grounds of Tongatapu has been estimated to be 947 km^2, of which reefs and mangroves make up 11.2% and 0.36% respectively, with the remaining consisting of shallow and deep lagoon with an outer shelf less than 160 m deep (Lovell and Palaki 2003). Tonga's potential Exclusive Economic Zone (EEZ) covers an area of approximately 700,000 km^2 as compared to about 395,000 km^2 declared under the 1887 Royal Proclamation, and a total coastline length of 419 km (Bell *et al.* 1994). Its maritime borders are shared with neighbours Fiji Islands in the west, Wallis and Futuna, Samoa and American Samoa in the north, and Niue in the east (Figure 1.4).

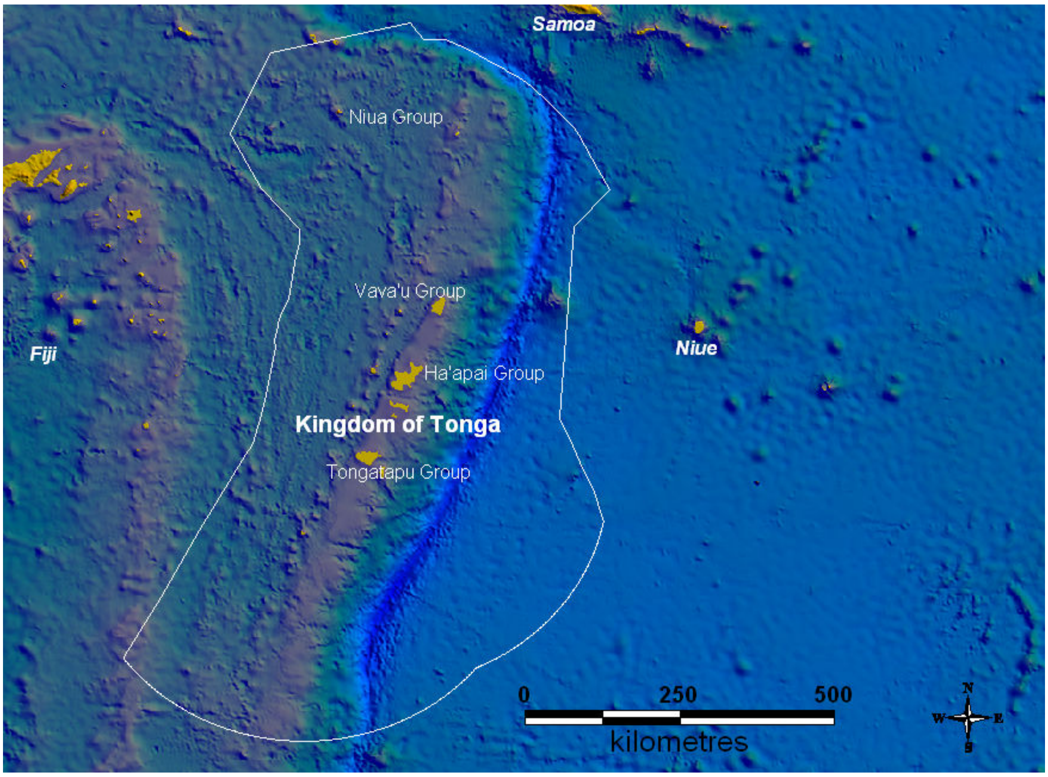

Figure 1.4: Map of Tonga.

The climate is tropical throughout the year, but influenced by variations brought about by the trade winds. A distinct warm period occurs from December to April, during which time temperatures rise above 32°C. A cooler period occurs from May to November with temperatures below 27°C. Annual rainfall ranges from 1700 mm in the south to 2970 mm in the northern islands; the mean daily humidity is 80% (Fletcher and Keller 2001). The southeast trades are the prevailing winds but, during the warmer months (October to March), tropical cyclones may form over the waters to the north and move southwards where they may cause considerable damage (Zann 1981).

Tonga has been a constitutional monarchy since 1875 and became a British Protectorate in 1900. In 1970 Tonga acquired its independence and became a member of the Commonwealth, but remains the only independent monarchy in the Pacific. Its recent population stands at 100,134 people of Polynesian origin, 70% of whom live on Tongatapu (Tonga Department of Statistics 2006). Many other Tongans live abroad, mainly in New Zealand, Australia and the USA.

Tonga's economy is heavily dependent on remittances from the country's population living abroad. An average of 200 million Pa'anga (TOP, equivalent to USD 96.7 million) is received through remittances in a year and 85% of this comes from Tongan communities in the United States (Islands Business 2007). Revenue from remittances is the main source of relief to the country's huge trade deficit (Fletcher and Keller 2001). The agriculture sector is small, comprising small-scale plantations and subsistence farming for root crops such as taro, banana, manioc, squash pumpkin, coconut for local market and minor export to New Zealand (Pacific Magazine 2007). The manufacturing sector is small, contributing only 3% of GDP. In 1999, the value of fisheries products exported represented 24% of all exports (Gillett and Lightfoot 2001, Gillett 2002); this in addition to access-licence fees and local employment in the fishing industry contributes significantly to the national economy.

Fishing has always been an important subsistence activity in Tonga, with the shallow-water reefs and lagoons surrounding the islands providing a vital source of protein for the local population. With the change from a barter system to a cash economy, these resources have been subjected to increasing pressures (Bell *et al.* 1994). The industrial tuna fishery is represented by mainly local fishing vessels and foreign vessels through bilateral arrangements. Tonga is a member of the Forum Fisheries Agency (FFA), through which a share of the benefits from the Multilateral Fishing Treaty between USA and FFA member countries is received. Tourism is relatively undeveloped, but whale-watching is a successful ecotourism attraction in the Vava'u group, estimated to be worth TOP 21 million annually (Islands Business 2007). In the rural areas, subsistence agriculture, fishing and raising of livestock, especially pigs and chickens, are practised. The majority of these farmers produce for subsistence and for ceremonial activities, although relatively large numbers also sell some of their produce (Tonga Department of Statistics 1991).

1.3.2 The fisheries sector

Fishing has always been an important subsistence activity in Tonga, with the shallow-water reefs and lagoons surrounding the islands providing a vital source of protein for the local population. The fisheries sector in Tonga comprises the offshore fisheries for tuna, the deep-bottom fishery for snapper, and the reef fisheries for fish, invertebrates and seaweed in the nearshore areas. There is also a strong focus on aquaculture. The commercial, export-oriented fisheries are tuna, snapper, aquarium fish and seaweed; together, these fisheries contributed to a 23% increase in export quantity in the first quarter of 2006, and most of this increase is from the tuna and snapper sector (Ministry of Fisheries 2006). In 2009, anecdotal information from the Tonga Fisheries Department and local fishers indicates a sharp decline in catches for the tuna fishery, while high operating costs and shrinking markets created instability in the deep-water snapper fishery, with several companies ceasing their fishing operations.

Offshore fisheries

Traditionally, Tongan fishers have fished outside the reef for a range of pelagic species using different small-scale fishing techniques; in the case of tuna, using canoes and pearlshell lures (SPC 1983). More recently, medium-scale tuna fishing and deep-water snapper fishing activities commenced along with the use of fish aggregating devices (FADs) for small-scale tuna fishing activities.

Offshore tuna fishery

Tonga is geographically located south of the major tuna-rich regions in the western and central Pacific, although there is sufficient tuna resource to support a local tuna fishing industry. The catch of skipjack tuna in Tongan waters is small, and was estimated at less than 40 mt in 1980 (SPC 1983). Several surveys have been conducted for surface-swimming tuna in the waters around Tonga, the first being in 1954 (Van Pel 1955a). Other surveys were conducted in 1965 and 1969, with Japan having four pole-and-line vessels operating in Tongan waters from 1970 to 1974 (SPC 1983). Two local pole-and-line vessels operated around Tonga from 1978 to 1981, with varying catch rates. Also during this period, the SPC Skipjack Survey and Assessment Programme conducted tagging research in the waters around Tonga, with 1402 skipjack and 258 yellowfin tagged and released in April/May 1978 (Kearney and Gillett 1978), and 567 skipjack and four yellowfin tagged and released over seven days in March 1980 (SPC 1983). Pole-and-line fishing operations proved to be unfeasible due to the limited tuna schools and the cost of operation.

Tuna longlining, targeting the larger and deeper-swimming tunas, also commenced in the 1950s in the waters around Tonga, undertaken by Japanese, Korean and Taiwanese longline fleets. In 1967 Tonga had its first trial fishing for tuna when it received two longliners FV *Ekiaki* in 1967 and FV *Tavake* in 1976 both donated by Japan (Weber 1979). However, it was not until 1982 when Japan donated the 37 m longline vessel FV *Lofa*, that tuna longlining became established in Tonga, with this vessel fishing consistently for albacore, increasing the albacore catch to a profitable level of around 300 mt and selling the catch to the canneries in Fiji Islands and American Samoa (Bell *et al.* 1994, Chapman 2001, 2004). Given the success of the government's longline operation, the government decided to corporatise the operation and established the Sea Star Fishing Company (SSFC) in 1991 (Sokimi and Chapman 2002). At this stage, the government also gave SSFC the sole rights to tuna longline fishing in Tongan waters; however, this was rescinded in 1993 to allow private-sector development in this fishery (Chapman 2004).

In support of tuna longline development, USAID funded a series of fishing trials for tuna from 1992 to 1994, with small-scale longlining being one of the methods trialled and with 22 mt of saleable fish taken over 34 fishing trips (50 fishing days), setting an average of 257 hooks/set (Hurrell and Swerdloff 1994, RDA 1994). Following the success of these fishing trials, several local businessmen purchased small-scale longliners from New Zealand in 1995/1996. Unfortunately, these vessels soon ran into difficulties as they were not really suited to the conditions of fishing in Tongan waters (Chapman 1997, 2004). Several studies were conducted in the mid-1990s to identify constraints to developing the domestic longline fishery in Tonga, with many constraints identified (Chapman 1997, Mellen 1995, Chapman 2001). During the late 1990s, additional vessels were brought into the domestic fleet and by 2000 there were 16 vessels (Aho 2002, Sokimi and Chapman 2002). The catch also increased over this period from 214 mt in 1997 (7 vessels), 327 mt in 1999 (7 vessels), and 931 mt in 2000 (16 vessels), to 21 vessels catching 1988 mt in 2001 (Aho 2002, Anon. 2006).

In 1998, the Government of Tonga received a new longline training and research vessel, the 39.5 m FTV *Takuo*. This vessel was operated commercially; however, the operation costs of this vessel were higher than the revenue from the catch. SPC was requested in 2001 to provide technical assistance and training for the crew of FTV *Takuo* (Sokimi and Chapman 2002).

SSFC continues to operate today as the major player in the local tuna industry with a fleet of around 14 to 18 longliners. Foreign fishing vessel activities were few in the 1990s; they suddenly increased from the 2002/2003 period, reaching 16 vessels in 2003. By 2005 these foreign vessels failed to renew their licences due to the low albacore catch caused by the El-Niño period, when the tuna catch in 2005 dropped to 500 mt (Likiliki *et al.* 2005, Anon. 2006). The highest annual catch in recent years was in 2001, when 1988 mt were caught, the majority of these from domestic vessels. Around 48–60% of tuna catches are exported to the canneries in Pago Pago; loins and sashimi grade tuna are sold to Japan, Hawaii and the USA, with bycatch sold locally. Tuna exports in 2001 and 2002 generated an estimated value of around USD 2–4 million (Likiliki *et al.* 2005). Onshore activities include loining, fresh cuts and packing facilities operated by five companies all under HACCP certification (Anon. 2006).

Tonga's national tuna management plan was approved in 2001 but has not been reviewed since its first adoption. A tuna management committee established under the tuna management plan had set a cap of 50 fishing vessels per year but reduced this to 30 licences in 2004. A national observer programme and the VMS monitoring system are in place. Tonga is a party to the Multilateral Treaty on Fisheries between FFA countries and the Government of the United States of America and through this membership benefits from the annual fee allocation by FFA (Likiliki *et al*. 2005, Anon. 2006).

Small-scale tuna fishery including fishing around FADs

Historically, Tongan fishers ventured to sea in canoes with pearshell lures to target surface tuna schools. In the mid-1900s these methods began to give way to more modern fishing methods and gears. In late 1954, Van Pel (1955a) conducted some fishing trials around Tonga using the Fisheries Section's 15 m vessel purchased from New Zealand earlier that year. Trials included both surface and deep trolling (using a paravane and a 'kite' arrangement), with the latter method producing three times the catch of the surface trolling (Van Pel 1955b). During the 1960s and 1970s, more fishers turned to trolling for coastal pelagic fish as outboard-powered skiffs became more readily available.

FADs were first introduced to Tonga in 1981/1982 by the Fisheries Department to assist local small-scale tuna fishers. From 1984 to 1988, the Fisheries Department deployed nine FADs, mainly off Vava'u and Nuku'alofa, with mixed results on the lifespan of the FADs (Chapman 2004). Additional FADs were deployed in the early 1990s. SPC was requested to assist with several of these deployments in 1993, which included training local fisheries staff (Wellington and Chapman 1999).

The USAID-funded tuna fishery development work in the early 1990s included both day and night handlining for tuna on seamounts and the use of vertical longlines around FADs. The night handlining on the Capricorn seamount produced the best results, with 454 fish caught over seven nights using six handlines (Hurrell and Swerdloff 1994, RDA 1994, Chapman 2001). For the vertical longline trials, the project deployed seven FADs. A total of 432 vertical longline sets were made, with a catch of 587 saleable fish (Chapman 2001). After the project was completed, the Fisheries Department continued to promote the use of vertical longlines and mid-water handlining, but the methods did not catch on and by the end of the 1990s the Fisheries Department focused more on tuna longlining (Chapman 2004).

The early 2000s saw some renewed interest in FADs, especially from the charter fishing operations in Vava'u. The Fisheries Department deployed several FADs off Tongatapu in 2002 (Anon. 2003), and a new AusAID-funded project was initiated at that time. The project deployed four FADs in 2002 and 16 in 2003 throughout the islands of Tonga (Chapman 2004). Many of these FADs had a short lifespan.

The most successful FAD programme in the 2000s was that run by the Sportsfishing Association in Vava'u, which maintains several FADs, including a couple of sub-surface ones (Chapman 2004). At this time there were four charter vessels operating out of Nuku'alofa and another 10–12 out of Vava'u, with some of these vessels only fishing part of the year (Whitelaw 2001, Anon. n.d.). There are regular gamefishing competitions held, with many private vessels as well as the charter vessels participating.

1: Introduction and background

Deep-water snapper

The Government of Tonga began to promote exploitation of the deep-water snapper, grouper and emperor resource during the mid-to-late 1970s, following several exploratory fishing trials. From 1975–1977 the FAO conducted a bottom-fishing (mainly fishing from 40 to 110 m depths) and trolling (mainly coastal) survey in Tonga, with the main bottomfish species landed being *Lethrinus chrysostomus* and *Pristipomoides filamentosus* (Thomas 1978). The SPC Deep Sea Fisheries Development Project (DSFDP) conducted its first visit to Tonga from June to September 1978, training local fishers around Tongatapu in the gear and fishing techniques, but fishing from 100–400 m depths (Mead 1979). This work was followed up with a second visit by the DSFDP from June to August 1979, again introducing the gear and techniques to local fishers in Tongatapu, Ha'apai and Vava'u (Mead 1980).

The commercial deep-water snapper fishery in Tonga commenced in 1980, as more fishers became involved in this fishery. The DSFDP conducted a third visit to Tongatapu and Ha'apai from September 1980 to May 1981 (Mead 1987). Also during this time, a FAO/UNDP project was underway to construct a range of vessels (single-hull, semi-displacement, 'V'-bottom craft based on an original FAO design, a trimaran, two catamarans and a round-bilge, single-hull craft) to trial and identify a suitable vessel to develop the deep-water snapper fishery (Anon. 1983). The round-bilge craft was the one accepted by fishers, and the United Nations Capital Development Fund (UNCDF) funded the development of two boatyards (in Ha'apai and Vava'u), including the materials for constructing the vessels, and a Japanese Government Grant covered the engines, equipment and fishing gear for these vessels (Anon. 1983).

The deep-water snapper fishery continued to expand in the mid-to-late 1980s, with the offshore seamounts being the main areas fished. From April 1985 to February 1986, the DSFDP conducted a fourth visit to Tonga, with the focus on fishing offshore seamounts (Mead and Chapman 1998). The fishery continued to expand with the newly-constructed vessels from the UNCDF project; 20 vessels 6–9.4 m in length were fishing by 1986 (Mead and Chapman 1998). In 1988 the boat-building project had completed a fleet of 40 vessels for the deep-water snapper fishery (Langi 2000). Other support facilities, including port development, cool storage and, a local fish marketing centre were established through aid projects. The top ten highly commercial species are *Etelis*, *Lutjanus*, *Pristipomoides* and *Gymnocranius*, although the most targeted species are *Etelis coruscans* and *Pristipomoides filamentosus*. Deep-water snappers became the main exported fish species from the 1980s to mid 1990s prior to the development of tuna exports. Catches peaked in 1987 at 514 mt, then declined to 214 mt in 1990 and from 1991 to 2002 fluctuated between 115 and 270 mt annually (Langi 2000).

There have been many estimates of maximum sustainable yield (MSY) for this fishery. Thomas (1978) estimated that the resource offered an annual potential yield of 1000 mt and development priorities were set for the deep-water snapper fishery to increase production to meet local and export demand and to lessen pressure on the already overexploited shallow-water reef fisheries. The Ministry of Fisheries started a comprehensive research and data-gathering project in the second half of 1986, with the aim of getting the biological data necessary for managing the fishery (Langi and Langi 1988, Langi *et al.* 1992). Langi and Langi (1988) estimated the 200 m isobaths to be 930 nm with 294 nm of this covering the seamounts, and this gave an MSY estimate of 217 mt for the seamount fishery. In 1992, Latu and Tulua estimated the MSY for the fishery to be around 350 mt for the five main species.

King (1992) used a range of models to estimate MSY for this fishery and came up with a range of 30–560 mt depending on the model used. Dalzell and Preston (1992) estimated the MSY to be within the range of 113–338 mt based on the predictions of others, the length of the 200 m isobaths and the catch-rate data from the DSFDP fishing trials. Bell *et al*. (1994) estimated the MSY for the fishery to be around 200 to 300 mt for the depths of more than 200 m and gave a preliminary estimate for the whole fishery of around 400–700 mt for depths of 40–400 m. In 2000, a management plan for the fishery recommended that entry into the fishery be limited to 14 licensed vessels, using Samoan handreels only, in order to sustain the fishery over time (Langi 2000).

The snapper fishery in 2006/2007 was the country's third-most important fishery, accounting for 13% of the national income generated from fisheries exports. The main target species are exported to markets in the United States, Japan and New Zealand. Recent trends reveal the resource is under pressure and could be operating at its optimal level despite the current exploitation level being below the estimated MSY (Tongan Department of Fisheries 2007). The deep-water snapper resource is fragile in nature, in that it involves species that are slow-growing, with long lifespans and limited habitat ranges. Current government policy includes the exclusion of foreign fishing vessels, and exporters operate under licence and close monitoring. In 2009, several of the main fishing companies exploiting the deep-water snapper resource ceased their fishing operations due to increased operating costs and stagnant prices for fish on export markets, resulting in a loss of some markets.

Deep-water shrimps

Trapping trials for deep-water shrimps were undertaken in the early 1980s off Nuku'alofa, with 11 species of shrimp recorded from 200–800 m depths. The four main species were the pyjama shrimp (*Parapandalus serratifrons*), stars and stripes shrimp (*Plesionika longirostris*), mino nylon shrimp (*Heterocarpus sibogae*) and smooth nylon shrimp (*H. laevigatus*). It was concluded that the catch rates were low compared to surveys undertaken in other parts of the Pacific, although abundances may be higher in other areas of Tonga if more suitable substrate for these species was available (King n.d.).

Aquaculture and mariculture

Many types of aquaculture have been tested in Tonga, mostly through government programmes with aid support. Experimental trials have been carried out on nine species of oysters (for food and pearl culture), one species of green mussel, three species of giant clams, four species of fish, two species of gastropods and two species of seaweed. Many of the species experimented on were introduced to Tonga beginning in the 1960s. However, there has been little commercialisation of the research results (SPC 2007).

Notable aquaculture experiments deemed successful are the culture of giant clams, in particular small-sized clams for the aquarium trade; farming of local seaweed *mozuku* (*Cladosiphon* spp.), which is now an important export product; and trochus and green snail seed production for reseeding purposes. Both trochus and green snail have established in Tonga but have yet to reach fishable levels. Among the introduced species, *Tilapia oreochromis* is the only one that has become an undesirable pest in ponds previously used for experimental fish cultures.

1: Introduction and background

Pearl oysters

Pearl oyster culture in Tonga commenced in the early 1960s; however, in 1975 the winged pearl oyster (*Pteria penguin*) was imported from Japan and culture trials commenced on this species. Assistance in carrying out stock assessment, spat-collection surveys and grafting techniques was provided in 1989 by the FAO South Pacific Aquaculture Development Project (Teitelbaum *et al.* 2008, Teitelbaum and Fale 2008). The commercial feasibility of pearl farming in Tonga was established in 1993, with Japanese specialists estimating an area of around 850 ha in the Vava'u island group could be farmed for half-pearl production. The production of half-pearls (mabe) has advantages, in that there is low capital and technological investment, and the value added opportunities through the production of jewellery and handicrafts (Teitelbaum *et al.* 2008; Teitelbaum and Fale 2008).

Spat collection and grow-out has been sporadic over the years. In 2001, 2000 spats were harvested after three months of rearing for grow-out. Half were transferred to Vava'u with the rest placed on a longline outside the reef crest adjacent to the Fisheries Centre at Sopu on Tongatapu (Anon. 2003). In 2002, ~200 of these survived at each of the two locations, with the high mortality attributed to the damage caused by cyclone Waka (Anon. 2003). In 2006, ACIAR commenced a 2.5 year project focusing on the development of appropriate hatchery culture techniques for the winged pearl oyster, so that hatchery-propagated oysters can be used for half-pearl production in the future to further support the development of this sector (Teitelbaum *et al.* 2008, Teitelbaum and Fale 2008).

Edible oysters and mussels

The edible oyster, or Sydney rock oyster (*Crassostrea commercialis*) was first introduced to Tonga in 1973 on a trial basis to look at growth rates. The first consignment of 4000 seed oysters was divided among four sites. In the first six months, the monthly growth rates were very low (0.77–6.6 mm) and the mortality rate was 9–20% (Wilkinson 1975). A batch of *Crassostrea gigas* seed was introduced to Tonga in September 1974, with growth rates over the following six months about the same as those for the first batch of oysters. In January 1975 some of the oysters were moved to areas outside the lagoon, with immediate improvements in growth rates, especially with the batch of *Crassostrea gigas*.

In 1976, Tonga received its first batch of green mussels (*Perna viridis*) from the Philippines. Unfortunately, the consignment was of large-sized shells (40 mm and over), which did not travel well, resulting in high mortality (Dinamani and Illingworth n.d.). The next consignment of green mussels came from Singapore and arrived in Tonga in November 1976. Most shells were less than 20 mm and their survival in Tongan waters looked more promising. They were placed in three locations and were held in suspended culture from rafts in three different ways. Many problems were encountered, the main one being the tendency of many mussels to detach from the rope at a size of 20–30 mm. Those mussels that were reared in the lagoon attained a desired length of 80 mm in 18 months (Dinamani and Illingworth n.d.).

One of the main obstacles to the culture of edible oysters and mussels in the Pacific Islands was identified as the difficulty in obtaining suitable seed in the absence of natural populations of these species locally (Wilkinson 1975).

Giant clams

Giant clam meat is one of the most favoured seafoods of Tongan people (Sone and Loto'ahea 1995). In the 1970s, it was fished heavily for local sale, with an estimated minimum landing of 24 mt in 1974 increasing to 153 mt in 1978 (whole weight including shell), and targeted three clam species (McKoy n.d.). Surveys by the Ministry of Fisheries in the 1980s found that the only species of giant clams living in Tonga were *Tridacna squamosa*, *T. maxima*, *T. derasa* and *T. devoroa.* In addition, evidence of the remains of other species such as *T. gigas* and *Hippopos hippopus* were found but had earlier become extinct (Anon. 1992, Langi and 'Aloua 1988).

An ACIAR-funded project was established in the late 1980s, which imported 10,000 *T. gigas* and 20,000 *Hippopus hippopus* juveniles from the James Cook University hatchery in Australia. A biofilter with recirculation was set up to maintain elevated water temperatures for these clams over the cooler winter months. Survival of the *T. gigas* was 60% to early October when they were placed in the ocean nursery. There was 75% survival of the *H. hippopus* to December when they were placed out in the ocean nursery (Anon. 1992).

In the early 1990s, Tonga Fisheries Department established a hatchery for giant clams as part of a joint Tonga–Japan project. The aim of the hatchery was to enhance clam stocks by releasing hatchery-produced clams in the hope that some of these would create a broodstock population that would reproduce naturally (Sone and Loto'ahea 1995). By 1995, the hatchery was producing 50,000 seed clams (2 cm length) annually. Some clams were destined for the aquarium trade; some went to village ocean nurseries, which were established in 1993 in two locations; others were placed in a central ocean nursery located close to the hatchery (Sone and Loto'ahea 1995).

In 2001/2002, a total of 18,012 clams of 2.5–22.5 cm were sold to aquarium exporters and this was valued at TOP 39,637 (Anon. 2003). Other clams were also provided to community sanctuaries. Unfortunately, the community-based clam farming initiated through ACIAR and JICA projects to replenish wild stocks have not been successful due to the high rate of poaching (SPC 2007).

Trochus and green snails

Trochus (*Trochus niloticus*) and green snails (*Turbo marmoratus*) do not occur naturally in Tonga (Kikutani *et al.* 1995). Trochus were first introduced to Tonga from Fiji Islands in 1992, with 350 shells imported (Anon. 1996). Most of the shells were released in the waters around Vava'u, with 35 shells retained at the Sopu Mariculture Centre (SMC) at Nuku'alofa for spawning experiments. The first introduction of green snails occurred in 1994, with 300 shells from Japan and 50 shells from Vanuatu imported to Tonga and released around Tongatapu (Anon. 1996). Again, 76 green snail shells were retained at the SMC for spawning experiments (Kikutani *et al.* 1995). Successful spawning of both trochus and green snails occurred in 1995 (2200 shells) and 1996 (8000 shells) respectively (Anon. 1996).

Further introductions of trochus occurred during the 1990s. In 1994, 1100 shells were imported from Fiji Islands with 900 released and the rest retained at SMC as broodstock (Manu *et al.* 1994). In 1995, another 591 shells were imported from Fiji Islands and released in the Ha'apai island group (Gillett 1995). Surveys were undertaken three-to-four months after the release of the trochus, with recovery rates ranging from 23.3% to 61% (Kikutani *et* *al.* 1995). From 1998 to 2002, 31,500 green snails were reared at the SMC hatchery, with 17,500 released around Tonga and 14,000 retained at the hatchery (Anon. 2003). Also in 2000, around 2000 trochus were spawned for reseeding purposes (Anon. 2003).

Although the spawning of trochus and green snails was successful at the SMC in the mid-1990s, the facility needed upgrading, especially the seawater supply system. JICA assisted with this in 1999 and 2000, with the facility having 50 rearing tanks in the hatchery, three seawater intake pumps, four blower air pumps, one generator and control panel, plus other necessary equipment (Fa'anunu *et al.* 2001). Growth rates for the green snails increased markedly with the new seawater supply system.

Seaweed

The cooler climate during winter months in Tonga is highly conducive for the growth of seaweeds. *Eucheuma* spp. seaweed was farmed during the 1980s and sold to Coastal Biologicals for use in pet food, etc. However, although growth rates were good, losses due to storm damage were frequent and the venture proved unprofitable for the farmers (Langi 1986). Local edible seaweeds include three species of *Caulerpa* known as *limu* and *Cladosiphon* spp. known locally as *limutanga'u*. While other seaweeds are used for subsistence, the farming of *Cladosiphon* spp. is highly commercial and mainly conducted for export. *Cladosiphon* seaweed is exported as frozen, semi-dry, powder, and dried form to markets in Japan and, more recently, America. In 2002, 286 mt of seaweed were exported, with a value of TOP 100,044 (Anon. 2003). Annual exports are in the range of 200–500 mt, representing 3% of the total annual fishery exports. Production is dependent on market performance, activity of local processors and growing conditions (Tongan Department of Fisheries 2007).

Fish culture (tilapia, milkfish and mullets)

There were some early experiments with fish culture, starting with tilapia (*Tilapia mossambica*), which was placed in a half-acre pond at Sopu. The fish proliferated and inundated the entire brackish water system in Tonga (Wilkinson 1975). In 1974, some milkfish fry (*Chanos chanos*) were stocked in the pond, with records that they appeared to spawn and multiply. A further experiment was undertaken with the introduction of 60 Cuban mollies (*Poecilia vittata*) from American Samoa. This species was held in a screened enclosure within the pond and propagated well (Wilkinson 1975). There was also interest in rearing mullet species, with a study undertaken in the mid-1990s that concluded that the farming of most of these species was not feasible (Anon. 1996).

Eco-tourism

Eco-tourism, though not directly under the responsibility of the Fisheries Department, was highlighted in the Tonga Fisheries Conference 2007 as an area where the fisheries sector needs to focus efforts. In particular, protection of aquatic resources and development of eco-tourism activities was recommended, following the success of the whale sanctuary development and a highly successful whale-watching industry, now worth over TOP 21 million a year (Islands Business 2007).

Reef fisheries (finfish and invertebrates)

Shallow-water reef fish have been a vital source of protein at the subsistence level and, with the transition from barter to a cash economy, these have become important in the artisanal and the commercial fisheries. In Ha'apai, reef/lagoon resources supply more than 70% of the total annual catch, and this is supplemented by subsistence agriculture and cash cropping (Halapua 1982).

In Tongatapu, the reef fish fishery is the main source of income for most male fishers. As is common among Pacific Islanders, almost all potential food fish are eaten by Tongans and these comprise many species in 16 families (Bell *et al.* 1994). The only exceptions are certain species when they are suspected of being ciguatoxic. Shallow-water coral reefs, lagoons and mangrove areas are the main habitats for the shallow-water fish species. As such, fishing for these fish is normally confined within or near these habitats and involves various techniques, including netting, handlining, spearfishing, fish fencing (traps) and trolling, but night spearfishing and netting are important according to a 1993 survey (Bell *et al.* 1994). Artisanal fishing is mostly done from small, motorised boats and paddling canoes. Landings of reef fish in Nukualofa in 1993 made up 70% (200 mt) of the total artisanal finfish landings, with Scaridae (parrotfish) being the main family caught (Bell *et al.* 1994).

Several trials have been undertaken to exploit small pelagics, such as bigeye scad (*Selar crumenophthalmus*) and mackerel scad (*Decapterus macarellus* and other species of *Decapterus*) in the late 1980s and early 1990s. In 1988, a survey was undertaken in Vava'u to target *Decapterus* species using a Hawaiian hoop net; however, a lack of schools of these species resulted in very low catches (Gillett 1988). At the same time, the Ministry of Fisheries was undertaking some small-scale purse-seine fishing trials using light attraction at night, with catches of different scads totalling around 116 kg/set (Gillett 1988). In 1992 and 1993, further small-scale purse-seining trials were undertaken around Vava'u to try to catch suitable bait (bigeye scad and mackerel scad) for tuna fishing trials as part of a USAID-funded project. A total of 93 sets were made and it was noted that catch rates declined towards the end of the project (King *et al.* 1994).

The reef fish of Tonga are moderately to seriously overexploited. Some species have become less abundant while others have decreased in average size (Malm 2001). 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 (Bell *et al.* 1994). 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 (Langi *et al.* 1987, 1988).

Aquarium fishery

The marine aquarium trade started in 1989 with one company, and this has grown to five companies active today. A resource assessment survey conducted by SPC in 1996 recommended reopening coral and live-rock harvests but with a quota limit of 100,000 fish, 300 live corals and 100 t of live rocks per company per year (Anon. 2003). Aquarium fish was initially the most targeted product but, from the late 1990s, invertebrate products increased significantly and by 2000 live-rock export had also increased. Today the export of aquarium products from Tonga is dominated by live rocks and invertebrates. The value of the trade increased annually from about TOP 1.5 million in 2001 to TOP 3.2 million in 2003

(Anon. 2003). Invertebrates and live rocks together contributed 70% of the total exports in 2001 to about 89% in 2004. The main groups of fish exported from 2001 to 2006 included anemonefish and damselfish, wrasse, hawkfish, angelfish, surgeonfish, tangs and moorish idols (Ministry of Fisheries 2006). Giant clams were supplied by the Tonga Fisheries mariculture centre. The live-coral export includes both hard coral species (*Scleractinia*, *Coenothecalia*, *Athecata* and *Stolonifera*) and soft corals (*Alcyonaria*). A recent follow-up survey to determine the impact of the fishery in 2005 is yet to deliver its report. A draft management plan is in preparation pending the findings and recommendations of the 2005 survey (Tongan Department of Fisheries 2007).

Invertebrates

Three species of Tridacnidae giant clams are present in Tonga: *Tridacna maxima*, *T. squamosa* and *T. tevoroa*. *T. maxima* is the most common species and *T. tevoroa* was discovered in Tonga and Fiji Islands in the 1990s (Lucas *et al.* 1990). *Tridacna gigas* and *Hippopus hippopus* are believed to have become locally extinct, and were re-introduced along with *T. derasa* in 1991 under the ACIAR giant clam project (Bell *et al.* 1994). Giant clam meat is a delicacy featured more in the subsistence fisheries although surplus clams are offered for sale at Nuku'alofa markets (Bondurant 1987). Giant clam meat is sold as whole shells, in baskets, or as meat only, in plastic bags or in bottles mixed with viscera of the sea cucumber *Stichopus variegatus* known as *lomu*. Some minor exports for home use were made in the past to families overseas but declining stocks have limited such exports (Bell *et al.* 1994). The local giant clam stocks are becoming scarce in many islands in Tonga due to overexploitation. Stock replenishment activities through introductions, mariculture and reseeding activities in the 1980s were not successful because of poaching of the clams in established clam circles (Malm 2001, Bell *et al.* 1994). Existing minimum sizes for harvesting giant clams are difficult to enforce and the practice of consuming small-sized clams at home while the large ones are offered for sale is normal.

The other edible bivalves locally present are *Saccostrea cucculata*, *Pinctada radiata*, *P. furcata, Spondylus squamosus* and *Chama iostoma.* In addition, seven other edible oyster species (*Crassostrea commercialis*, *C. gigas*, *Ostrea edulis*, *C. belcheri*, *C. virginica*, *C. iradalei* and *S. glomerata*) were introduced for test farming but were unsuccessful (Bell *et al.* 1994). Two pearl oyster species *Pinctada maxima* and *Pteria penguin* were introduced for culture trials in Vava'u but, again, tangible results are yet to be seen. The local *Pinctada margaritifera* stocks are unknown. Other local edible bivalves present include four species of *Anadara* and three species of *Gafrarium*, but current stocks are overexploited.

There are 15 species of sea cucumbers in Tongan waters, including the high-value *Holothuria scabra*, *H. fuscogilva* and *H. nobilis*; the rest are medium- to low-value species (Ministry of Fisheries 1996). Tonga is among a few Pacific islands where sea cucumber is featured in the subsistence fishery as a food item. Local edible species include *Stichopus hermanni*, *H. scabra*, *H. atra*, *Bohadschia vitiensis* and *B. argus.* The intestines of these species are eaten or sold in bottles as *lomu*, which are consumed raw or mixed with clam meat or sea hare *(Dolabella* spp.) viscera.

Production of bêche-de-mer for export only began to develop during the mid 1980s, but more obvious productions were undertaken in the early 1990s. The high-value teatfish were produced solely from Vava'u, while sandfish were taken from both Tongatapu and Ha'apai. Production peaked in 1992 when 67 t were exported by thirteen registered exporters at a total value of TOP 615,432. Production suddenly declined soon after 1992 then, in 1997, a 10-year ban was implemented after a stock assessment survey the previous year reported very low stocks (Lokani *et al.* 1996). Monitoring activities are currently underway to assess the viability of reopening the fishery (Kim Friedman pers. comm. 2007). The fishery was re-opened in 2008 for a limited season.

The commercial gastropods *Trochus niloticus* and *Turbo marmoratus*, both naturally absent in Tonga, were introduced in the 1990s. Both species became established (Fa'anunu *et al.* 2001) and baseline assessment activities are being carried out with the help of SPC to look at the stock status. Other gastropod species used for ornamental purposes include *Charonia tritonis* and species of the genera *Turbo*, *Tectus*, *Cyprea*, *Conus* and *Lambis*. Four species of common lobsters occur in Tongan waters: *Panulirus penicillatus*, *P. longipes femoristriga*, *P. versicolor* and possibly *P. ornatus*; and two species of slipper lobster: *Scyllarides squamosus* and *Parribacus caledonicus*; and a few species of land crabs and reef crabs. The crustacean resource of Tonga is limited and is used in the subsistence and artisanal fishery.

1.3.3 Socioeconomics of fisheries

Employment in the fisheries sector in 1996 consisted of 702 people in the subsistence sector and 1305 in the artisanal sector (Gillett and Lightfoot 2001). Export-oriented fisheries used about 215 people in 2001 (Gillett and Lightfoot 2001). A coastal reef fisheries production estimate for the late 1990s put the coastal subsistence sector at 2863 mt (value of TOP 6,385,000) and coastal commercial fisheries at 3561 mt (value of TOP 11,362,500) (Gillett and Lightfoot 2001).

The subsistence and small-scale artisanal reef fisheries are best characterised as hand-operated, multi-geared and multi-species. Fishing is restricted to nearby coastal areas and, as in other South Pacific Island communities, involves little entrepreneurial skill, small informal groups, small fishing vessels, low capital investment, and correspondingly low productivity (Veitayaki 1993, Kronen 2004a). Four fisher groups were identified based on gear types, fishing method, motorisation, and market base. In these four groups, ownership or use of non-motorised or motorised boat transport is one important factor that determines access and choice of fishing grounds. Availability and use of different fishing gear is another major distinguishing parameter. Ice may be used during fishing trips, and bait may or may not be commercially acquired (Kronen 2004a).

The division of labour in Tonga in relation to fisheries can be traced back to the early contact period and it is quite possible it is even more ancient (Malm 2007). This division of labour dictates that males' work includes typically feminine tasks, such as agriculture, and most other fishing activities, including fishing outside the reefs. Females' tasks are characterised as light, simple, clean and requiring little or no mobility and are mainly house chores (Malm 2007). Although social and gender roles have been redefined to encourage wider participation of females in village fishing activities, Tongan female fishers still focus on reef gleaning close to shore just as they used to do in ancient times (Kronen 2002, Malm 2007). Males continue to dominate most fishing activities, the processing of catch, and marketing. Prices for reef and lagoon fish differ markedly between the outer islands and rural Tongatapu on one hand, and markets in Tonga's capital Nuku'alofa, on the other hand (Kronen 2004a).

The subsistence and small-scale artisanal fishery in Tonga and its associated marketing are quite sophisticated; they aim to satisfy social networking values and obligations, fulfil traditional principles and accommodate changes that accompany a society in transition from a barter and direct-sustenance system to a cash-based economy. Fishers do not fish for economic fortunes, but for food, social support, subsistence requirements and traditional values, and therefore cannot be regarded as pursuing an occupation. Coastal small-scale fisheries will continue to be essential to the livelihood of rural people in Tonga (King and McIlgorm 1989, Kronen 2004a).

1.3.4 Fisheries research activities

Many research activities have been conducted in the aquaculture sector, involving the experimental culture of local and introduced species to assess their suitability for development. The major ones are the mullet culture project funded by the Japanese International Cooperation Agency (JICA), the mussel culture project funded by New Zealand aid in 1974, the pearl farming project in Vava'u by the Tongan government and the FAO South Pacific Aquaculture Development Project (SPADP) in 1989 and 1993, although its full commercialisation remains to be seen. The ACIAR-funded giant clam culture and reseeding project in the 1980s resulted in the introduction of three species of giant clams to Tonga (ACIAR 1992). In 1991, JICA launched a major project on hatchery development at the Sopu station and carried out the introduction, culture and reseeding of trochus and green snail to reefs in the country.

The recent Tonga Fisheries Project funded by AusAID focuses on strengthening fisheries management through improved compliance and enforcement, planning and monitoring, and community-based management activities in the rural areas. Inshore resources assessment surveys for aquarium fish on Tongatapu (Matoto *et al.* 1996) and sea cucumbers in Ha'apai (Lokani *et al.* 1996) were completed in 1996 with the assistance of SPC. Effective management guidelines developed from these surveys have been adopted.

1.3.5 Fisheries management

In the 19th century, ownership of fishing rights in Tonga belonged only to the adjacent people who were under chiefly control (Malm 2001). This, however, changed with the abolishment of chiefly privileges between 1839 and 1862, and the country's first constitution in 1875. As a result the Tongan community lost any exclusive fishing rights or responsibilities over marine areas and the resources within. The sea and its resources became common property where all people have the right to fish wherever they like and community management controls become limited (Malm 2001). The feeling of open-access infiltrates into newly established reserves and parks where harvesting is practised from time to time and law enforcement is weakened by the fact that legally the resource belongs to everyone (Malm 2001). The giant clam gardening project established under the ACIAR project in the 1980s faced management problems due to poaching for this very reason of open-access, where "if not taken, another fisherman will take it".

Existing fisheries management systems are conventional ones, including catch limitation through gear restrictions, size limits, export restrictions through licensing and permit control on export companies, quota allocation on some fisheries such as the aquarium trade, closed seasons, prohibited fishing techniques and a ban on SCUBA and hookah (Ministry of Fisheries 1995). A 10-year ban since 1997 is in place for sea cucumber harvest and export. In addition, there are five marine reserves in Tonga, although control of entry into these reserves by male fishers is limited (Malm 2001). Public awareness and education is important to generate better understanding of resource concerns and therefore their conservation.

1.4 Selection of sites in Tonga

Six PROCFish sites were originally selected in the Kingdom of Tonga following consultations with the Ministry of Fisheries: Ha'atafu and Manuka on Tongatapu, Koulo and Lofanga on Ha'apai, and Ovaka and Mataika on Vava'u (Figure 1.5). These sites were selected as they shared most of the required characteristics for our study: they had active reef fisheries, were representative of the country, were relatively closed systems[5], were appropriate in size, possessed diverse habitats, presented no major logistical limitations that would make fieldwork unfeasible, had been investigated by previous studies, and presented particular interest for the Ministry of Fisheries. Four of these sites were re-surveyed in 2008, with socioeconomic and finfish surveys conducted in Ha'atafu and Manuka on Tongatapu, and Koulo and Lofanga on Ha'apai. This gave a unique opportunity to do a comparison of results six years after the initial surveys.

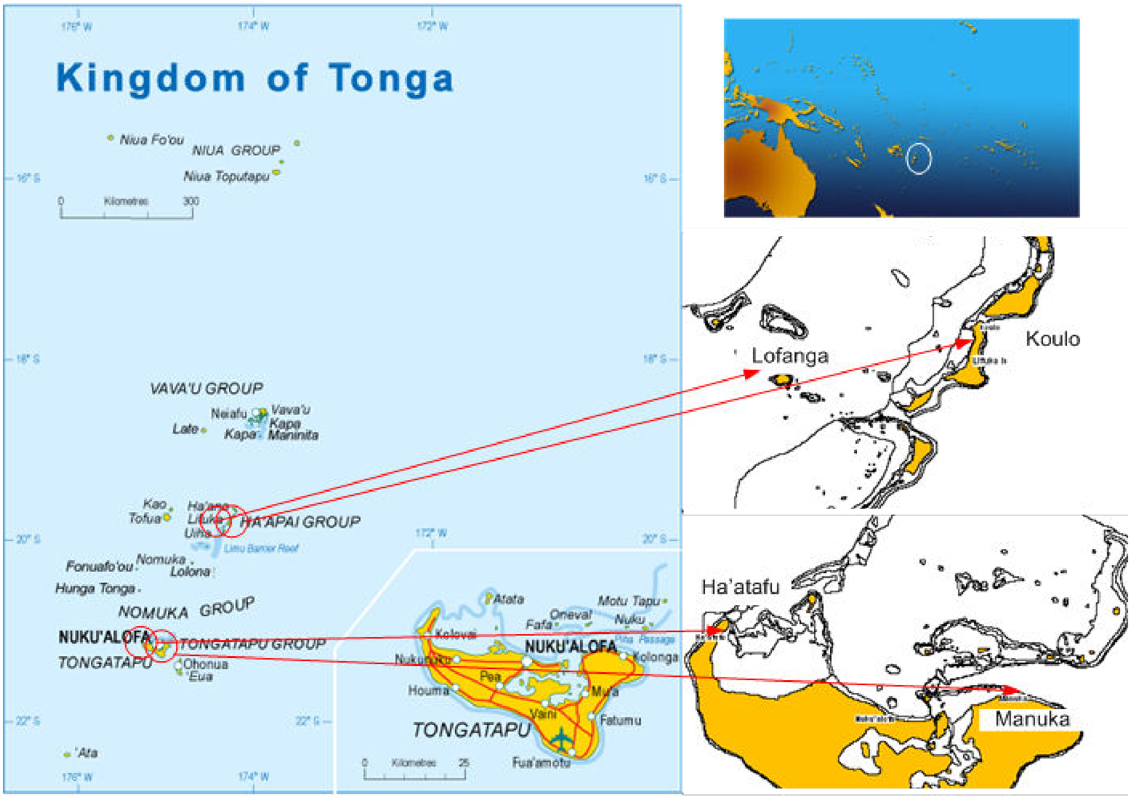

Figure 1.5: Map of the four PROCFish sites selected in Tonga.

[5] A fishery system is considered 'closed' when only the people of a given site fish in a well-identified fishing ground.

2. PROFILE AND RESULTS FOR HA'ATAFU

2.1 Site characteristics

Tongatapu is a coral atoll with mean coordinates of 21°10' S and 175°10' W, and a lagoon that has the unusual feature of opening to the north, which gives it the shape of a crescent and should classify it in the 'pseudo lagoon' category. Ha'atafu (Figure 2.1) is located on the western side of the lagoon, with no clearly defined fishing areas as the inhabitants conduct 'open-access' fishing. The fishing surface area of the lagoon is about 18.5 km wide and 37 km long, and is shared with Manuka and other villages. Around Ha'atafu, the coastal reef is mainly made up of seagrass beds and small patches of coral; in the centre, the reef flat is much narrower and is mainly made of coral debris, sand and seagrass beds. Fish traps are placed on this structure.

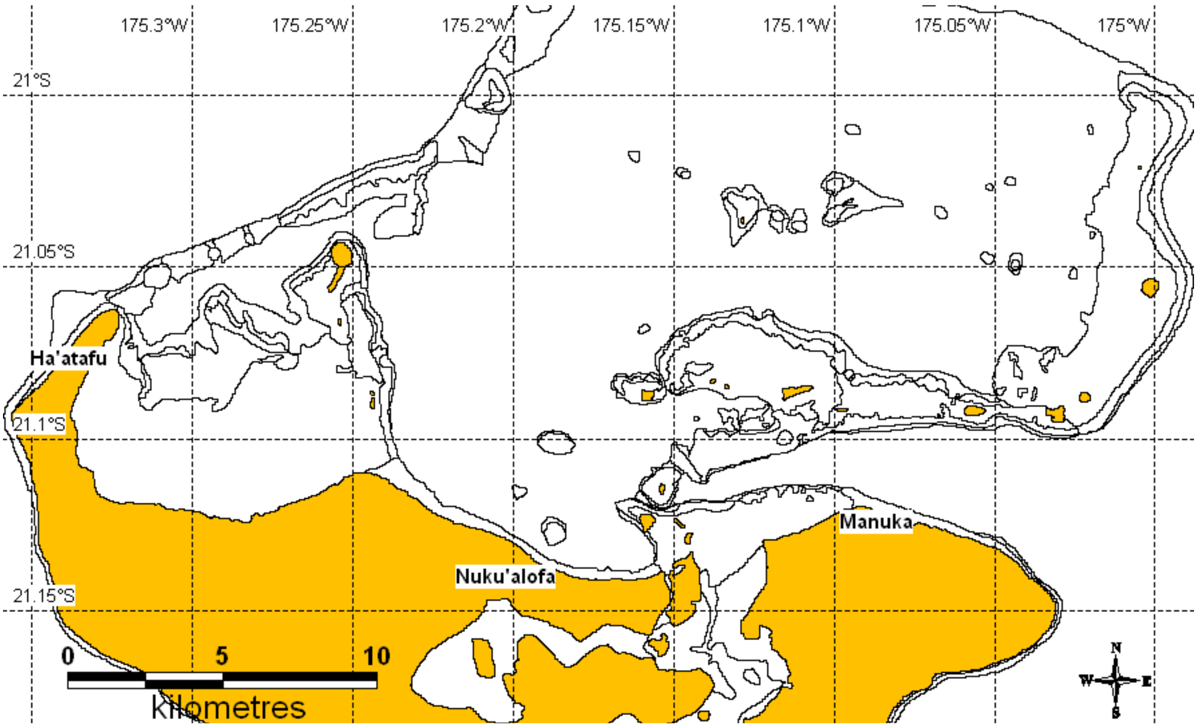

Figure 2.1: Map of Ha'atafu.

2.2 Socioeconomic survey: Ha'atafu

Socioeconomic fieldwork was carried out in Ha'atafu, one of the major fishing communities on Tongatapu in April and September 2008. The survey included households and fishers of the Ha'atafu community only.

The Ha'atafu community has a resident population of 267 people with a total of 40 households. A total of 21 households, which is >52% of total households in the community were surveyed, with most (~90%) of these households being engaged in some form of fishing activities. In addition, a total of 11 finfish fishers (males only) and 22 invertebrate fishers (10 males and 12 females) were interviewed. The average household size is six people per household. Household interviews focused on the collection of general demographic, socioeconomic and consumption data.

2.2.1 The role of fisheries in the Ha'atafu community: fishery demographics, income and seafood consumption patterns

Our results (Figure 2.2) suggest that 'other' income sources (~43% first income, 24% second income) mainly representing remittances and mat weaving (done by females), and salaries (~33% first income, 14% second income) are by far the most important income sources for the Ha'atafu households. Nevertheless, fisheries provide about 28% of all households with first and another 5% of all households with secondary income. Agriculture plays a role only in providing secondary income to 29% of all households. The Ha'atafu community has limited access to agricultural land, which reflects the general scarcity of agricultural land on Tongatapu. However, the community is located at the beach front and has access to a variety of fishing habitats and marine resources. Access to Nuku'alofa's main centre is by road; however, the long distance to be traveled to market fisheries produce may be a disadvantage as compared to other communities on Tonga's main island. The majority (71%) of all households have a couple of pigs, and one-third (33%) have chickens, most of which are for home consumption and feasts.

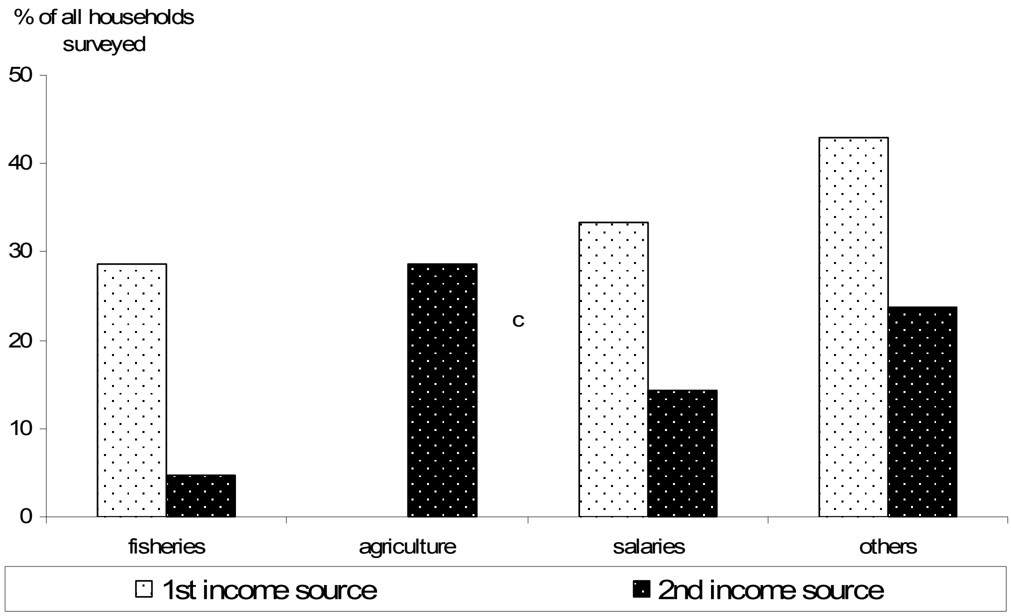

Figure 2.2: Ranked sources of income (%) in Ha'atafu.
Total number of households = 21 = 100%. Some households have more than one income source and those may be of equal importance; thus double quotations for 1st and 2nd incomes are possible.
'Others' are mostly home-based small businesses.

Our results (Table 2.1) show that annual household expenditures are high with an average of USD 3426 and reflect the proximity of this community to the country's capital, as well as its access to salary-based and other cash income. Nevertheless, remittances play an important role for Ha'atafu's household income, with 80% receiving remittances. Those who do receive remittances get an average of USD ~2413 /year, corresponding to 70% of the average basic household expenditure.

Table 2.1: Fishery demography, income and seafood consumption patterns in Ha'atafu

Survey coverage	Site (n = 21 HH)	Average across sites (n = 87 HH)
Demography		
HH involved in reef fisheries (%)	90.5	82.8
Number of fishers per HH	1.48 (±0.21)	1.47 (±0.16)
Male finfish fishers per HH (%)	35.5	43.0
Female finfish fishers per HH (%)	0.0	0.0
Male invertebrate fishers per HH (%)	6.5	2.3
Female invertebrate fishers per HH (%)	32.3	32.0
Male finfish and invertebrate fishers per HH (%)	25.8	22.7
Female finfish and invertebrate fishers per HH (%)	0.0	0.0
Income		
HH with fisheries as 1st income (%)	28.6	39.1
HH with fisheries as 2nd income (%)	4.8	4.6
HH with agriculture as 1st income (%)	0.0	10.3
HH with agriculture as 2nd income (%)	28.6	20.7
HH with salary as 1st income (%)	33.3	21.8
HH with salary as 2nd income (%)	14.3	10.3
HH with other source as 1st income (%)	42.9	29.9
HH with other source as 2nd income (%)	23.8	31.0
Expenditure (USD/year/HH)	3425.87 (±299.77)	3160.33 (±610.10)
Remittance (USD/year/HH) (1)	2413.44 (±451.32)	1165.99 (±150.20)
Consumption		
Quantity fresh fish consumed (kg/capita/year)	91.77 (±17.12)	68.57 (±6.36)
Frequency fresh fish consumed (times/week)	3.83 (±0.35)	3.44 (±0.19)
Quantity fresh invertebrate consumed (kg/capita/year)	20.99 (±7.30)	11.58 (±6.36)
Frequency fresh invertebrate consumed (times/week)	1.33 (±0.21)	1.13 (±0.11)
Quantity canned fish consumed (kg/capita/year)	17.21 (±3.25)	16.99 (±1.57)
Frequency canned fish consumed (times/week)	2.00 (±0.28)	2.00 (±0.15)
HH eat fresh fish (%)	100.0	100.0
HH eat invertebrates (%)	95.2	77.0
HH eat canned fish (%)	90.5	89.7
HH eat fresh fish they catch (%)	76.2	76.2
HH eat fresh fish they buy (%)	42.9	42.9
HH eat fresh fish they are given (%)	81.0	81.0
HH eat fresh invertebrates they catch (%)	71.4	71.4
HH eat fresh invertebrates they buy (%)	14.3	14.3
HH eat fresh invertebrates they are given (%)	52.4	52.4

HH = household; (1) average sum for households that receive remittances; numbers in brackets are standard error.

Survey results indicate an average of 1–2 fishers per household and, when extrapolated, the total number of fishers in Ha'atafu is 59. Among these are 36 exclusive finfish fishers (males only), 23 exclusive invertebrate fishers (19 females, 4 males), and 15 fishers who fish for both finfish and invertebrates (males only). During this survey, females denied active participation in finfish fishing, although they do at times catch fish for subsistence purposes and as a side product of gleaning activities. Only a quarter (24%) of households own a boat; most boats (83%) are motorised, and a few (17%) are non-motorised paddling canoes.

Consumption of fresh fish is high by comparison to the rural Tonga consumption level, at 92 kg/person/year. This consumption level is also significantly higher than the estimated average given by Preston (World Bank 2000) of 25.2 kg/person/year, or the regional average of ~35 kg/person/year (Figure 2.3). By comparison, consumption of invertebrates (edible meat weight only) (Figure 2.4) is much lower but, when compared to results obtained for other sites studied in Tonga, is high at 21 kg/person/year. Canned fish (Table 2.1) also adds a considerable amount (17.2 kg/person/year) to the annual protein supply from seafood. Canned fish is an established substitute in Tongan nutrition and available even in remote locations. The consumption pattern of seafood found in Ha'atafu highlights the fact that people have a high dependency on marine resources for food and that income generation is also very dependent on money sent from family members overseas to cope with the elevated living cost.

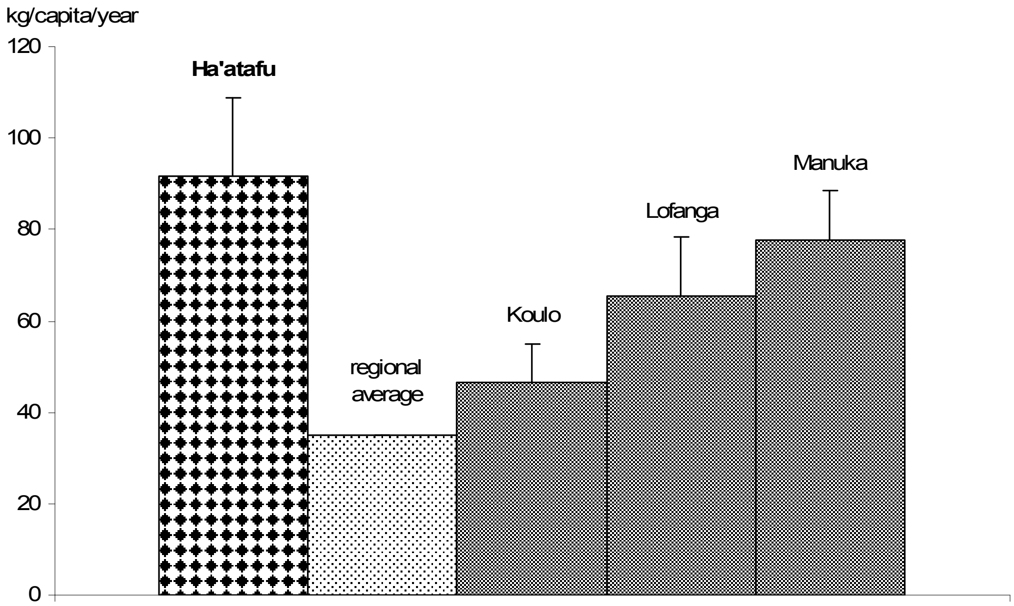

Figure 2.3: Per capita consumption (kg/year) of fresh fish in Ha'atafu (n = 21) compared to the regional average (FAO 2008) and the other three PROCFish sites in Tonga.
Figures are averages from all households interviewed, and take into account age, gender and non-edible parts of fish. Bars represent standard error (+SE).

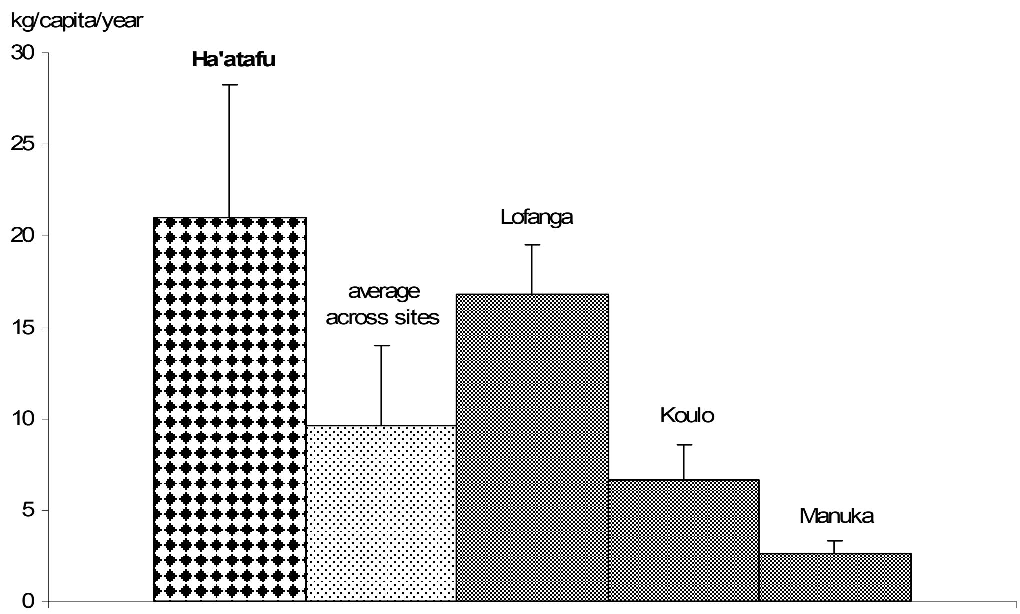

Figure 2.4: Per capita consumption (kg/year) of invertebrates (meat only) in Ha'atafu (n = 21) compared to the other three PROCFish sites in Tonga.
Figures are averages from all households interviewed, and take into account age, gender and non-edible parts of invertebrates. Bars represent standard error (+SE).

Comparing results obtained for Ha'atafu to the average figures across all four sites surveyed in Tonga, people of the Ha'atafu community eat fresh fish and invertebrates more often and in considerably higher quantities. They also eat more canned fish. In general, the proportion of the Ha'atafu population that eats fresh and canned fish is similar to the average found across all sites studied in Tonga. However, more people eat invertebrates. Ha'atafu people catch, buy and are given fish and invertebrates as found on average. Sharing seafood among community members on a non-monetary basis is very common and suggests that this community, although close to the country's capital, still pursues traditions. Salaries, remittances and mat weaving are the most important income sources, which are above the average found across all sites, while the community's income dependency on fisheries is less. Agriculture is also less important than found elsewhere. Household expenditure level is higher than the average across all sites studied in Tonga but Ha'atafu households also receive much more remittances. By comparison, boat ownership is as common as found elsewhere and the dominance of motorised boats is consistent with the overall country survey results.

2.2.2 Fishing strategies and gear: Ha'atafu

Degree of specialisation in fishing

Tonga has an open-access system; however, communities may consider certain areas as their fishing grounds. This observation is partly true for Ha'atafu; however, population density on Tongatapu is high and has substantially increased over the past decades. Thus, fishing grounds are shared with fishers external to the community studied. User conflicts are not reported and generally not of major concern. Fisheries management plan and resource surveys have been undertaken in cooperation with an AusAID-funded project and Tonga Fisheries. However, the survey on Tongatapu only included the two islands of 'Atata and 'Eueiki, not the community of Ha'atafu.

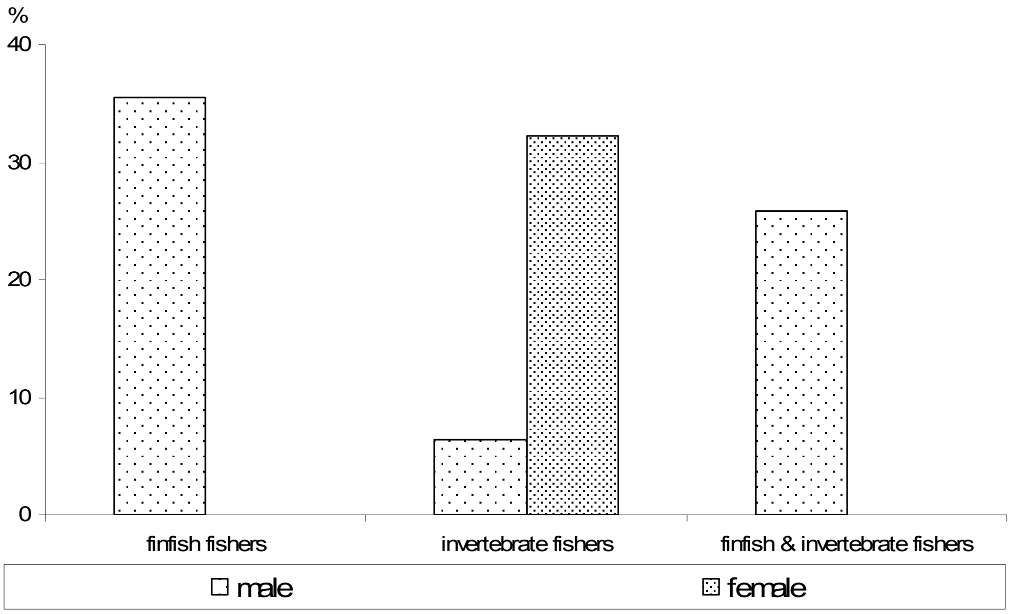

Figure 2.5: Proportion (%) of fishers who target finfish or invertebrates exclusively, and those who target both finfish and invertebrates in Ha'atafu.
All fishers = 100%.

As mentioned earlier, Ha'atafu fishers follow traditional gender roles, with males being the major finfish fishers, while females take the lead in invertebrate collection. However, as shown in an earlier study (Kronen and Bender 2006), gender roles have changed over time and females also catch finfish at times, while males actively participate in the collection of invertebrates. Nevertheless, due to the traditional *tabu* and the diverse lifestyle of Ha'atafu people, there is not much incentive or need for Ha'atafu females to get involved in finfish fisheries. Females contribute mainly to household income by weaving mats for sale locally and for the tourism industry.

Targeted stocks/habitats

Because Ha'atafu is located at the seafront of Tongatapu, several habitats can be targeted. Fishing in the sheltered coastal reef or soft-benthos habitats does not necessarily require boat transport. However, male fishers targeting the lagoon and coral reefs located within the lagoon system, passages and the outer reef need motorised boats to reach fishing grounds and to move between locations. Because the sheltered coastal reef itself is a very shallow zone, fishing is usually done by combining lagoon and coral reefs located within the lagoon system, as well as back-reef sites. Fishers may also target the outer reef or outer reef in combination with the passages. The relationship of major impact on the sheltered coastal reef/lagoon and less impact on the outer-reef (and passage) resources is shown in Table 2.2. Interviews showed that invertebrate fishers target reef-associated and soft-benthos species by walking along the reeftop surfaces and free-diving on the coral reefs inside the lagoon system (Figure 2.6). Both habitats also provide holothurians, which are mainly collected by females for home consumption. Reeftop gleaning is a female domain, but males also actively participate in harvesting invertebrates (Figure 2.7).

Table 2.2: Proportion (%) of male and female fishers harvesting finfish and invertebrate stocks across a range of habitats (reported catch) in Ha'atafu

Resource	Fishery / Habitat	% of male fishers interviewed	% of female fishers interviewed
Finfish	Sheltered coastal reef & lagoon	90.9	0.0
	Outer reef	9.1	0.0
	Outer reef & passage	18.2	0.0
Invertebrates	Soft benthos	10.0	25.0
	Soft benthos & reeftop	40.0	75.0
	Soft benthos & reeftop & other	10.0	0.0
	Reeftop	20.0	0.0
	Reeftop & other	20.0	0.0
	Other	10.0	0.0

'Other' refers to the octopus fishery.
Finfish fisher interviews, males: n = 11; females: n = 0. Invertebrate fisher interviews, males: n = 10; females, n = 12.

Fishing patterns and strategies

The number of fishers, the frequency of fishing trips and the average catch per fishing trip are the basic factors used to estimate the fishing pressure imposed by people from Ha'atafu on their fishing grounds (Tables 2.2 and 2.3).

Our survey sample suggests that fishers from Ha'atafu have a good choice of types of fishing ground that they can target. Basically, they can choose whether to fish close to shore or in the lagoon, or to venture out on a much longer fishing trip to the outer reef and passages. The same observation is true for invertebrate fisheries as the island has reeftop, soft-benthos and seagrass habitats and reefs within the lagoon system, as well as outer-reef slopes that can be targeted. Free-diving may be done on the top of the exposed isolated coral reefs within the lagoon area, or along the back-reef and the outer reef (Figure 2.6, Figure 2.7).

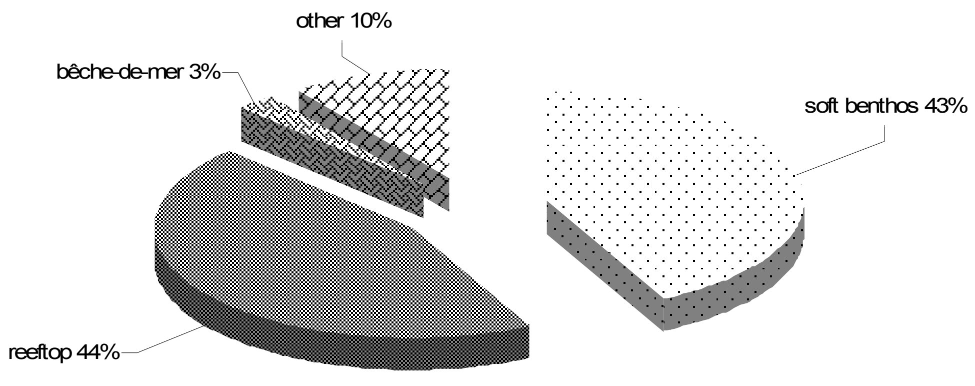

Figure 2.6: Proportion (%) of fishers targeting the four primary invertebrate habitats found in Ha'atafu.
Data based on individual fisher surveys; data for combined fisheries are disaggregated. 'Other' refers to the octopus fishery.

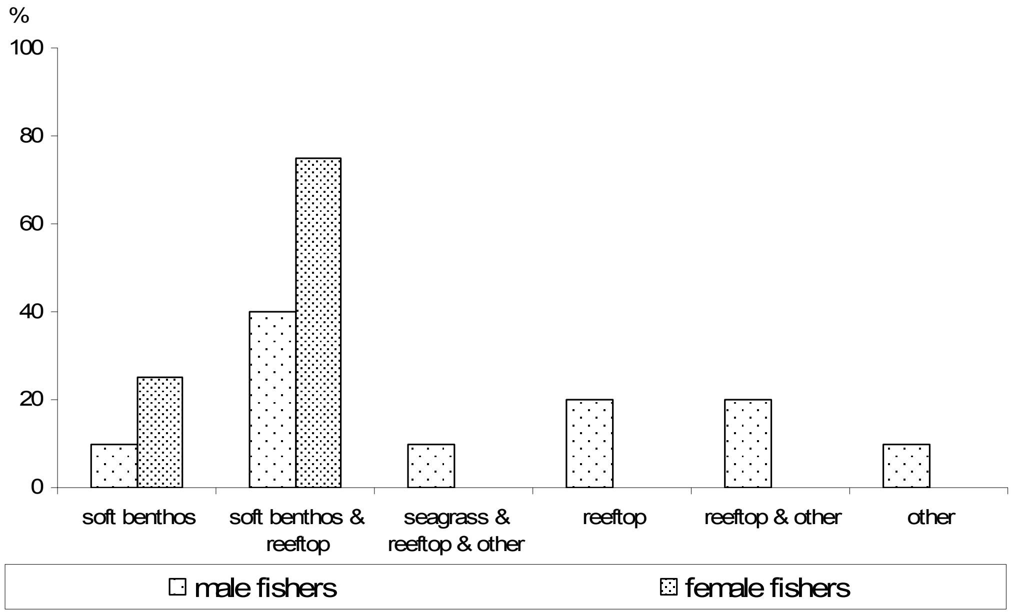

Figure 2.7: Proportion (%) of male and female fishers targeting various invertebrate habitats in Ha'atafu.
Data based on individual fisher surveys; data for combined fisheries are disaggregated; fishers commonly target more than one habitat; figures refer to the proportion of all fishers that target each habitat: n = 10 for males, n = 12 for females; 'other' refers to the octopus fishery.

Gear

Figure 2.8 shows that Ha'atafu fishers use a variety of fishing gear. For sheltered coastal reef and lagoon fishing, handlining, cast netting and some spear diving are mostly used, often in combination during one fishing trip. Gillnets and trolling within these two habitats combined are rarely used. For the outer-reef and passage fishing, handlines are definitely the most important technique. Combining handlines with gillnetting and perhaps trolling may be another alternative practised. Some fish fences are established further away from the village; however, they do not represent an important fishing method for Ha'atafu.

To collect invertebrates, most fishers use very simple techniques, such as digging, collecting by hand or poking with sticks, iron rods and knives in tidal pools and crevasses. Hand-woven baskets and plastic buckets are used to collect the catch and carry it back home for processing or cooking. Free-diving is done by males using mask, snorkel and fins, often while spear diving for finfish or in combination with finfish fishing trips.

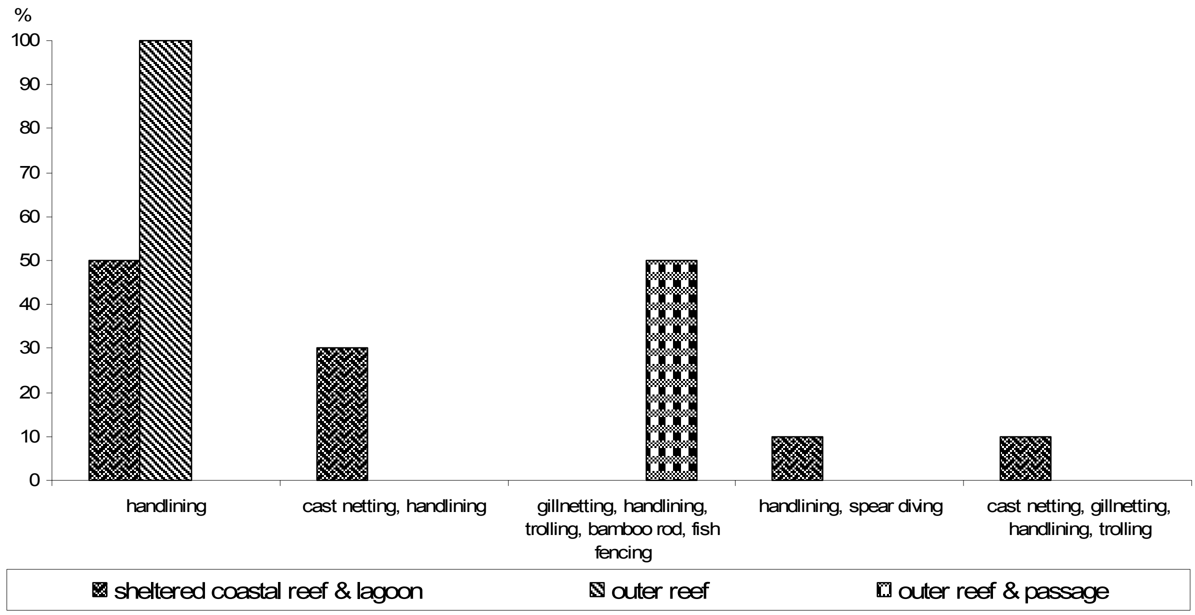

Figure 2.8: Fishing methods commonly used in different habitat types in Ha'atafu.
Proportions are expressed in % of total number of trips to each habitat. One fisher may use more than one technique per habitat and target more than one habitat in one trip.

Frequency and duration of fishing trips

Male fishers go out to catch finfish about 2 to 3 times per week regardless of which habitat they choose. As shown in Table 2.3, an average fishing trip targeting the outer reef and passages takes longer (8 hours) because of the long travel distances to these habitats. This may also explain why these habitats are less targeted than the sheltered coastal reef and lagoon areas. Sheltered coastal reef and lagoon fishing trips take on average about 3–4 hours.

Invertebrate fishers go fishing less often than do finfish fishers, on average about 1–2 times per week. The average fishing trip by male and female fishers gleaning the reeftops or male fishers free-diving lasts about 3 hours (Table 2.3).

Finfish fishing and invertebrate collection are practised throughout the year. Half of all finfish fishing trips are strictly scheduled according to tidal conditions if targeting the sheltered coastal reef and lagoon system; 40% are done during the day; and 10% exclusively at night. Fishers targeting the outer reef and passages go out at night only. The use of ice during fishing trips is rather rare, and mostly done if targeting the outer reef and passages. This may indicate that fishers targeting these habitats mainly pursue commercial interests.

Most of the invertebrate collection is done by walking, and is performed exclusively during day time. Most invertebrate collection activities are done throughout the year; however, free-diving may cease during winter when sea temperatures are very low.

Table 2.3: Average frequency and duration of fishing trips reported by male and female fishers in Ha'atafu

Resource	Fishery / Habitat	Trip frequency (trips/week)		Trip duration (hours/trip)	
		Male fishers	Female fishers	Male fishers	Female fishers
Finfish	Sheltered coastal reef & lagoon	2.00 (±0.28)		3.80 (±0.20)	
	Outer reef	3.00 (n/a)	0	8.00 (n/a)	0
	Outer reef & passage	1.75 (±0.25)	0	8.00 (±0.00)	0
Invertebrates	Soft benthos	1.00 (n/a)	1.00 (±0.00)	2.00 (n/a)	3.00 (±0.00)
	Soft benthos & reeftop	1.37 (±0.38)	1.19 (±0.21)	2.25 (±0.25)	3.00 (±0.00)
	Soft benthos & reeftop & other	2.00 (n/a)	0	4.00 (n/a)	0
	Reeftop	0.87 (±0.63)	0	2.50 (±0.50)	0
	Reeftop & other	1.35 (±0.65)	0	3.00 (±0.00)	0
	Other	2.00 (n/a)	0	3.00 (n/a)	0

Figures in brackets denote standard error; n/a = standard error not calculated; 'other' refers to the octopus fishery .
Finfish fisher interviews, males: n = 11; females: n = 0. Invertebrate fisher interviews, males: n = 10; females: n = 12.

2.2.4 Catch composition and volume – finfish: Ha'atafu

The reported catches from the sheltered coastal reef and lagoon, and from outer reef and passage fishing in Ha'atafu contain numerous species and species groups. Lethrinidae and, to some extent, Carangidae and Scaridae are the most important families quoted for catches from the combined fishing of the sheltered coastal reef and lagoon. Fish from the Lethrinidae family determine catches from the outer reef. If the outer reef and passages are targeted in one fishing trip, Lethrinidae, Serranidae and Carangidae mainly make up the reported catch composition. Overall, the catches reported from any of the habitats targeted and as expressed by vernacular names are not very diverse compared to catches reported from other study sites in Tonga. Detailed information on catch composition by species, species groups and habitats is reported in Appendix 2.1.1.

Figure 2.9 confirms the findings from the socioeconomic survey reported earlier, that finfish fishing is conducted mainly for subsistence and less for income purposes. The total annual catch is estimated to amount to ~27 t; ~77% is used for subsistence, while 23% is used for sale only. As previously mentioned, most of the impact (55%) is due to sheltered coastal reef rather than fishing in the lagoon and in the outer reef and passages. The latter represent only 8% and 37% respectively of the total annual impact.

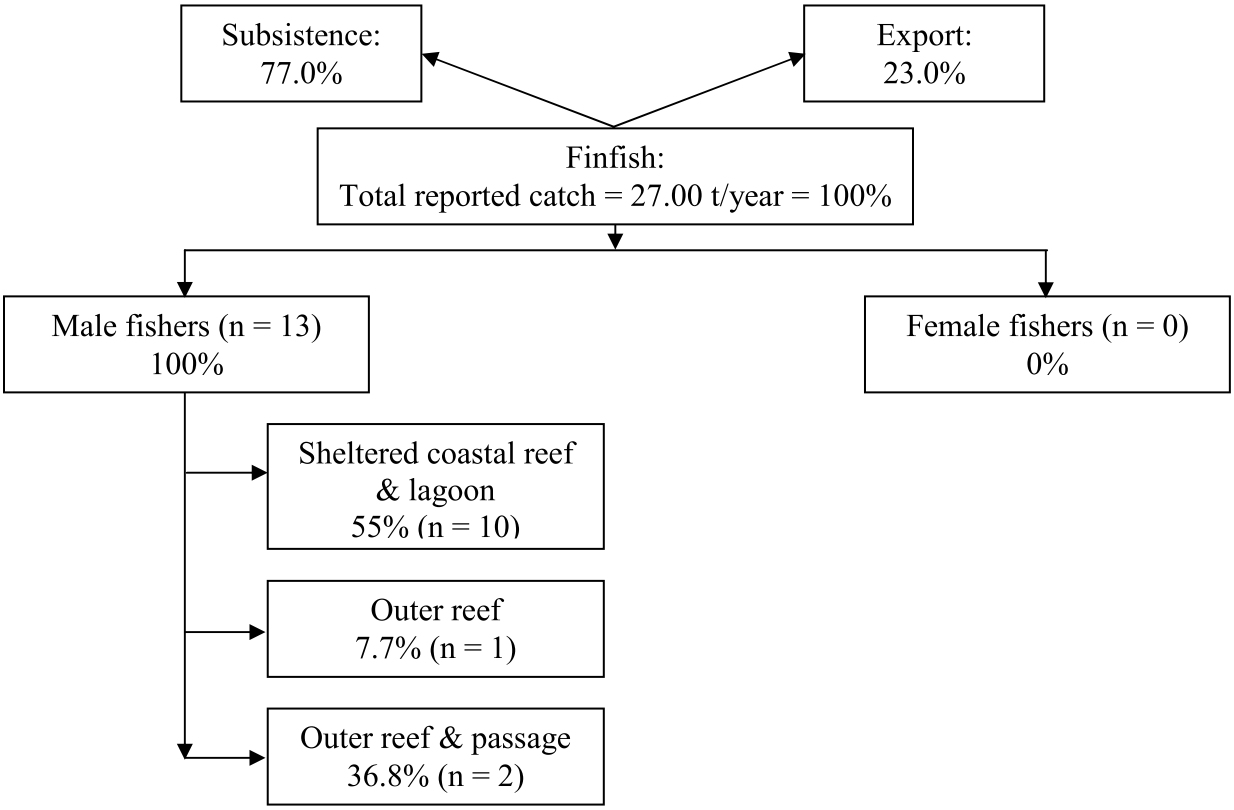

Figure 2.9: Total annual finfish catch (tonnes) and proportion (%) by fishery and gender (reported catch) in Ha'atafu.
n is the total number of interviews conducted per each fishery; total number of interviews may exceed total number of fishers surveyed as one fisher may target more than one fishery and thus respond to more than one fishery survey.

The distribution of annual catch weight between the more accessible sheltered coastal reef and lagoon, and the much more distant outer-reef and passage areas is a consequence of the number of fishers rather than the catch per unit effort (CPUE) and total annual productivity. As shown in Figure 2.10, the average annual catch per fisher is only one-third as high if the sheltered coastal reef and lagoon or the outer reef alone is targeted as compared to fishing the outer-reef and passage habitat in one fishing trip.

Comparing productivity rates between genders and among habitats (Figure 2.11), there are also substantial differences. An average of 1.5 kg fish are caught per hour of fishing trip at the sheltered coastal reef and lagoon and outer reef and 2.8 kg/hour of fishing trip achieved if combining the outer reef and passages. It cannot be ruled out that differences in the resource status may explain the important variation in CPUE. This argument applies if comparing the comparable CPUE figures for sheltered coastal reef and lagoon with those for outer-reef fishing. However, it should also be borne in mind that fishing trips targeting the sheltered coastal reef and lagoon are mainly undertaken for subsistence needs rather than commercial purposes, while fishing at the outer-reef and passages serves commercial interests. Thus, the variation in CPUE may also be attributed to differences in the fishing strategies used.

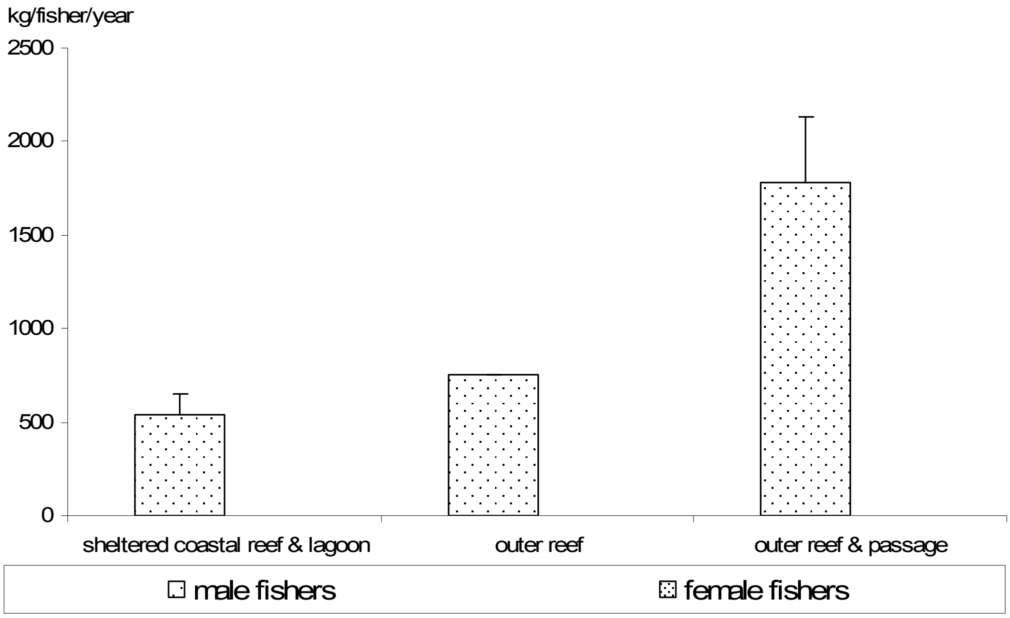

Figure 2.10: Average annual catch (kg/year, +SE) per fisher by gender and habitat in Ha'atafu (based on reported catch only).

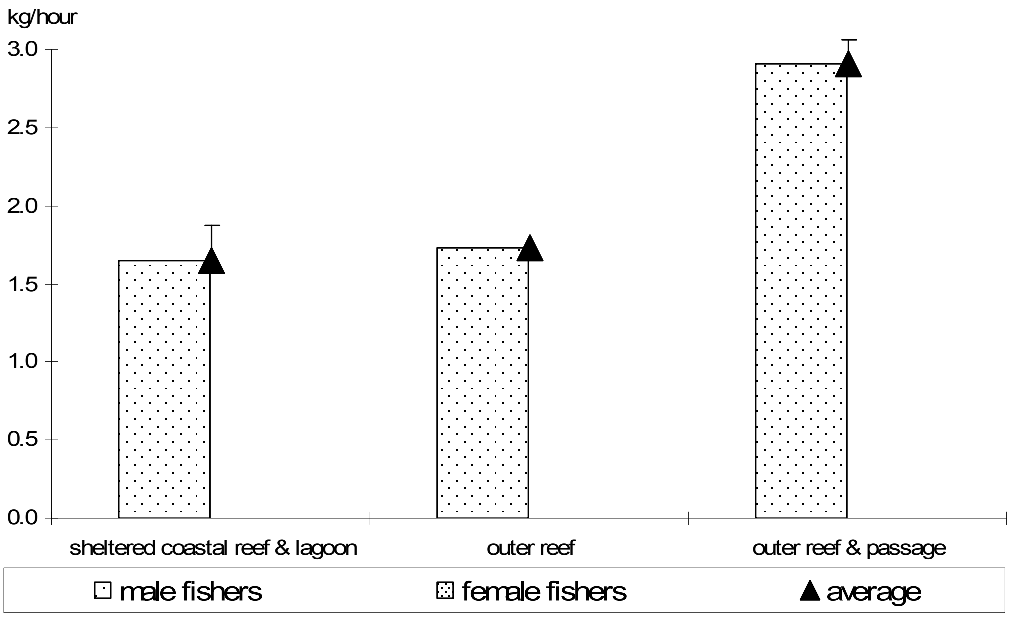

Figure 2.11: Catch per unit effort (kg/hour of total fishing trip) for male and female fishers by habitat type in Ha'atafu.
Effort includes time spent transporting, fishing and landing catch. Bars represent standard error (+SE).

The fact that subsistence fishing is more important than commercial fishing for Ha'atafu fishers clearly shows in Figure 2.12. As observed earlier, male fishers targeting the outer reef and outer reef and passages combined mainly fish for income-generating purposes. The fishing of the sheltered coastal reef and lagoon, an activity pursued by most fishers in Ha'atafu, is mainly done to provide food for the family and the community, and to a lesser extent to generate income.

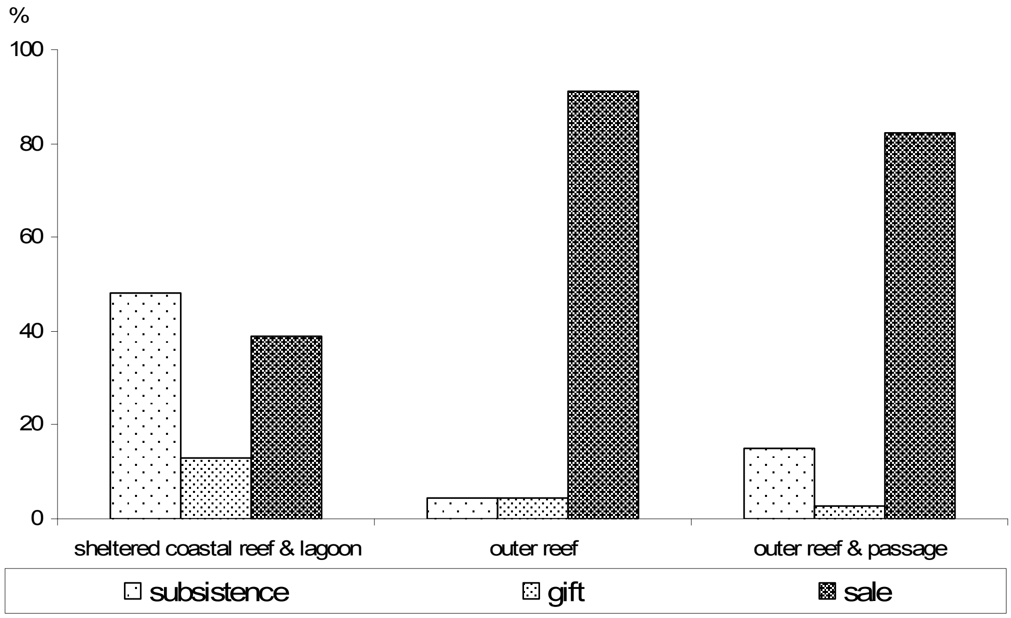

Figure 2.12: The use of finfish catches for subsistence, gifts and sale, by habitat in Ha'atafu. Proportions are expressed in % of the total number of trips per habitat.

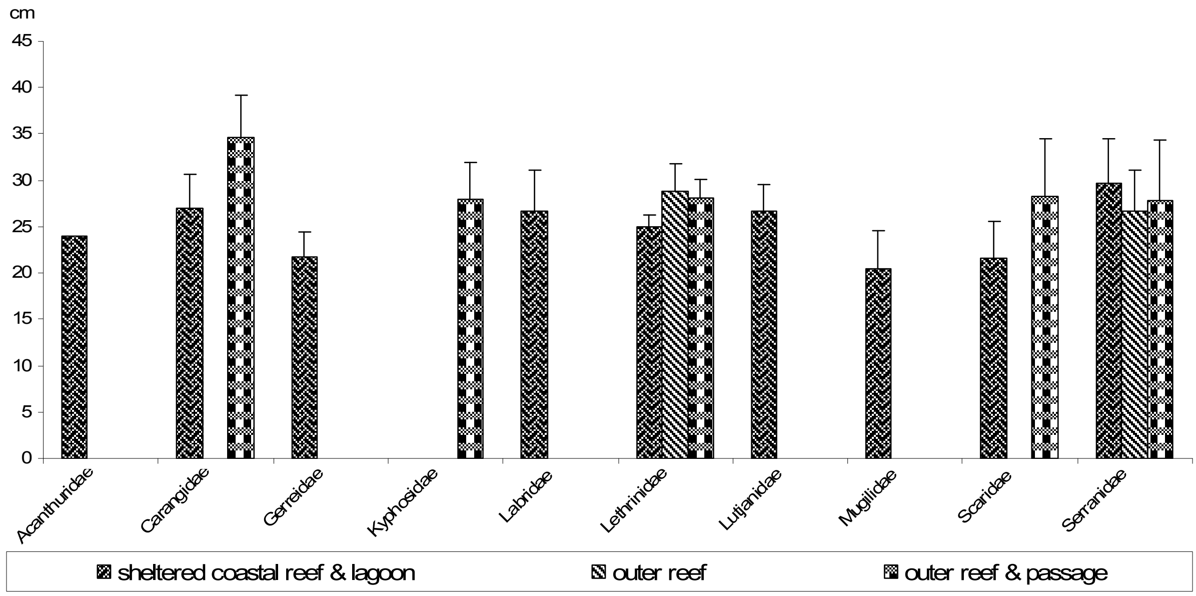

Figure 2.13: Average sizes (cm fork length) of fish caught by family and habitat in Ha'atafu. Bars represent standard error (+SE).

Analysis of overall finfish fishing productivity among habitats suggests a much higher efficiency (CPUE) in the combined fishing of outer reef and passages as compared to sheltered coastal reef and lagoon and outer-reef fishing (Figure 2.11). This observation is supported by the much larger Carangidae and Scaridae specimens reported for catches from the outer-reef/passage fishing. For Serranidae, average fork lengths are about the same for catches from all the different habitats if the variation (SE) of average lengths reported is taken into account. In the case of Lethrinidae, the average reported fork lengths in catches from the outer reef are larger than those in catches from the sheltered coastal reef and lagoon, and about the same as fish sizes from the outer reef and passages fished in one trip. Absence of comparative catch size data for other families does not allow us to conclude how much the average size of fish caught varies per habitat (Figure 2.13). Overall, reported average fish sizes are medium and range from 20 to 30 cm.

The parameters selected to assess current fishing pressure on Ha'atafu's reef and lagoon resources are shown in Table 2.4. Overall, all parameters calculated for fishing pressure are low. This applies to finfish fisher density in any of the habitats considered, population density for total reef and fishing ground areas, and the impact due to subsistence fish catch. Even if we consider the total export annual catch, which accounts for 23% of the total annual catch, catch rates remain very low. Thus, overall, there is no indication that the Ha'atafu fishing community currently catches finfish at a rate which is detrimental to resource levels. However, it must be borne in mind that the open-access system in the Tongatapu lagoon and the high population density on the island are likely to add considerable pressure on the resources, here allocated to the Ha'atafu community only. Underwater resource survey results revealed that, in fact, fish resources in the Ha'atafu reef and lagoon areas are in poor condition and far below average as compared to sites studied in the Ha'apai group. Therefore, it is concluded that the current low finfish catch rates are a response to a poor resource status. Furthermore, it is concluded that the actual resource status is a result of past and current fishing pressure imposed by fishers not only from Ha'atafu but also from elsewhere in Tongatapu.

Table 2.4: Parameters used in assessing fishing pressure on finfish resources in Ha'atafu

Parameters	Habitat				
	Sheltered coastal reef & lagoon	Outer reef	Outer reef & passage	Total reef	Total fishing ground
Fishing ground area (km^2)	142.3	3.6	9.4	81.2	151.7
Density of fishers (number of fishers/km^2 fishing ground) (1)	0.2	0.8	0.7	0.4	0.2
Population density (people/km^2) (2)				3.3	1.8
Average annual finfish catch (kg/fisher/year) (3)	538.2 (±108.8)	749.6 (n/a)	1783.6 (±345.0)		
Total fishing pressure of subsistence catches (t/km^2)				0.3	0.1
Total number of fishers	33	3	7	36	36

Figures in brackets denote standard error; n/a = standard error not calculated; (1) total number of fishers is extrapolated from household surveys; (2) total population = 267; total number of fishers = 36; total subsistence demand = 20.8 t/year; (3) catch figures are based on recorded data from survey respondents only.

2.2.5 Catch composition and volume – invertebrates: Ha'atafu

Analysis of reported catches from invertebrate fishers by wet weight shows that holothurian catches account for the highest impact, followed by octopus, sea urchins and *Turbo crassus*. By comparison, *Strombus*, *Dolabella* and other target species add relatively little to the overall impact (Figure 2.14).

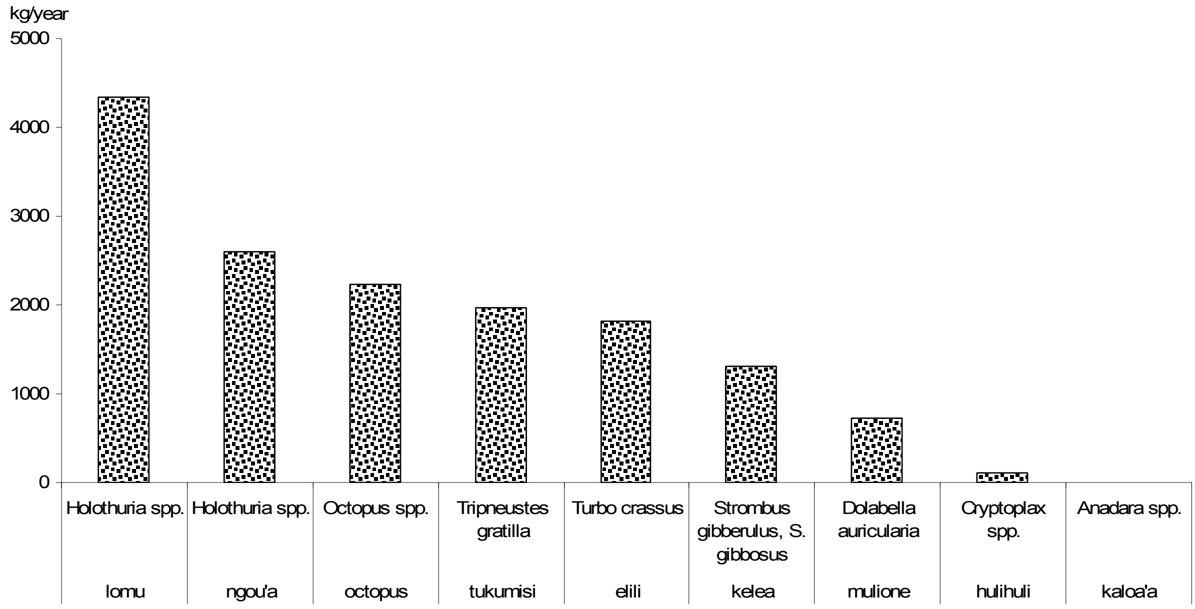

Figure 2.14: Total annual invertebrate catch (kg wet weight/year) by species (reported catch) in Ha'atafu.

The fact that most impact is on a few species only also shows in the number of vernacular names that have been reported by respondents. Reeftop and soft-benthos gleaning, which is often combined in one fishing trip, is represented by a maximum of 12 vernacular names, reeftop species alone include about three different targets identified by vernacular names (Figure 2.15).

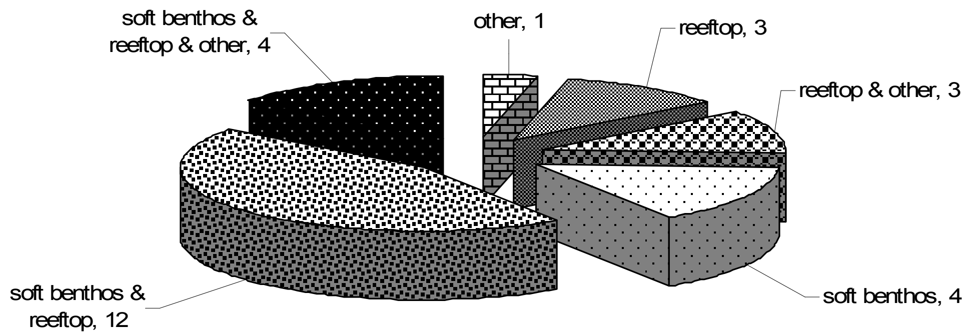

Figure 2.15: Number of vernacular names recorded for each invertebrate fishery in Ha'atafu.

The average annual catch per fisher by gender and fishery (Figure 2.16) reveals substantial differences among fisheries. Highest average annual catches are obtained by male fishers gleaning soft benthos and reeftops and perhaps other habitats, probably seagrass areas, in one combined fishing trip. Female fishers have generally much lower average annual catches as compared to male fishers. Average annual catches per fisher indicate that invertebrates serve mainly subsistence purposes and do not represent any major commercial fishery.

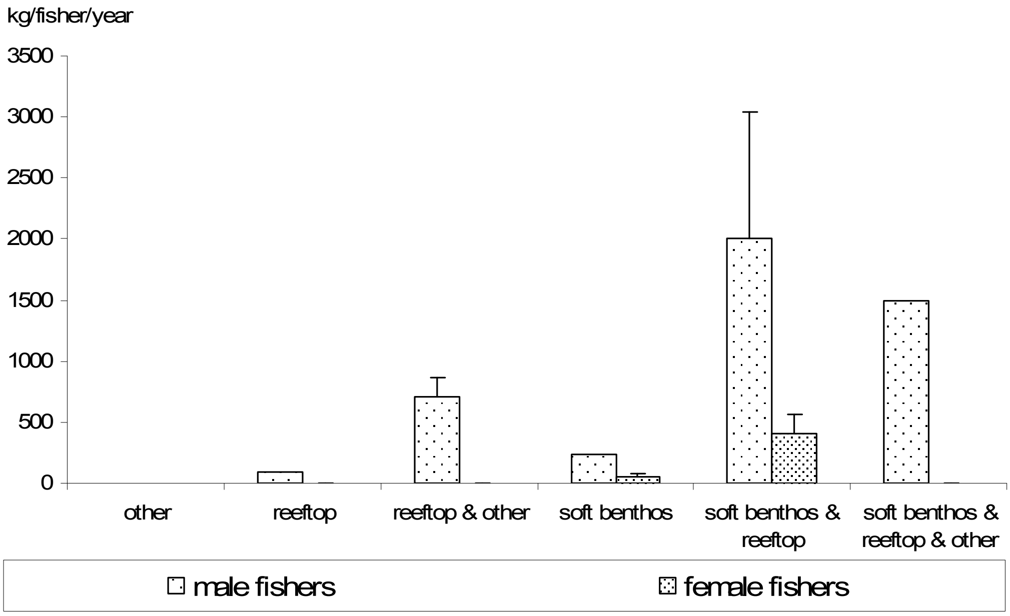

Figure 2.16: Average annual invertebrate catch (kg wet weight/year) by fisher and gender in Ha'atafu.
Data based on individual fisher surveys. Figures refer to the proportion of all fishers who target each habitat (n = 10 for males, n = 12 for females).

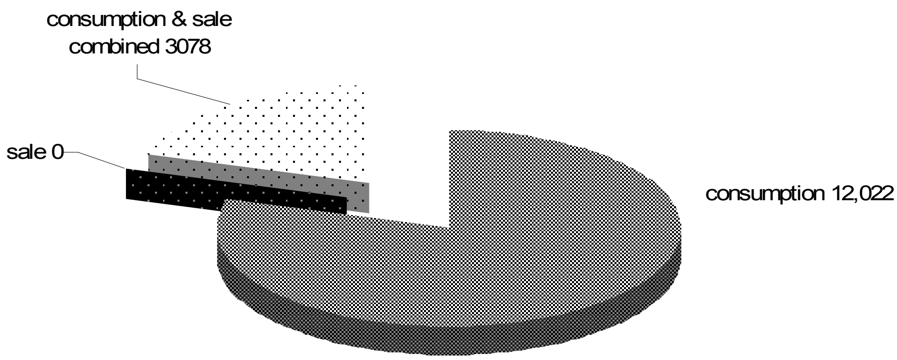

Figure 2.17: Total annual invertebrate biomass (kg wet weight/year) used for consumption, sale, and consumption and sale combined (reported catch) in Ha'atafu.

This argument is further supported by Figure 2.17, which shows that most of the invertebrate catches are used for subsistence purposes, and a maximum of 10% may be sold, assuming that half of the catch reported for consumption and sale may indeed be sold. No fisher reported collecting invertebrates only for sale.

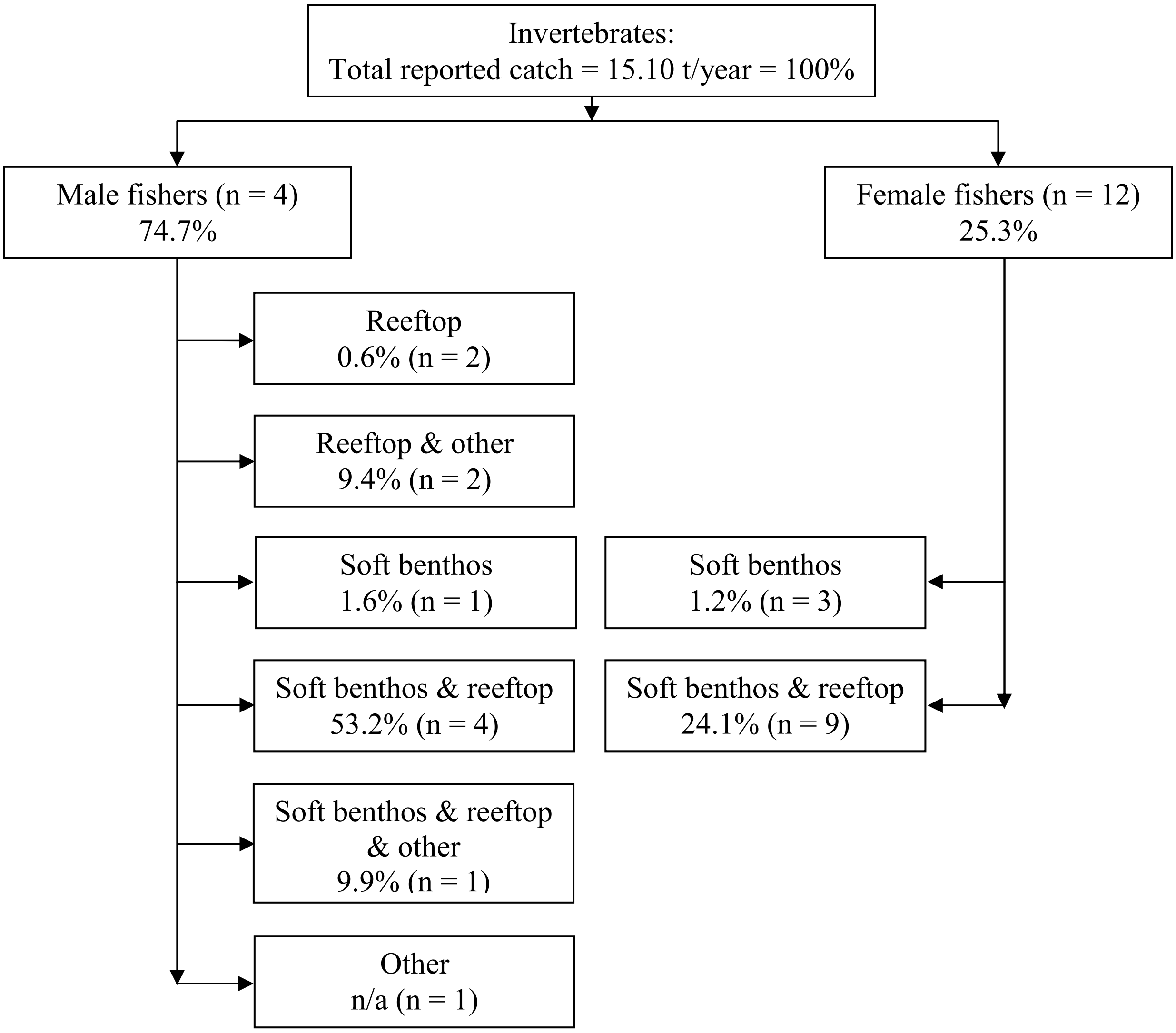

Figure 2.18: Total annual invertebrate catch (tonnes) and proportion (%) by fishery and gender (reported catch) in Ha'atafu.
n is the total number of interviews conducted per each fishery; total number of interviews may exceed total number of fishers surveyed as one fisher may target more than one fishery and thus respond to more than one fishery survey; n/a = no information available.

As mentioned earlier, male and female fishers from Ha'atafu are both engaged in invertebrate collection and, somewhat surprisingly, male fishers account for the largest proportion in wet weight. This observation confirms that male fishers take higher average annual catches. Also, as stated earlier, the highest pressure is on the combined reeftop and soft-benthos habitats, i.e. a total of 77% of the annual reported catch, with 53% taken by male fishers and 24% due to female fishers' gleaning activities.

Table 2.5: Parameters used in assessing fishing pressure on invertebrate resources in Ha'atafu

Parameters	Fishery / Habitat					
	Other	Reeftop	Reeftop & other	Soft benthos	Soft benthos & reeftop	Soft benthos & reeftop & other
Fishing ground area (km^2)	63.64	63.64	63.64	n/a	n/a	n/a
Number of fishers (per fishery) [(1)]	2	4	4	7	22	2
Density of fishers (number of fishers/km^2 fishing ground)	0.0	0.1	0.1	n/a	n/a	n/a
Average annual invertebrate catch (kg/fisher/year) [(2)]		98.0 (n/a)	709.4 (±159.2)	102.6 (±46.7)	898.3 (±370.7)	1493.9 (n/a)

Figures in brackets denote standard error; n/a = no information available or standard error not calculated; [(1)] total number of fishers is extrapolated from household surveys; [(2)] catch figures are based on recorded data from survey respondents only.

Taking into account figures on the available reeftop surface, reeftop fisheries have, as expected, a low fisher density, i.e. <1 fisher per km^2 of reeftop surface. Even though invertebrate fisheries are relatively important for Ha'atafu, in particular for home consumption, and the focus is on a few target species only, the average annual catch rates, fisher numbers and the available reef area all suggest low fishing pressure and thus no detrimental effect caused by current fishing levels (Table 2.5). However, again it must be noted that the open-access system coupled with a high population density on Tongatapu may add considerable stress on the resources here allocated to the Ha'atafu community only. Thus, final conclusions on resource status and possible visible impacts need verification with results from the invertebrate resource survey.

2.2.6 Fisheries management issues: Ha'atafu

Ha'atafu is a community that is located relatively far from Nuku'alofa and is relatively isolated at the most western tip of Tongatapu. The Ha'atafu population has, undoubtedly, access to urban market facilities and products and enjoys an elevated living standard with electricity and public water supply. However, the large amount of remittances received and the outstandingly high seafood consumption figures suggest that the community still follows a rather traditional lifestyle. This is also supported by the fact that the community is largely managed by traditional social institutions. As elsewhere in Tonga, fishing is governed by the open-access system, which does not restrict people from fishing wherever they wish. While no conflicts are reported, external fishers may add considerable pressure on the marine resources that are located around the Ha'atafu area, which the community may still regard as 'their' fishing grounds. Marketing of fishery produce may be limited due to the transport cost involved to get catch to the Nuku'alofa market and that may be higher than for other communities on the island, making Ha'atafu fishers less competitive (Kronen 2004). Ha'atafu has not been included in the ongoing fisheries community management planning that has been undertaken in two islands close to Tongatapu by Tonga fisheries in cooperation with a former AusAID project.

2.2.8 Discussion and conclusions: socioeconomics in Ha'atafu

Ha'atafu is a rural coastal community at the most western tip of Tongatapu, at some distance from the capital's market. It has, however, access to urban and market facilities by road. The living standard is relatively high with electricity and public water supply; however, a considerable amount of income is provided by remittances from overseas. Community life is still determined by traditional and, to some extent, religious institutions. People have limited access to agricultural land and depend primarily on marine resources.

Due to the low population and fisher density, and the large size of appropriated fishing grounds and reef surfaces, fishing pressure is relatively low. However, the marine resources allocated in this study to the Ha'atafu community are also subject to presumably significant external impact due to the open-access fisheries system and the considerable population density on Tongatapu.

In summary, survey results suggest:

- The Ha'atafu population has a significant dependence on marine resources (finfish and invertebrates), as well as on canned fish for home consumption. Revenues obtained from the marketing of fisheries produce, however, are far less important than income from salaries, remittances and mat weaving done by females.

- Per capita seafood consumption is the highest of all the communities studied in Tonga.

- Tradition demands different gender roles in fisheries and these still show in Ha'atafu. Male fishers are the only official and commercial finfish fishers, while females take the lead in invertebrate collection. Although females also catch fish at times, it is difficult to obtain any information on female finfish fishing activities. Males are increasingly involved in invertebrate harvesting and account for 75% of the total annual invertebrate catch (by wet weight).

- Finfish is mainly sourced from the sheltered coastal reef and lagoon habitats and less from the outer reef and passages.

- Overall, CPUEs are low-to-moderate, lowest for sheltered coastal reef and lagoon and highest for outer-reef and passage fishing.

- Handlining, cast netting and a combination of gillnetting, handlining, trolling and spear diving are the dominant fishing techniques used; trolling and fish fences are rare. Invertebrates are collected using very low-cost equipment. Male fishers may free-dive for invertebrates using mask, snorkel and fins. The average reported fish sizes are small to medium and range between 20 and 30 cm. Conclusions on the effect of habitats on average reported fish sizes are limited due to the lack of comparative data across the various families reported.

- Results from the invertebrate fisher survey show that catches of holothurians, octopus, sea urchins and *Turbo crassus* account for most of the annual harvest (wet weight). By comparison, catches of *Strombus*, *Dolabella* and other species are low.

- Average annual finfish catches show considerably higher productivity for fishers targeting the outer reef and passages as compared to fishers who catch fish in the sheltered coastal reef and lagoon. This coincides with the different objectives of fishing trips, which are more commercial when the outer-reef and passage habitats are targeted. Significant differences were also found in the average annual catches per invertebrate fishery. Annual average catches reported for the combined gleaning of soft benthos and reeftops and, possibly, other habitats (seagrass) are far higher than all other catch rates reported. Highest average annual catches are accounted for by male fishers.

- Fishing pressure parameters calculated for finfish fisheries suggest low finfish fishing pressure due to the large available reef and overall fishing ground area, low fisher and population densities and catch rates. The same conclusion is suggested for the invertebrate catch, reef area and fisher density data. In summary, the current exploitation level imposed on finfish and invertebrates for subsistence and commercial purposes does not give any reason to assume any detrimental effect on resources. However, this estimation is due to current catch data and does not take into account past exploitation history or the possible significant impact that may be caused by external fishers targeting the same fishing grounds. The results from the underwater finfish resource survey reveal that Ha'atafu finfish resources are in poor condition. Hence, previous and current fishing effort, including impact from fishers from outside the Ha'atafu community has imposed substantial pressure on finfish resources, and detrimental effects are clearly visible.

2.3 Finfish resource surveys: Ha'atafu

Finfish resources and associated habitats were assessed between 16 and 22 September 2008, for a total of 12 transects (2 back-reef, 6 coastal reef, 4 outer reef, Figure 2.19).

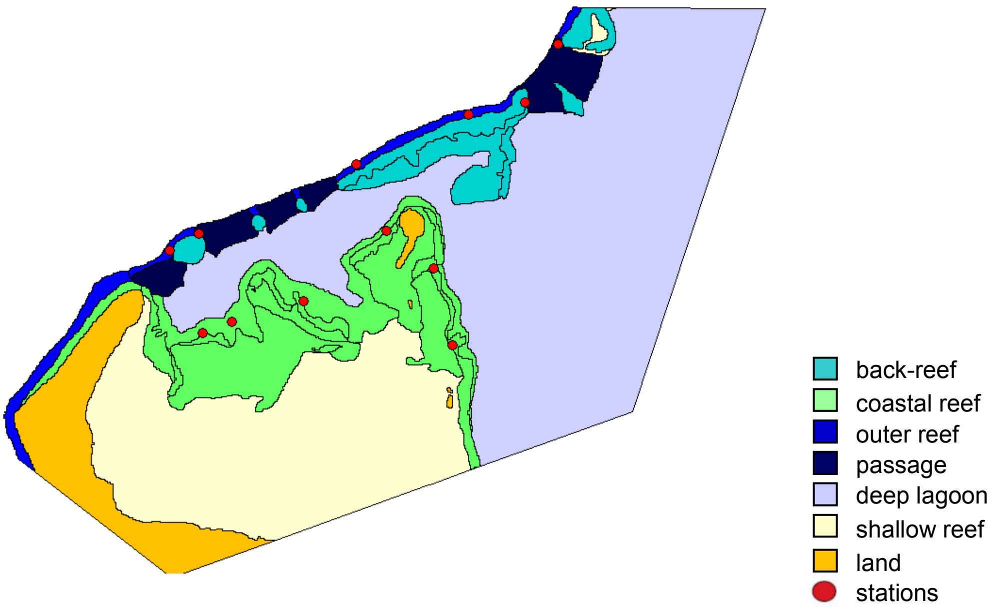

Figure 2.19: Habitat types and transect locations for finfish assessment in Ha'atafu.

2.3.1 Finfish assessment results: Ha'atafu

A total of 16 families, 39 genera, 110 species and 3014 fish were recorded in the 12 transects (See Appendix 3.1.2 for list of species.). Only data on the 14 most dominant families (See Appendix 1.2 for species selection.) are presented below, representing 37 genera, 108 species and 2901 individuals.

Finfish resources varied slightly among the three reef environments found in Ha'atafu (Table 2.6). Density was highest at the coastal reefs (0.4 fish/m^2) but biomass displayed the same value among all the reefs (20–26 g/m^2). Size was noticeably higher at the back-reefs

(15 cm FL and 58% respectively) and size ratio at the outer reefs (59%). Biodiversity was the highest at the back-reefs (41 species/transect).

Table 2.6: Primary finfish habitat and resource parameters recorded in Ha'atafu (average values ±SE)

Parameters	Habitat			
	Sheltered coastal reef (1)	Back-reef (1)	Outer reef (1)	All reefs (2)
Number of transects	6	2	4	12
Total habitat area (km^2)	15.56	16.56	3.60	35.72
Depth (m)	5 (3–9) (3)	6 (4–10) (3)	6 (3–10) (3)	5 (3–10) (3)
Soft bottom (% cover)	16 ±6	4 ±1	1 ±0	11
Rubble & boulders (% cover)	24 ±6	2 ±1	4 ±2	17
Hard bottom (% cover)	25 ±4	28 ±1	24 ±6	26
Live coral (% cover)	25 ±5	29 ±7	43 ±6	28
Soft coral (% cover)	7 ±2	29 ±1	20 ±6	13
Biodiversity (species/transect)	35 ±2	41 ±0	38 ±2	37 ±1
Density (fish/m^2)	0.4 ±0.1	0.3 ±0.0	0.3 ±0.0	0.3
Size (cm FL) (4)	12 ±1	15 ±1	14 ±1	13
Size ratio (%)	45 ±2	57 ±5	59 ±4	49
Biomass (g/m^2)	20.5 ±3.3	26.6 ±8.0	22.3 ±2.2	22.1

(1) Unweighted average; (2) weighted average that takes into account relative proportion of habitat in the study area; (3) depth range; (4) FL = fork length.

Sheltered coastal reef environment: Ha'atafu

The sheltered coastal reef environment of Ha'atafu was dominated by four families in terms of density and biomass: Acanthuridae, Siganidae, Scaridae and Mullidae (Figure 2.20, Table 2.7). These four families were represented by 31 species; particularly high biomass and abundance were recorded for *Ctenochaetus striatus*, *Siganus argenteus*, *Zebrasoma scopas*, *Chlorurus sordidus*, *Siganus spinus* and *Mulloidichthys flavolineatus* (Table 2.7). This reef environment was composed of a similar cover of live coral (25%), hard bottom (25%) and rubble and boulders (24%), while soft bottom was scarcer (16%, Figure 2.20).

Table 2.7: Finfish species contributing most to main families in terms of densities and biomass in the sheltered coastal reef environment of Ha'atafu

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.08 ±0.02	5.6 ±1.0
	Zebrasoma scopas	Two-tone tang	0.06 ±0.02	1.6 ±0.4
Siganidae	*Siganus argenteus*	Forktail rabbitfish	0.04 ±0.04	0.7 ±0.6
	Siganus spinus	Little spinefoot	0.02 ±0.00	0.5 ±0.1
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.03 ±0.01	2.5 ±0.3
Mullidae	*Mulloidichthys flavolineatus*	Yellowstripe goatfish	0.01 ±0.01	1.0 ±0.8

The size, size ratio and biodiversity of finfish in the coastal reefs of Ha'atafu were lower than the outer-reef and back-reef values. Density was slightly higher than at both other reefs, but biomass was the lowest, although of comparable amount. The trophic structure of fish in Ha'atafu coastal reefs was highly dominated by herbivorous fish, here mainly represented by Acanthuridae, Siganidae and Scaridae. Carnivores were represented mainly by Mullidae. Size ratio was below 50% values for most families: Acanthuridae, Holocentridae, Lethrinidae, Labridae, Mullidae, Scaridae and especially Siganidae, strongly highlighting an impact from fishing, especially spearfishing. These reefs displayed a substrate composed of a similar percentage of hard coral and hard bottom but a very small percentage of soft bottom, normally favouring carnivores.

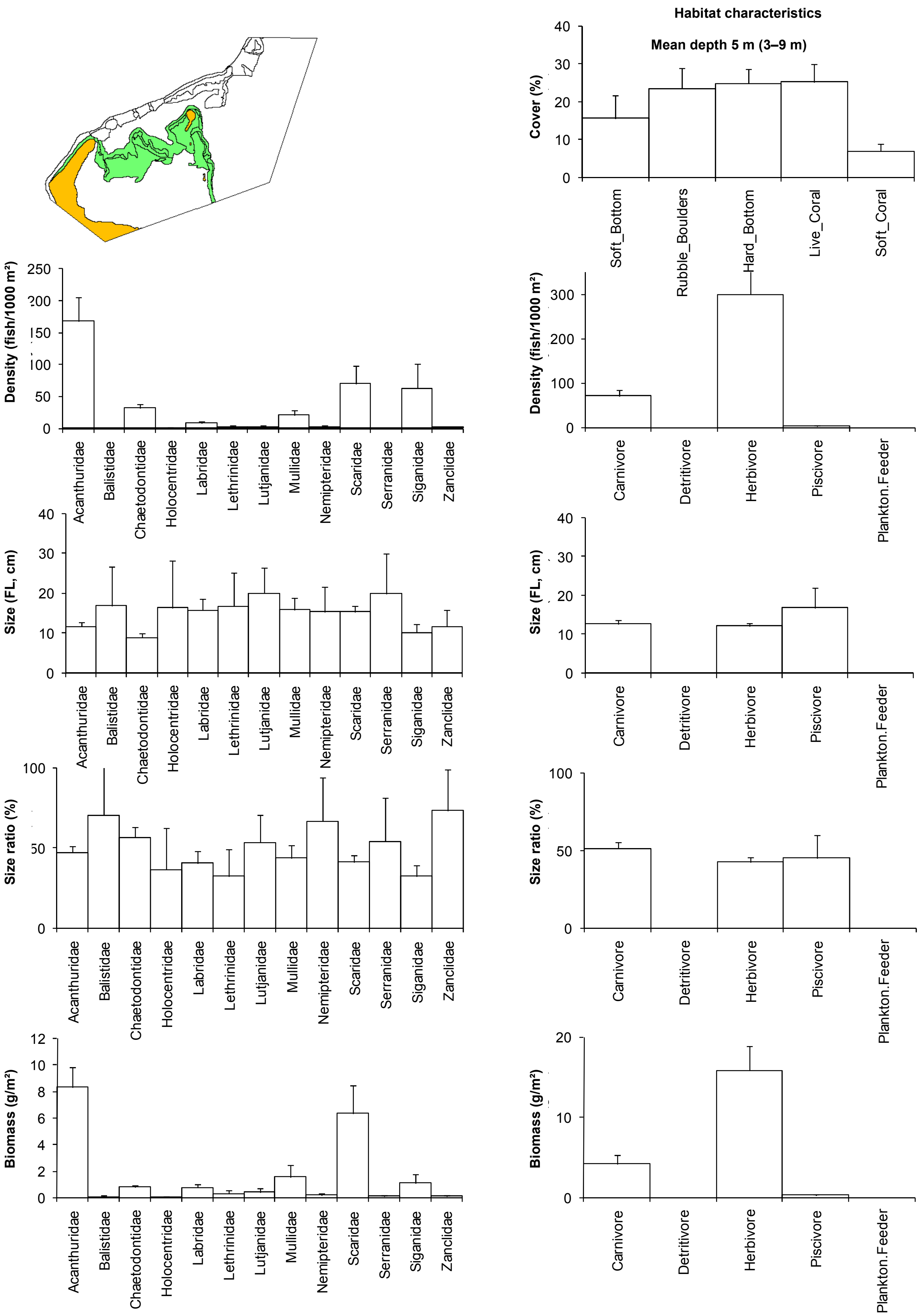

Figure 2.20: Profile of finfish resources in the sheltered coastal reef environment of Ha'atafu.
Bars represent standard error (+SE); FL = fork length.

Back-reef environment: Ha'atafu

The back-reef environment of Ha'atafu was dominated by two major families of herbivores: Acanthuridae and Scaridae (Figure 2.21, Table 2.8). These two families were represented by 14 species; particularly high biomass and abundance were recorded for *Ctenochaetus striatus*, *Zebrasoma scopas*, *Chlorurus sordidus*, *Scarus psittacus* and *Scarus schlegeli* (Table 2.8). This reef environment was mostly composed of hard bottom (28%), relatively large hard coral cover (29%) and little soft bottom (4%, Table 2.6, Figure 2.21).

Table 2.8: Finfish species contributing most to main families in terms of densities and biomass in the back-reef environment of Ha'atafu

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.13 ±0.05	14.1 ±7.4
	Zebrasoma scopas	Two-tone tang	0.02 ±0.05	1.1 ±0.5
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.02 ±0.02	2.2 ±1.5
	Scarus psittacus	Common parrotfish	0.01 ±0.01	1.4 ±0.9
	Scarus schlegeli	Schlegel's parrotfish	0.01 ±0.01	0.5 ±0.5

The fish density at the back-reefs of Ha'atafu was lower than at the coastal reefs but higher than at the outer reefs. Size was the highest among all reefs and size ratio was intermediate between that at the coastal reef and that at the outer reefs. Biomass had a comparable but slightly higher value compared to the other two reefs. Biodiversity was the highest. The trophic structure of the fish community was highly dominated by herbivorous fish in both density and biomass terms. Acanthuridae dominated in density and biomass and Scaridae were second but in much lower concentration. Both groups were represented by small-sized species (Table 2.8). Carnivores were almost absent and mainly represented by Labridae. Size ratios were below 50% values for Scaridae and Serranidae. Such small average size ratios suggest an impact from fishing. The back-reefs of Ha'atafu displayed a substrate dominated by hard bottom and live coral, with low cover of soft bottom, offering a limited choice of habitats to the different fish families. The almost total lack of all carnivore families is, however, not fully explained by these ecological conditions.

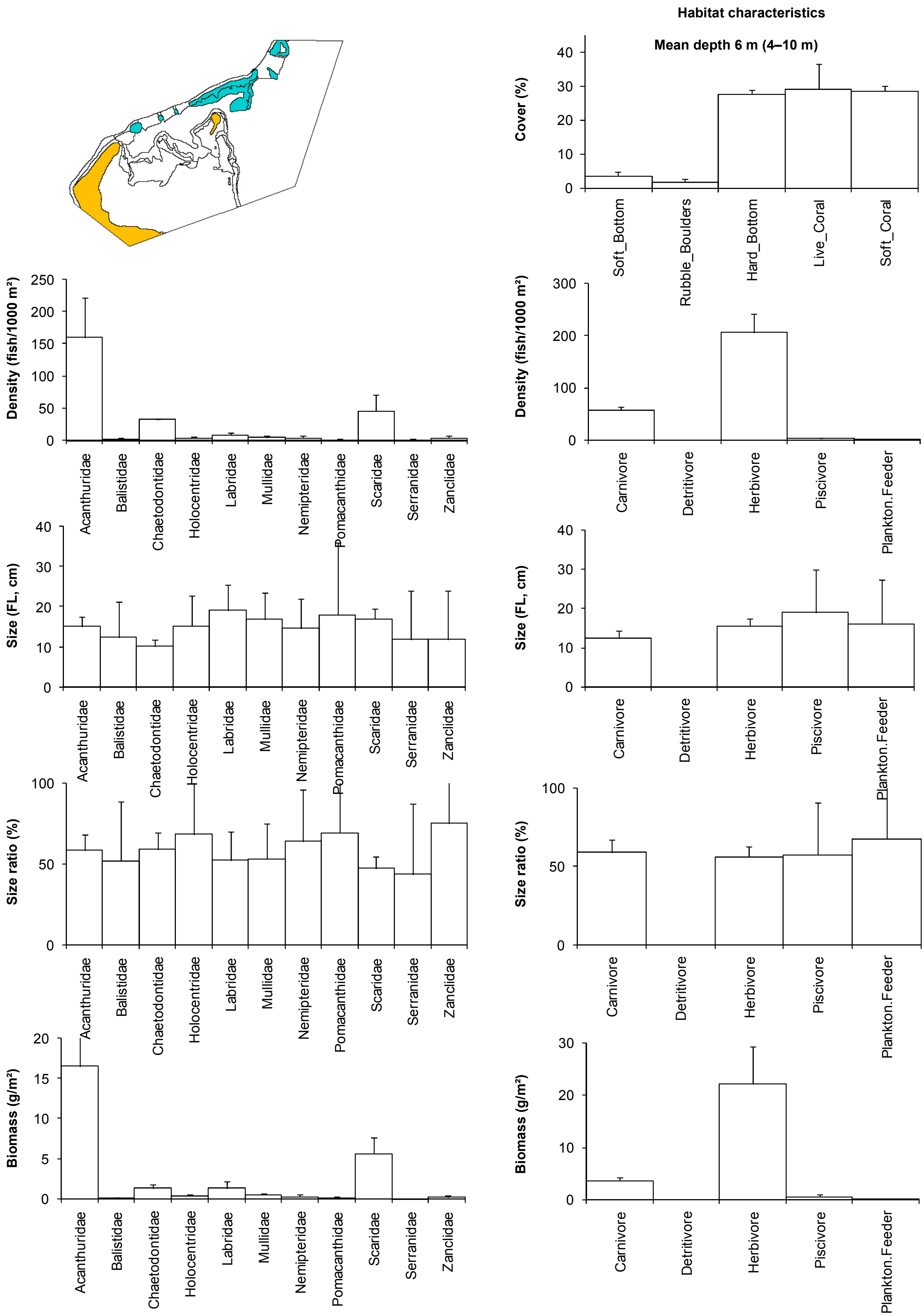

Figure 2.21: Profile of finfish resources in the back-reef environment of Ha'atafu.
Bars represent standard error (+SE); FL = fork length.

Outer-reef environment: Ha'atafu

The outer reef of Ha'atafu was largely dominated, in terms of both density and biomass, by herbivores Acanthuridae and Scaridae and carnivores Holocentridae and Chaetodontidae (Figure 2.22). The three major commercial families were represented by a total of 24 species, dominated by *Ctenochaetus striatus*, *Zebrasoma scopas*, *Myripristis kuntee* and *Chlorurus sordidus* (Table 2.9). Live-coral cover was very high (43%), and soft coral was well represented (20%). The remaining substrate was mostly composed of hard bottom (24%, Table 2.6 and Figure 2.22).

Table 2.9: Finfish species contributing most to main families in terms of densities and biomass in the outer-reef environment of Ha'atafu

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.08 ±0.02	9.6 ±2.5
	Zebrasoma scopas	Two-tone tang	0.02 ±0.01	0.9 ±0.4
Holocentridae	*Myripristis kuntee*	Shoulderbar soldierfish	0.03 ±0.02	3.2 ±2.7
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.01 ±0.00	0.8 ±0.3

The density, size, size ratio, biomass and biodiversity of this reef displayed intermediate values between coastal and back-reef values. However, size ratio was the highest. Trophic structure was dominated by the high abundance of herbivores, but carnivore and planktivore feeders were also well represented. Besides Chaetodontidae, only Holocentridae represented carnivores in relatively good numbers. Size ratio was below 50% for Scaridae, Mullidae and Labridae, suggesting an impact from fishing. The composition of habitat, dominated by hard bottom and live coral (67%), clearly favoured herbivores and disadvantaged soft bottom-associated carnivores, such as Lethrinidae and Mullidae.

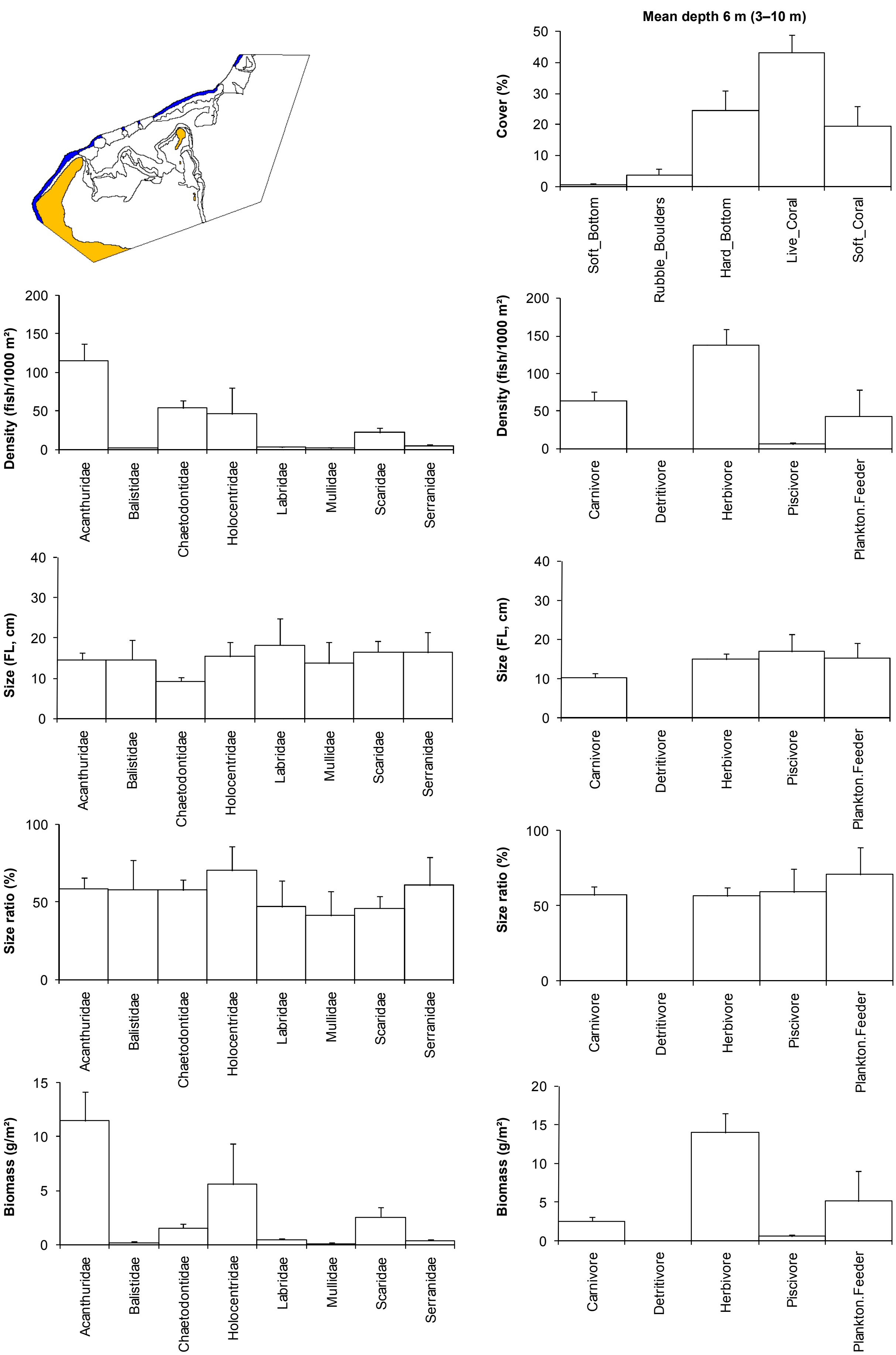

Figure 2.22: Profile of finfish resources in the outer-reef environment of Ha'atafu.
Bars represent standard error (+SE); FL = fork length.

Overall reef environment: Ha'atafu

Overall, the reefs of Ha'atafu were heavily dominated by four families in terms of density: Acanthuridae, Scaridae, Siganidae and Chaetodontidae, but this latter only in terms of density (Figure 2.23). The three major families were represented by a total of 28 species, dominated by *Ctenochaetus striatus*, *Zebrasoma scopas*, *Siganus argenteus*, *Chlorurus sordidus*, *Scarus psittacus* and *S. schlegeli* (Table 2.10). Overall, live coral dominated the habitat (28%) and hard-bottom cover was relatively high (26%, Table 2.6 and Figure 2.23). The overall fish assemblage in Ha'atafu shared characteristics of primarily back-reefs (46% of total habitat) and coastal reefs (43%) followed by outer reefs (10%).

Table 2.10: Finfish species contributing most to main families in terms of densities and biomass across all reefs of Ha'atafu (weighted average)

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.09	7.9
	Zebrasoma scopas	Two-tone tang	0.05	1.4
Siganidae	*Siganus argenteus*	Forktail rabbitfish	0.03	0.4
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.03	2.3
	Scarus psittacus	Common parrotfish	0.02	1.5
	Scarus schlegeli	Schlegel's parrotfish	0.01	1.1

Overall, Ha'atafu appeared to support a poor finfish resource, with intermediate conditions between those found at Manuka and Koulo. Density, biomass and biodiversity were higher than at Manuka, but size and size ratios were the smallest among the four sites. The detailed assessment of the fish community composition revealed poorer density and biomass of carnivore and piscivore species compared to herbivores, which strongly dominated the fish community. Few families dominated the community and a general lack or serious poverty of carnivores was the dominant profile; Mullidae were the most significant carnivores but present in extremely low numbers. The dominance of herbivores can be partially explained by the composition of the habitat, mostly composed of hard rock and live coral, with little percentage of soft substrate which normally favours most invertebrate-feeding carnivores. However, the study of size and size ratio trends disclosed the presence of very small fish in all families, indicating a high impact from fishing.

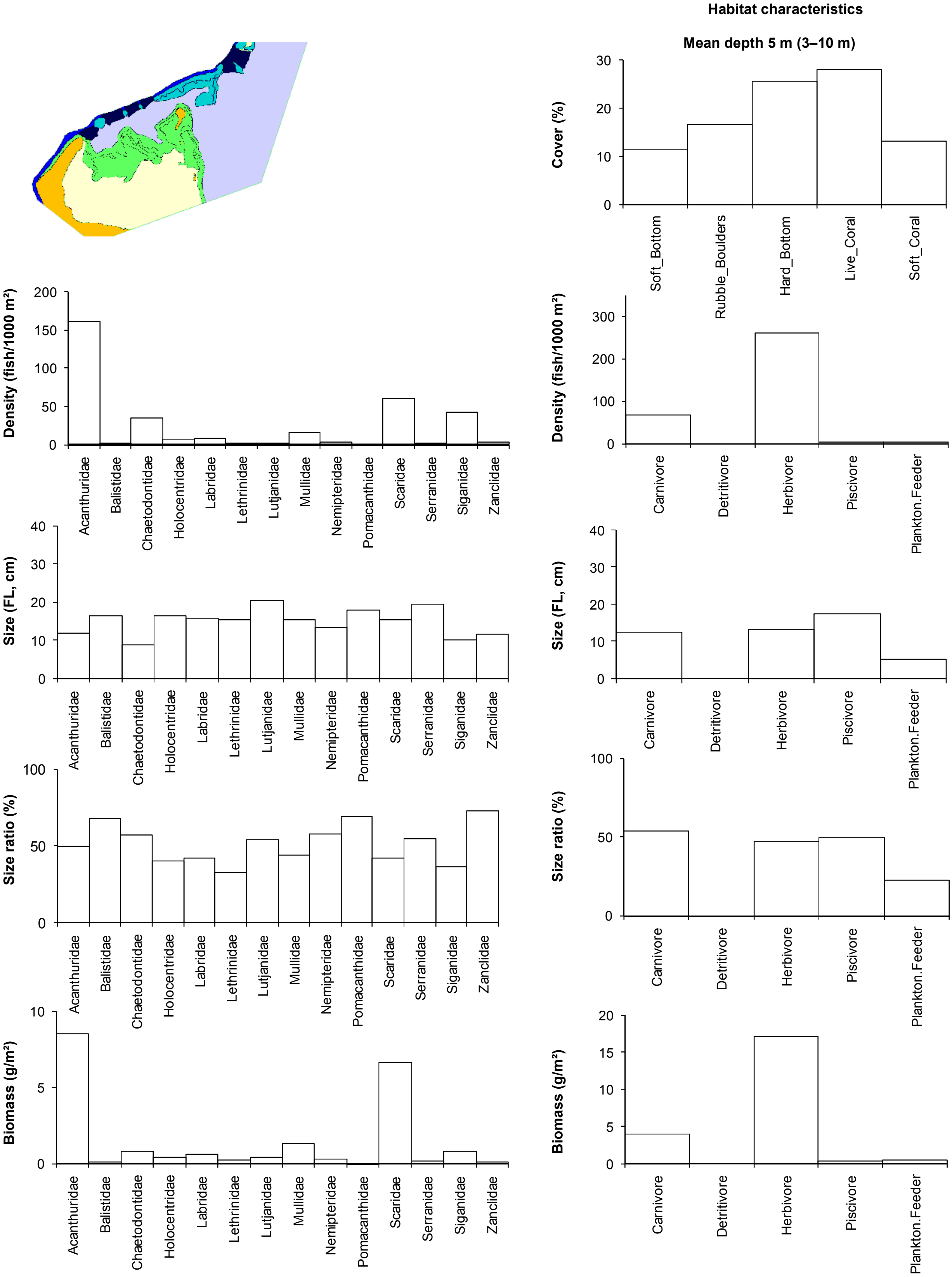

Figure 2.23: Profile of finfish resources in the combined reef habitats of Ha'atafu (weighted average).
FL = fork length.

Comparisons with 2002 survey

Biodiversity of fish was lower in 2002 than in 2008 (27 compared to 37 species/transect, Table 2.11). However, average size, size ratios and biomass were much lower in 2008 (Table 2.11). Density was slightly higher in 2008, therefore the decrease in biomass is mainly due to a decrease in sizes of Lethrinidae, Lutjanidae, Mullidae, Serranidae and Siganidae between the two surveys (Figure 2.24). Trophic composition did not change between the two surveys but piscivore biomass strongly decreased (Figure 2.25). Most importantly, species composition changed: *Chlorurus sordidus* and *Scarus psittacus*, the two most important species in 2002 (Table 2.12), displayed lower density and biomass in 2008 and were replaced by *Ctenochaetus striatus*, which had much higher density and biomass (Table 2.10).

Table 2.11: Primary finfish habitat and resource parameters recorded in Ha'atafu in 2002 and 2008

Parameters	Year of survey	
	2002	2008
Number of transects	17	12
Total habitat area (km^2)	32.12	35.72
Depth (m)	5 (1–15) (1)	5 (3–10) (1)
Soft bottom (% cover)	26	11
Rubble & boulders (% cover)	10	17
Hard bottom (% cover)	37	26
Live coral (% cover)	17	28
Soft coral (% cover)	6	13
Biodiversity (species/transect)	27 ±1	37 ±1
Density (fish/m^2)	0.3	0.3
Size (cm FL) (2)	15	13
Size ratio (%)	50	49
Biomass (g/m^2)	36.5	22.1

(1) depth range; (2) FL = fork length.

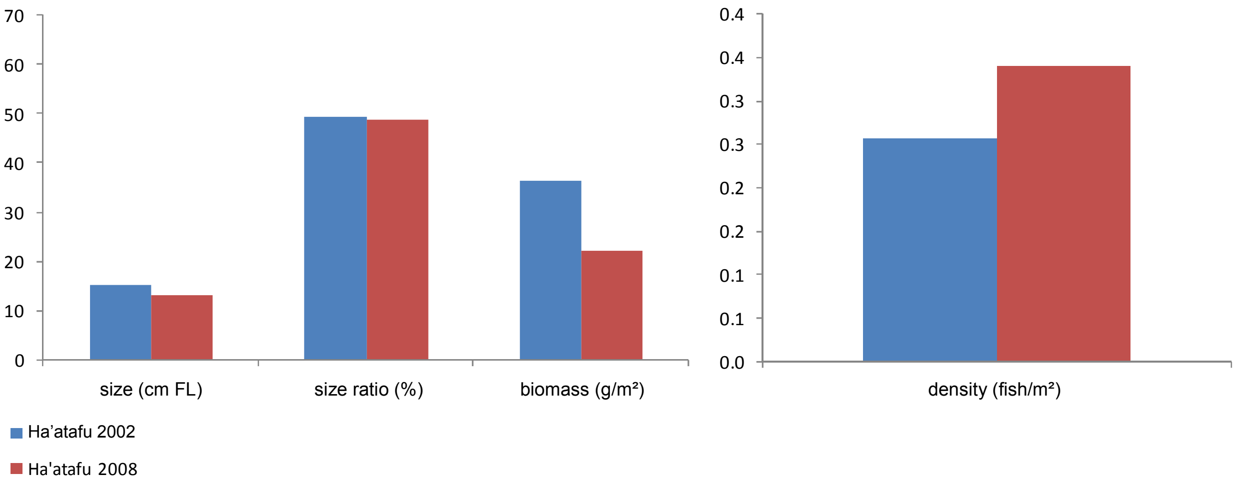

Figure 2.24: Variation in average size, size ratio, biomass and density of finfish in Ha'atafu between 2002 and 2008.

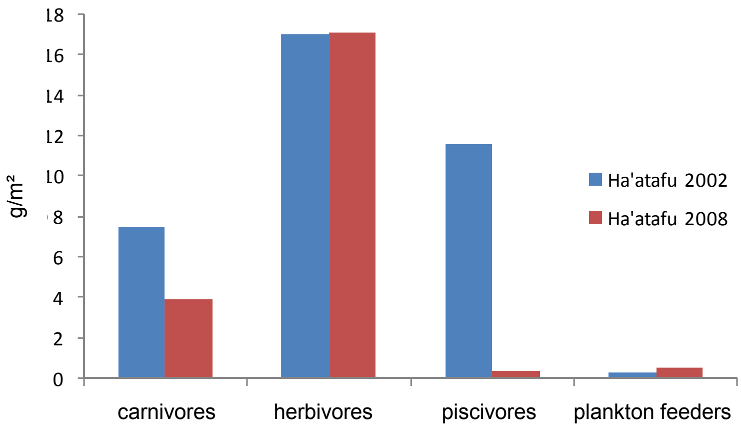

Figure 2.25: Trophic composition in terms of biomass in Ha'atafu in 2002 and 2008.

Table 2.12: Finfish species contributing most to main families in terms of densities and biomass across all reefs of Ha'atafu in 2002 (weighted average)

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.04	4.2
	Scarus psittacus	Common parrotfish	0.03	2.6
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.03	3.1
	Zebrasoma scopas	Two-tone tang	0.02	1.5

2.3.2 Discussion and conclusions: finfish resources in Ha'atafu

The western village in Tongatapu, Ha'atafu, showed poor but slightly better conditions than Manuka, with higher biodiversity of species, density and biomass of fish, but smaller average sizes. The average values for the site are, however, much smaller than the Ha'apai values, with lower biodiversity, much smaller average sizes of fish and lowest biomass. Coral cover was lower in coastal reefs but higher in back-reefs compared to Manuka, and much higher on the outer reefs. Herbivores, and especially Acanthuridae, dominated the fish community with a total density slightly higher than at Manuka. Other relevant families were Scaridae, with much lower density and biomass than Acanthuridae, and Holocentridae (still with very low values). The mean sizes of several fish families were below 50% of the maximum values, an index of impacted conditions on the fish population. Similar to at Manuka, the most representative species for this site in terms of density and biomass were small-sized species of Acanthuridae and Scaridae. Conditions were poorer in 2008 compared to 2002 in terms of sizes and biomass of fish as well as in terms of fish community composition. The small Acanthuridae *Ctenochaetus striatus* dominated the fish community in 2008, and was much more abundant than in 2002.

- Resources were in poor condition. The inner reefs were poor in terms of coral cover as well as finfish resources.
- Fish displayed higher diversity than at Manuka but the total number of species was still low when compared to the regional values.
- Density and biomass were comparable among the three reef types and were slightly higher than Manuka values.

- Sizes and size ratios were on average smaller than at Manuka, especially in the back-reefs and coastal reefs.

- The average sizes of most fish families were much smaller than 50% of their maximum values ever recorded, indicating an impact from fishing.

- Conditions were less degraded in the first assessment in 2002: average sizes and biomass were higher in 2002 compared to those in the second assessment. Since density slightly increased, the decrease of biomass was mainly due to a serious decrease in average sizes as well as to a replacement of larger species with small species. A greater decrease in biomass was observed for piscivores.

- As at Manuka, the establishment of more community-driven reserves, such as the Atata Island reserve at the west of Tongatapu, should quickly be established to restore the exploited resources, while making sure a patrolling system is set in place and compliance assured.

- A monitoring system should be set in place to follow any further changes in finfish resources.

2.4 Invertebrate resource surveys: Ha'atafu

The diversity and abundance of invertebrate species at Ha'atafu were independently determined using a range of survey techniques (Table 2.13), broad-scale assessment (using the 'manta-tow' technique; locations shown in Figure 2.26) and finer-scale assessment of specific reef and benthic habitats (Figures 2.27 and 2.28).

The main objective of the broad-scale assessment is to describe the distribution pattern of invertebrates (rareness/commonness, patchiness) at large scale and, importantly, to identify target areas for further fine-scale assessment. Then, fine-scale assessment is conducted in target areas to specifically describe the status of resource in those areas of naturally higher abundance and/or most suitable habitat.

In-water work completed at the two sites at Tongatapu was not all conducted according to the standard PROCFish survey design, as we used the opportunity of this scheduled work to respond to a specific request by the Government of Tonga to assess the sea cucumber resource by surveys linked with those in Ha'apai, and to conduct in-water work to train staff and advise on the colonisation of trochus, *Trochus niloticus*, following the concerted effort by the authorities to introduce mother-of-pearl resources to local reefs.

Table 2.13: Number of stations and replicate measures completed at Ha'atafu

Survey method	Stations	Replicate measures
Broad-scale transects (B-S)	12	71 transects
Slope 'manta' transects (10–20 m)		0 transect (2)
Deep 'manta' transects (20–30 m)		12 transects (2)
Reef-benthos transects (RBt)	10	60 transects
Soft-benthos transects (SBt)	11	50 transects
Soft-benthos infaunal quadrats (SBq)	11	59 quadrat groups
Mother-of-pearl transects (MOPt)	8	57 transects
Mother-of-pearl searches (MOPs)	3	24 search periods
Reef-front searches (RFs) (1)	7	57 search periods
Reef-front search by walking (RFs_w)	0	0 search period
Sea cucumber day searches (Ds)	See deep 'manta' transects	12 transects (2)
Sea cucumber night searches (Ns)	0	0 search period

(1) Reef-front search stations were completed with more than the normal two officers and therefore each station can have more than six replicates; (2) search periods for deep-water work were 100 m in length and 4 m swathe.

Figure 2.26: Broad-scale survey stations for invertebrates in Ha'atafu.
Data from broad-scale surveys conducted using 'manta-tow' board;
black triangles: transect start waypoints.

Figure 2.27: Fine-scale reef-benthos transect survey stations and soft-benthos transect survey stations for invertebrates in Ha'atafu.
Black circles: reef-benthos transect stations (RBt);
black stars: soft-benthos transect stations (SBt).

Figure 2.28: Fine-scale survey stations for invertebrates in Ha'atafu.
Inverted black triangles: reef-front search stations (RFs);
black squares: mother-of-pearl transect stations (MOPt);
grey squares: mother-of-pearl search stations (MOPs).

Sixty-four species or species groupings (groups of species within a genus) were recorded in the invertebrate surveys at Ha'atafu. These included 9 bivalves, 20 gastropods, 21 sea cucumbers, 5 urchins, 5 sea stars, 1 cnidarian and 1 lobster (Appendix 4.1.1). Information on key families and species is detailed below.

2.4.1 Giant clams: Ha'atafu

Shallow-reef habitat that is suitable for giant clams on the fringing, intermediate and offshore reefs associated with Ha'atafu was extensive. The main access to hard-bottom invertebrate fishing areas is through the gleaning of fringing and patch reefs, and an extensive limestone pavement area, which borders the village in the west. On the other side of the village in the east is a protected seagrass area with patch reef fringing the main lagoon areas. Fishing is generally open-access in Tonga and no set fishing area is noted in this report. The shallow-water reef area was calculated from satellite images of Tongatapu at 34.6 km^2.

The environment of Ha'atafu was a mix of oceanic- (W & N) and land- (E) influenced habitats. As there was no enclosed lagoon and significant through-flow of oceanic water, the benthos was relatively well flushed.

Reefs at this site held two species of giant clam: the elongate clam *Tridacna maxima* and the fluted clam *T. squamosa*. The smooth derasa clam *T. derasa* has on occasion been introduced to the waters of Tongatapu (from hatchery spawnings). One individual clam was noted that might have been a *T. derasa* or *T. tevoroa* that was 15 cm in length (west of Atata Island, near the small islands on the barrier), but no clear identification could be made. The devil's clam (*T. tevoroa*), which was found in deeper-water surveys in Ha'apai, was not found in these surveys.

Broad-scale sampling in shallow-water surveys provided an overview of giant clam distribution and density; *T. maxima* had the widest distribution (found in 6 stations and 13 of 71 transects), followed by *T. squamosa* (2 stations and 3 transects). The average station density of *T. maxima* in broad-scale shallow-water surveys was 4.1 /ha ±2.1, see Figure 2.29).

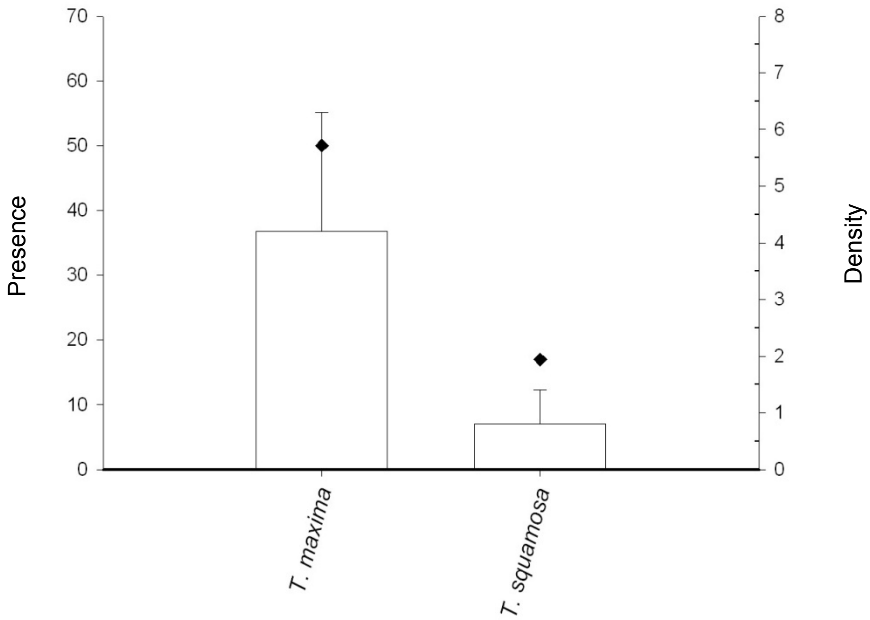

Figure 2.29: Presence and mean density of giant clam species in Ha'atafu based on broad-scale survey.
Presence is measured as % of stations surveyed where clams were present and denoted by black diamonds; density is measured in numbers per hectare and is represented by bars (+SE).

Based on the findings of the broad-scale survey, finer-scale surveys targeted specific areas of clam habitat (Figure 2.30). In these reef-benthos assessments (RBt), *T. maxima* was present in 60% of stations at a mean density of 38.1 /ha ±11.6.

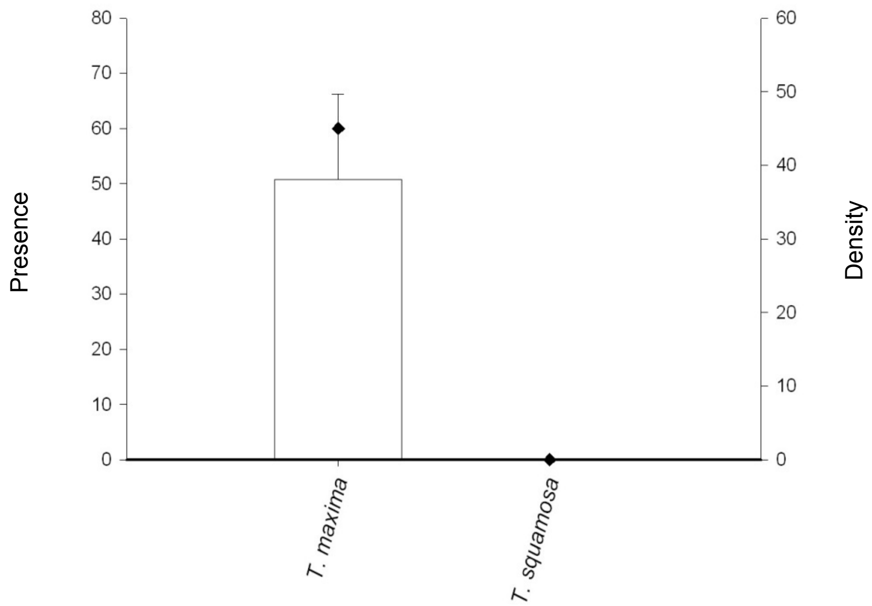

Figure 2.30: Presence and mean density of giant clam species in Ha'atafu based on fine-scale survey.
Presence is measured as % of stations surveyed where clams were present and denoted by black diamonds; density is measured in numbers per hectare and is represented by bars (+SE).

In general, clams were uncommon at Ha'atafu, with four of the ten RBt stations holding no records of clam and the highest station average density being just 83 /ha. At best this represents just two clams in six transects of 40 m^2.

From a total of 52 clam records taken for all assessment techniques at Ha'atafu, 20 length recordings were made. The average length of *T. maxima* clams taken in surveys was 11.0 cm ±1.1 (n = 16), which represents a clam of greater than five years old (See Figure 2.31.). Only four *T. squamosa* (which grow to an asymptotic length L_∞ of 40 cm) were noted and the average length from the three measured was 18.0 cm ±6.7. These clams are faster growing and an 18 cm *T. squamosa* is probably around 4–5 years of age.

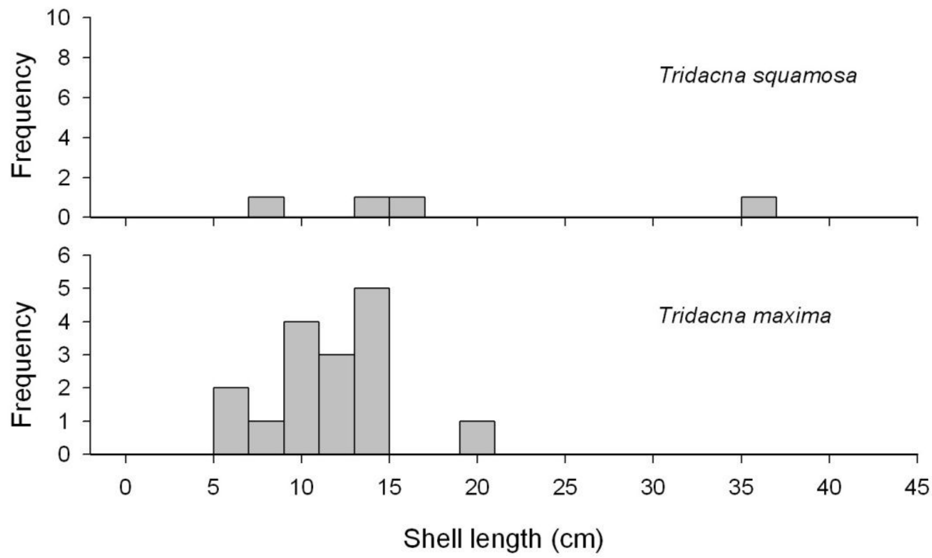

Figure 2.31: Size frequency histograms of the giant clams *Tridacna squamosa* and *T. maxima* shell length (cm) for Ha'atafu.

Small *T. maxima* (<10 cm in length) were recorded at Ha'atafu, which shows that recruitment is still occurring, although large *T. maxima* clams (≥16 cm) were not common (See Figure 2.31.). Size records for *T. squamosa* show both small and mature size classes.

2.4.2 Mother-of-pearl species (MOP) – trochus and pearl oysters: Ha'atafu

Tongatapu is the largest and main island of the Tonga archipelago. Tongatapu lies 21°S and 175°E, which is outside the east–west range of the commercial topshell *Trochus niloticus* (found naturally on islands as far east as Wallis). As in other eastern Pacific islands, commercial mother-of-pearl shells have been moved to Tongatapu from countries with endemic stocks.

After the successful translocation and establishment of trochus and green snail (*Turbo marmoratus*) in Cook Islands and French Polynesia in the 1950s, the Tongan government requested assistance for the introduction of these species. As Tonga is situated just east of the natural distribution range of *Trochus niloticus* and there was success in translocating stocks to the Cook Islands and French Polynesia, it was logical to think there may be success with movement of this species to Tonga. The first translocation was carried out in August 1992, when 250 wild trochus broodstock were brought in from Fiji's Lau Group and released on Tabana Island in the Vava'u Group (Gillett 2002). In May 1994, another 1092 trochus shells were donated to Tonga again by Fiji; these were released on Tongatapu, although some were retained for breeding purposes in the hatchery (Table 2.14).

Prior to the releasing of the shells, a habitat-suitability survey was conducted at 17 sites around Tongatapu (Sone 1992). Eighty per cent of the sites assessed on the north-facing side of Tongatapu, which covered fringing reefs, islet reefs, patch reefs and barrier reefs, and on the island of Eueiki, recorded the presence of potential index species, such as *Turbo argyrostomus*, *T. setosus* and *T. crassus* (Sone 1992). The presence of *Turbo* and *Tectus* species was used as an index for suitable trochus habit and sites were selected as release areas for the introduced adult trochus and green snail (Sone 1992).

The sites at the 'Liku coast' (*liku* meaning cliff) on the southwest, south and southeast coast of the island are highly exposed to strong waves and reef habitat here was limited by the narrow fringing reefs. The barrier-reef front off Fukave islet and the reef around the island of Eueiki were selected for the release of green snails. Both sites have characteristically good habitat of extended reef front, clean water and good wave action and are relatively far away from the mainland.

In May 1994, 500 shells were released at the front of the barrier reef at Fukave island. The other 400 shells were released at Eueiki island, an offshore island off Fukave island. The record of adult trochus releases is summarised in Table 2.14.

Table 2.14: Summary of imported broodstock *Trochus* released in Tonga

Date	Origin	Number	Alive	Release/sites
8/1992	Fiji	250	250?	250 – Tapana Island, Vava'u (untagged)
5/1994	Fiji	1092	1046	-
11/5/94				400 – Fukave, Tongatapu (tagged)
11/5/94				400 – Eueiki, Tongatapu (tagged)
30/5/94				100 – Fukave, Tongatapu (tagged, 140 – for breeding in hatchery)

Gillett 2002; Manu *et al.* 1995; Fa'anunu and Kikutani 1994; Loto'ahea *et al.* 2000.

Release of hatchery-produced trochus

The Tonga Fisheries mariculture programme was implemented under the JICA/Tonga Aquaculture Research and Development project, a five-year project that began in 1991. During the project period, a full hatchery facility was constructed on Tongatapu and necessary training on hatchery management and shellfish seed production was implemented for aquaculture species, including MOP species and clams. The objective of the mariculture programme was to support the transplantation of trochus and green snail juveniles to local reefs. Artificial breeding of trochus shells in the hatchery took three years before the first batch of seeds was ready for release at the average size of 50 mm shell basal diameter. The first batch of juveniles was released at unknown sites in Ha'apai and Vava'u in 1998. A further eight releases were done from 1999 to 2003, one in Ha'apai and the rest on reefs around Tongatapu and Eueiki (Table 2.15). The minimum size of juveniles released was 50 mm. According to the records available, there are no recapture data nor any anecdotal information on the survival of released juveniles.

Table 2.15: Summary of hatchery-produced *Trochus* released in Tonga

Year	Released site	Released (number)	Released size (mm)
1998	Ha'apai Vava'u	350 380	50 + 50 +
1999	Ha'apai	450	50 +
2000	Fukave, Tongatapu Ha'apai	350 500	50 + 50 +
2001			
2002	Ulanga Lalo, Tongatapu Atata Island, Tongatapu	400 400	50 + 50 +
2003	Ulanga lalo, Tongatapu	600	50 +

Gillett 2002; Manu *et al.* 1995; Fa'anunu and Kikutani 1994; Loto'ahea *et al.* 2000; Tonga Fisheries Annual Report for 2003.

The reef in the lagoon front of Ha'atafu constitutes an extensive benthos for *T. niloticus* and records show (Table 2.16) that introductions of adult shell have been sufficient to build up a moderate level of stock and to create the conditions suitable for the formation of a fishery in the medium-term future.

PROCFish survey work located 799 live *T. niloticus* at Ha'atafu (Table 2.16). The mean size (basal width) of *T. niloticus* was 9.3 cm ±0.1 (n = 482 individuals). Trochus shell sizes at Ha'atafu had a good range of small (<7 cm basal width) and large (>11 cm) sized shells. For this cryptic species, younger shells are normally only picked up in surveys from the size of about 5.5 cm, when small trochus are emerging from a cryptic style of life and joining the main stock. Therefore, it is normal to find only a few of these smaller-sized trochus; however, in Ha'atafu smaller shells were evident (13% of the measured stock, see Figure 2.32). Shells within the capture size classes (~8–11cm) made up 54% of the population, while shells larger than 11 cm, which have a very large capacity to produce gametes to produce future generations of trochus, made up 20% of the results. These results indicate that the stocks at Ha'atafu have a 'good' spread of shell sizes, which is promising for the future development of this potential fishery.

Tectus pyramis, a closely related gastropod, was also recorded (n = 47 individuals). The average size was 7.7 cm ±0.3 (n = 15 individuals). This less valuable species of topshell (also an algal grazer, with a similar life history to trochus) was not as common as trochus at Ha'atafu.

Table 2.16: Presence and mean density of *Trochus niloticus*, *Tectus pyramis* and *Pinctada margaritifera* in Ha'atafu
Based on various assessment techniques; mean density measured in numbers per ha (±SE)

	Density	SE	% of stations with species	% of transects or search periods with species
Trochus niloticus				
B-S	0.2	0.2	1/12 = 8	1/71 = 1
RBt	0	0	0/10 = 0	0/60 = 0
RFs	207.1	105.2	5/7 = 71	42/57 = 74
MOPt	772.6	177.1	8/8 = 100	55/57 = 96
MOPs	6.7	6.7	1 / 3 = 33	3/24 = 13
Tectus pyramis				
B-S	0	0	0/12 = 0	0/71 = 0
RBt	76.8	22.2	8/10 = 80	13/60 = 22
RFs	6.8	3.5	4/7 = 57	9/57 = 6
MOPt	0	0	0/8 = 0	0/57 = 0
MOPs	25.3	18.2	2 / 3 = 66	6/24 = 25
Pinctada margaritifera				
B-S	2.4	1.1	5/12 = 42	10/71 = 14
RBt	0	0	2/10 = 0	0/60 = 0
RFs	0.4	0.4	1/7 = 14	1/57 = 2
MOPt	0	0	0/8 = 13	0/57 = 2
MOPs	0	0	0/3 = 0	0/24 = 0

B-S = broad-scale survey; RBt = reef-benthos transect; RFs = reef-front search; MOPt = mother-of-pearl transect; MOPs = mother-of-pearl search.

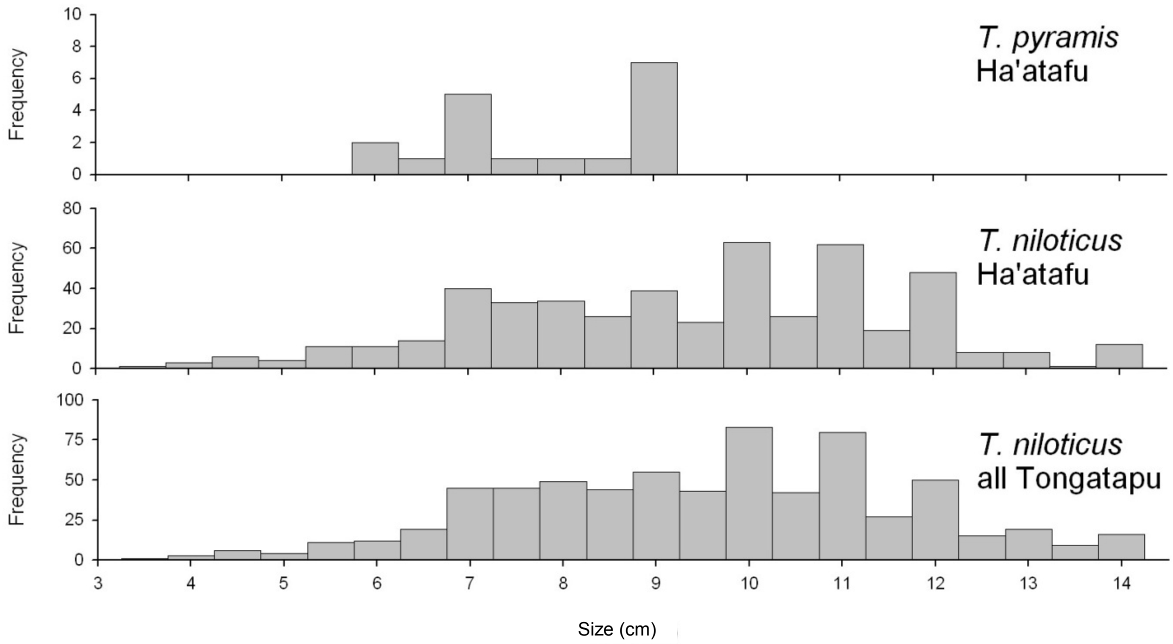

Figure 2.32: Size frequency histograms of trochus (*Trochus niloticus*) and 'false' trochus (*Tectus pyramis*) shell base diameter (cm) for Ha'atafu.

Green snail (*Turbo marmoratus*) juveniles were also stocked on to the reefs in Tongatapu, although there is little information about the locations where they were released. In surveys, only a single *T. marmoratus* was recorded, but this was in the east of the lagoon, on Fukave reef, associated with another PROCFish site (the village of Manuka).

Blacklip pearl oysters (*Pinctada margaritifera*) are normally cryptic and sparsely distributed in open lagoon systems. However, the dynamic through-flow of water at the complex reef system in front of Ha'atafu presented suitable shallow-water reef for this species (a total of n = 13 individuals recorded). The average density of this species never exceeded 35 /ha for any single broad-scale transect (and was 2.4 /ha ±1.1 overall in broad-scale surveys).

2.4.3 Infaunal species and groups: Ha'atafu

Fine-scale infaunal stations on soft benthos (quadrat surveys) were made at Ha'atafu to get a signal from species groups within the soft benthos. This type of coastal margin was common to the east of the headland where the village of Ha'atafu was located, and comprised extensive areas of seagrass (with coral-rubble outer margins). Concentrations of in-ground resources (shell 'beds'), such as arc shells (*Anadara* spp. called *kaloa'a*), were not identified, but fishers ranged widely to collect them when searching for the sea cat *Dolabella auricularia*.

Locations sampled for in-ground species showed that arc shells were not common in Ha'atafu (2 of 11 stations held *Anadara*). This species was recorded at a mean station density of 0.1 ±0.1 individuals/m^2. At the two stations where *Anadara* spp. were recorded, shells were only noted in two of the eight quadrat groupings (See Methods.).

Arc shells (*Anadara* spp.) were also present in most catches, but again did not make up a large part of the catch; they were only being specifically targeted in small, shallow-water sand patches in the seagrass, where the telltale 'slit' of the inhalent siphon could be seen when the water surface was still (*fakamata* – spotting by observation). Fishers often chewed coconut, which was periodically spat onto the water in front of the fisher (*fakatofu* – to make calm), to smooth the surface and facilitate this type of searching. Catch rates at Ha'atafu averaged 13.8 individuals/hour ±1.8 (n = 4 fishers).

The average shell length of *kaloa'a* (*Anadara antiquata*) was small at 5.7 cm ±0.1 (n = 5) at Ha'atafu. The average length of all gleaned *Anadara* spp. significantly exceeded ($F_{4.233}$ = 37.8, P = 0.001) those sold in Nuku'alofa market which had a mean shell length of 4.9 cm ±0.07 (n = 128) (generally sourced from the Patangata and Popua areas).

Although infaunal species were not assessed within soft-benthos transect surveys, some adult *Anadara* shells were also noted on the surface of the substratum. Detection rates in this style of survey are undoubtedly an underestimate, but the average density was 18.3 individuals/ha ±7 (n = 13 stations) for Ha'atafu.

The main invertebrate species collected by fishers at Ha'atafu was typically the dolabellid sea cat, *Dolabella auricularia* (locally called *mulione*, or *ngou'a* when it is smoother-skinned and generally smaller, see Figure 2.33). *D. auricularia* is herbivorous and well camouflaged, remaining cryptic during the day, burrowed just under the surface of the substrate or under rubble or within indentations and hollows. Although part of its dorsal surface (inhalant-siphon opening in the mantle folds) remains partially emerged, its visibility is usually obscured by seagrass or debris around the burrowed animal.

Figure 2.33: *Dolabella auricularia*, locally called *ngou'a* (left) and *mulione* (right) in Ha'atafu.

Fishers locate *D. auricularia* by feel (using the foot) or by prodding depressions in the tidal flat substrate (called *umu umu* or, if a deeper indentation, *pangoa*) with a metal rod (usually a piece of sharpened reinforcing bar). Although it is referenced as growing to 40 cm in length, in Tongatapu *D. auricularia* was typically harvested at ~16 cm. Post-harvest processing occurs at the place of capture as *D. auricularia* releases large amounts of purple dye on capture. The bulk of the animal is discarded after processing, the processed portion being ~36% of its caught weight.

Collected *D. auricularia* individuals were segregated by the fishers into *mulione* and *ngou'a*, the latter having a smaller size, smoother skin and different processing requirement as the foot is less tough (holds less sand) and therefore can be retained for eating. The processed portion of *D. auricularia* included the liver, parts of the intestine and the red-coloured buccal mass (The foot in *mulione* and dorsal sections with some viscera are discarded.). Quinn and Davis (1997) reported a lower percentage of *D. auricularia* retained; 19% retention from fishing in Fiji Islands. The soft, visceral parts of *D. auricularia* are kept for eating and usually carried along with the egg masses ('vermicelli'-like string masses, called *te'efihifihi*), which are found in clumps attached to seagrass in close proximity to the burrowed adults (See Figure 2.34.).

Figure 2.34: *Dolabella auricularia* foot and edible parts with string-like egg mass (also edible) in Ha'atafu.

Average catch rates for this species were 10–16 pieces/hour (13.8 ±3.3, n = 14 fishers) although dedicated dolabellid fishing yielded an average of 35 pieces/hour at Ha'atafu (n = 2 fishers). The general catch rate at the extensive seagrass beds was 16.0 pieces/hour ± 4.3

(n = 4 fishers). As a point of comparison, Quinn and Davis (1997) recorded catch rates of ~24 pieces/hour for non-replicated observations in Fiji Islands. There was a significantly higher CPUE at Ha'atafu than at the easterly PROCFish site of Manuka ($F_{2.11}$ = 4.05, P = 0.5).

Detection rates of *D. auricularia* in survey transects were moderately high in Ha'atafu (found in 85% of soft-benthos transect stations, 51% of transects). Densities were recorded at an average of 289.4 individuals/ha ±69.4 (n = 13 stations), with a maximum average density at one site of 761.9 individuals/ha ±95 for a single station (n = 6 transects). These would be minimum densities due to the fact that fully buried individuals would not have been detected by this type of assessment. Note that *D. auricularia* is the source of Dolastatin 10 and 15, which are small peptides shown to be potential inhibitors of cell growth in human ovarian and colon-carcinoma cell lines. Anti-cancer research using these molecules is ongoing.

Mussels (*Modiolus* spp., *kuku*) were not recorded in seagrass patches in Ha'atafu, but fishers collected small amounts (0.12 individuals/hour recorded in creel surveys). Close to the low-tide mark among the sand and coral stone/limestone platform can be found *Tellina* (*quidnipagus*) *palatam* (*mehingo*) at both Ha'atafu and Manuka. This species is also not preferentially targeted in Tongatapu, possibly due to the difficulty of finding patches of clear sand (without stone pieces to hamper digging). Other species were also collected during soft-benthos gleaning (*Fragum* and the faceless *Calappa* crab). Octopus (*Octopus cyanea*) was also much sought after by gleaners, but collection rates were not high on regularly fished seagrass areas near villages. From the observed gleaning of seagrass (total of 42 hrs 40 mins fisher time) only one octopus was taken.

2.4.4 Other gastropods and bivalves: Ha'atafu

Tongan fishers have over 203 names for marine invertebrates and 87 for molluscs (Malm 1999). Seba's spider conch *Lambis truncata* (the larger of the two common spider conchs) was not recorded in shallow-water broad-scale transects. In Ha'atafu, *L. lambis* (n = 23) were relatively common (recorded in B-S, RBt and RFs stations) and this species is often the first on the list of primary *fingota* (shellfish) taxa (called *anga anga* locally; see Malm 1999). At the Ha'atafu seagrass area only one *Lambis* specimen was collected in 13 hrs 15 min of fishing (n = 6 fishers) and this was at the eastern margin of the seagrass, distant from the village. In less controlled observations of invertebrate gleaning conducted west of Atata island, interviews and inspection of catches taken from seagrass and *Halimeda* shallows also held no *L. lambis* (4.5 hours of gleaning, n = 3 fishers). The average density of *L. lambis* at Ha'atafu seagrass was very low (none found in transects) at 4.8 individuals/ha ±4.8 (n = 10 RBt stations). Another important resource species, the strawberry or red lipped conch *Strombus luhuanus* was also not recorded at Ha'atafu, but *Strombus gibberulus gibbosus* was commonly noted in soft-benthos infaunal quadrats (40% of quadrat groups; see Methods and Appendices 4.1.2 to 4.1.9).

In addition to the single *Turbo marmoratus*, a full range of small turban shells were recorded (e.g. *T. crassus*, *T. argyrostomus*, *T. chrysostomus* and *T. setosus*). In quantity, the phenotypically similar *T. crassus* and *T. argyrostomus* were relatively common (n = 61 individuals noted). In three reef-benthos transect survey stations on the reef platform east of Ha'atafu, where water movement was very dynamic, the density of these turban species was relatively high. At this site, the station that was closer inshore held fewer *T. crassus* and *T. setosus*, while the station most greatly exposed and influenced by wave action held fewest of the smaller gold-mouthed *T. chrysostomus* (Table 2.17). The average size of *T. crassus* was 6.8 cm ±0.3, *T. argyrostomus* was 6.1 cm ±0.1, *T. setosus* was 5.7 cm ±0.1, whereas *T. chrysostomus* was the smallest at 4.5 cm ±0.1.

Table 2.17: Density per ha of *Turbo* spp. turban shells on the reef platform east of Ha'atafu

	T. argyrostomus	*T. chrysostomus*	*T. crassus*	*T. setosus*
Reef_Benthos_Transect_1	47.6	1619.0	0.0	0.0
Reef_Benthos_Transect_2	666.7	95.2	285.7	0.0
Reef_Benthos_Transect_3	381.0	0.0	476.2	3476.2

Other gastropod resource species targeted by fishers (e.g. *Astralium*, *Conus*, *Cryptoplax*, *Cypraea*, *Latirolagena*, *Mitra*, *Ovula*, *Pleuroploca*, *Polinices*, *Thais* and *Vasum*) were also recorded during independent surveys (Appendices 4.1.1 to 4.1.9). The taking of chitons, *Acanthopleura gemmata* from the shoreline and *Nerita polita* from rocky outcrops further from the shoreline is practised around Ha'atafu. In a search of suitable habitat for *A. gemmata* behind the reef platform west of Ha'atafu village (a 510 m stretch of limestone rock) only five live *A. gemmata* were found. *Nerita polita* was also rare, with the less desirable *Nerita plicata* and *N. albicilla* present.

There did not seem to be an active beach fishery for surf clams and *pipi* in Ha'atafu, but data on other bivalves in broad-scale and fine-scale benthos surveys, such as *Atrina*, *Chama*, *Fragum*, *Pinna* and *Spondylus* spp. are also in Appendices 4.1.1 to 4.1.9.

Creel surveys were conducted at Ha'atafu, both on soft and mixed benthos at the front of the village (7 fishers, 14 hours 15 mins total fishing time), and at Atata island (2 fishers, 2 hours 30 mins total; see Appendix 4.1.12), where sea cucumbers were being harvested.

2.4.5 Lobsters: Ha'atafu

Ha'atafu had extensive areas of exposed reef front (barrier reef). This exposed reef, with exposed reef platforms and submerged reef slopes, represents a large amount of habitat for lobsters. Lobsters are unusual invertebrate species that can recruit from near and distant reefs as their larvae drift in the ocean for 6–12 months (up to 22 months) before settling as transparent miniature versions of the adult (*pueruli*, 20–30 mm in length).

Although there was no dedicated night reef-front assessment of lobsters (See Methods.), surveys of the shallow and deep water (for sea cucumbers) were a potential source of lobster recordings. Despite the large amount of time spent surveying Tongatapu, only a single juvenile lobster, *Panulirus* sp., was noted.

2.4.6 Sea cucumbers[6]: Ha'atafu

Ha'atafu had extensive areas of shallow-water lagoon with complex reef structure and a range of soft-benthos areas bordering the large land mass of Tongatapu. A full range of protected, richer, depositional areas (land influence) were found within the lagoon to the east

[6] There has been a recent variation to sea cucumber taxonomy which has changed the name of the black teatfish in the Pacific from *Holothuria (Microthele) nobilis* to *H. whitmaei*. There is also the possibility of a future change in the white teatfish name. This should be noted when comparing texts, as in this report the 'original' taxonomic names are used.

of Ha'atafu, and more exposed, oceanic-influenced areas were present to the north and west. Fringing reef margins, reef slopes and areas of shallow, mixed hard- and soft-benthos habitat were largely very suitable for commercial sea cucumbers, which are generally deposit feeders (and eat organic matter in the upper few mm of bottom substrates).

Species presence and density were determined through broad-scale and fine-scale surveys (Table 2.18, Appendices 4.1.2 to 4.1.9, also see Methods.). In addition to the standard protocol for sampling, a special, additional sampling protocol was conducted at Ha'atafu in response to a request from the Tonga government. To assist in this endeavour, extra staff from Solomon Islands (Mr Chris Ramofafia and Mr Peter Ramohia, both co-funded by the Australian Centre for International Agricultural Research, ACIAR) and Mr Paul Lokani from Papua New Guinea (funded by SPC) took part in the surveys, and extra deep-water surveys (outside the general scope of PROCFish) were completed on SCUBA (Friedman *et al.* 2004).

A short history shows that, prior to encouraging exploitation in the early 1990s, the Tonga Fisheries Division, with technical assistance from the SPC Inshore Fisheries Research Project, evaluated the status of the resource in the Ha'apai group, an area of primary interest to the Fisheries Division (Preston and Lokani 1990). Another survey was done with the assistance of the SPC ICFMaP project in 1996, at which time the Ministry of Fisheries (as it was known by then) responded to the apparent decline in stocks by setting a zero quota on all sea cucumber exports to preserve the fishery. The Act provided for a 10-year moratorium, but also called for a 5-year review of stocks to advise on their recovery and status. This extra work constitutes part of this review.

Results from most of the individual survey methods are separated for the two PROCFish sites in Tongatapu (Ha'atafu and Manuka). The species list for Ha'atafu returned 20 commercial species of sea cucumbers from all in-water assessments (plus one indicator species, see Table 2.18). The range of sea cucumber species recorded reflects both the variable nature of the habitats present in Ha'atafu and the level of management control that has been enforced over the fishery.

Sea cucumber species associated with shallow-reef areas, such as the medium-value leopardfish (*Bohadschia argus*), were common (found in 55% of broad-scale transects) but only in 20% of reef-benthos transect stations. The average density recorded was also moderately high at an average above 23.3 /ha in broad-scale survey. In shallow reefs the density was never high, although most of these sites were subject to a high level of oceanic influence.

Stocks of high-value sea cucumbers, such as the black teatfish (*Holothuria nobilis*), which is also found in shallow reefs and is therefore easily targeted by fishers, were not common at Ha'atafu. Although they were only recorded in 4% of broad-scale transects, they were also noted at similar density in RFs stations. Wherever they were noted, black teatfish were at low average density (<2 /ha). There is some evidence that this species is highly susceptible to fishing pressure and, once depleted, can take years to recover to reasonable densities of >10 /ha. It is possible that previous heavy fishing around Tongatapu could still be impacting the viability of stocks at Ha'atafu. Sea cucumbers are single-sexed and release their eggs and sperm into the water column for fertilisation (broadcast spawners). Stocks such as black teatfish that are generally found at lower density ranges are susceptible to the negative effects that occur when overfishing decreases stock density, because reproduction success is decreased when individuals become too widely dispersed for the fertilisation of gametes to be maximised (See Figure 2.35.).

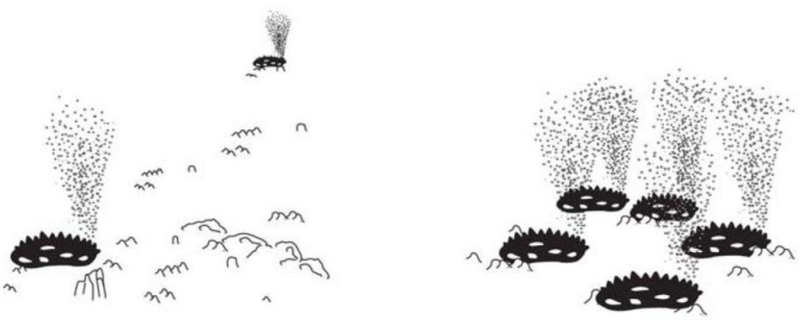

Figure 2.35: A diagrammatic representation showing individual black teatfish sea cucumbers both widely separated from each other (left), and close to conspecifics (right) during release of eggs and sperm.
Gametes need to meet in the water column to successfully form the larvae of a new sea cucumber.

The faster-growing and medium/high-value greenfish (*Stichopus chloronotus*) was more common (in 51% of broad-scale transects) and was also noted in most assessments (MOPs, MOPt and RFs) but the density was only moderate (generally <50 /ha; mean density in broad-scale transects was 26.9 ±8.1 /ha).

Surf redfish (*Actinopyga mauritiana*) were recorded at high density in Ha'apai but, although many reefs at Ha'atafu were especially suitable for this species (reefs of high complexity with rich epiphytic algae growth), the presence was low (1% of broad-scale transects). This species can be recorded at commercial densities of 500–600 /ha in oceanic-influenced and atoll islands in French Polynesia and Solomon Islands, but densities locally at Ha'atafu were not high (<10 /ha).

More protected areas of reef and soft benthos in depositional lagoon embayments were seen east of Ha'atafu village. We recorded reasonable coverage but low numbers of blackfish (*Actinopyga miliaris*), stonefish (*A. lecanora*) and elephant trunkfish (*Holothuria fuscopunctata*) across the site, and they were generally at low-to-moderate density. Curryfish (*Stichopus hermanni*) were moderately common, being recorded in 32% of transects at a low-to-moderate density of 8.7 /ha.

One higher-value species of great importance to Tonga is the golden sandfish, which is presently called *Holothuria scabra versicolor* (This scientific Latin name has changed very recently to *Holothuria lessoni* but, to maintain consistency in the reports, we still use the previous name.). This species is concentrated at only a few locations in the shallow-water seagrass fringing the harbour areas of Tongatapu and marginally around the seagrass east of Ha'atafu. We are not sure how this coverage reflects the original range for this species before large-scale harvests severely depleted stocks in the early 1990s. However, despite its often cryptic nature in the seagrass and rubble, it was still noted in 1% of broad-scale transects, at a low average density of 0.2 /ha.

Anecdotal reports from a marine produce agent who was buying product in Tongatapu at the time the fishery was most active (currently residing in Vanuatu) state that product was going out in large tonnages during the peak of the fishing activity. Initial survey results suggest that stocks of this species have not recovered to anywhere near the previous numbers suggested from these anecdotal reports.

Some lower-value species, e.g. lollyfish (*Holothuria atra*), pinkfish (*H. edulis*) and brown sandfish (*Bohadschia vitiensis*), were noted at moderate-to-high coverage and moderate density. Lollyfish is likely even more common in very shallow water not targeted by the surveys, on the margins of the main island of Tongatapu.

Gleaners fished five holothurian species in the seagrass areas around the more eastern PROCFish site of Manuka, but no records were collected at Ha'atafu. *Bohadschia vitiensis*, a species fished, was found in survey, as was *Stichopus horrens*, which was actively targeted at the lagoon bordering the west of Atata island. Here, catch rates were high at 138.2 individuals/hour ±37 (n = 3 fishers) and fishers collected or cut animals *in situ* that were <11 cm in length.

Mid-water and deep-water assessments were conducted using a broad-scale system on SCUBA to augment the main survey work conducted in Ha'apai (Friedman *et al.* 2004). In these surveys, six deep-water transects (100 m length, 4 m width, depth range 20–40 m, average depth 27 m) and six medium-water transects (100 m length, 4 m width, depth range 10–20 m, average depth 14 m) were completed to obtain a preliminary abundance estimate for white teatfish (*Holothuria fuscogilva*), prickly redfish (*Thelenota ananas*), amberfish (*T. anax*) and partially for elephant trunkfish (*H. fuscopunctata*) (Appendices 4.1.3). Oceanic-influenced benthos in the areas between reefs, at the foot of reef slopes and in passages had suitably dynamic water movement for these species and a single white teatfish was noted. Surveys also noted *Actinopyga echinites*, *A. miliaris* (likely *A. palauensis*), *Bohadschia argus*, *H. edulis*, *T. ananas* and *T. anax*.

2.4.7 Other echinoderms: Ha'atafu

The edible collector urchin *Tripneustes gratilla* was present and recorded in small numbers in independent surveys (n = 5 individuals). This urchin, also known as the pincushion or hairy urchin (*tukimisi*), is generally cryptic, covered with pieces of seagrass, and only located by feel (foot, metal rod) and by recognition of the unusual clumping of seagrass fronds that can characterise its position. The spines on *T. gratilla* are short and sufficiently blunt to allow handling. Collection rates were 5.76 individuals/hour ±2.2 (n = 5 fishers) at Ha'atafu. Average densities of pincushion urchins recorded in soft-benthos transect surveys at Ha'atafu showed that their distribution was wide-ranging (12 of 13 stations) and at reasonable density 106.2 ±21 /ha (n = 13 stations). Data collected on the sizes of *Tripneustes* among sites reveals that urchins were significantly smaller at Ha'atafu (77.4 mm test ±2.1, n = 5) than at Onevai (84.5 mm test ±0.8, n = 106). There did not seem to be any selectivity in the size of urchins for collection; there was no significant difference in size between pincushion urchins collected by fishers and those found in independent surveys.

Slate urchins *Heterocentrotus mammillatus* were more common (n = 847), being recorded in 33% of broad-scale stations, 70% of RBt stations and 57% of RFs stations. The average density of these urchins across the oceanic-influenced reef-benthos transect stations was high (1287.5 ±595.5 /ha). Other urchins that can be used as a food source or potential indicators of habitat condition (*Diadema* spp., *Echinothrix* spp. and *Echinometra mathaei*) were also recorded, with *E. mathaei* noted at high density in some locations, with one station reaching a mean density over 6000 /ha (overall RBt station average 2171.4 ±920.2 /ha). The large, black

Echinothrix species (*E. diadema* and *E. calamaris*) were not as common (recorded in 20% of RBt stations, with a mean station density below 50 /ha; see Appendices 4.1.2 to 4.1.9).

Starfish were well represented at Ha'atafu. The common blue starfish *Linckia laevigata* was recorded in 25% of broad-scale transects, and pincushion stars *Culcita novaeguineae* had a similar coverage (24% of broad-scale transects). *L. laevigata* was at low-to-moderate density (mean of 25.4 /ha for broad-scale stations). *Culcita* was at far lower density (13.8 /ha in broad-scale survey) as was another coralivore (coral eating) starfish, the crown-of-thorns starfish (*Acanthaster planci*, mean of 0.8 ±0.4 /ha). Although this coral-eating starfish was rare in broad-scale searches, a total of 27 individuals were noted, predominantly west of Atata Island and on the barrier reefs west of the lagoon (north of Ha'atafu; see presence and density estimates in Appendices 4.1.2 to 4.1.9). Other starfish recorded included *Archaster typicus*, a star found in shallow-water sandy areas, and both *Choriaster granulatus* and *Protoreaster nodosus*, which are both found in deeper and shallow water.

Table 2.18: Sea cucumber species records for Ha'atafu

Species	Common name	Commercial value [5]	B-S transects n = 71			Other stations RBt = 10; SBt = 13			Other stations RFs = 7			Other stations MOPt = 8, MOPs = 3		
			D [1]	DwP [2]	PP [3]	D	DwP	PP	D	DwP	PP	D	DwP	PP
Actinopyga echinites	Deep-water redfish	M/H	0.5	16.7	3				0.9	3.1	29			
Actinopyga lecanora	Stonefish	M/H	1.1	26.7	4							2.6	20.8	13 MOPt
Actinopyga mauritiana	Surf redfish	M/H	0.2	16.7	1	8.9	44.6	20 RBt						
Actinopyga miliaris	Blackfish	M/H	1.6	28.1	6									
Actinopyga palauensis	Blackfish	M/H												
Bohadschia argus	Leopardfish	M	23.3	42.3	55	8.3	41.7	20 RBt	15.1	35.1	43	2.6 62.3	20.8 93.4	13 MOPt 67 MOPs
Bohadschia similis	False sandfish	L	0.7	25.1	3	23.9	63.5	15 SBt						
Bohadschia vitiensis	Brown sandfish	L	30.1	66.8	45	8.3 14.7	83.3 95.2	10 RBt 15 SBt						
Holothuria atra	Lollyfish	L	563.5	869.7	65	203.0 326.0	529.5 423.8	80 RBt 77 SBt	21.4	49.9	43	5.2 114.5	41.7 171.7	13 MOPt 67 MOPs
Holothuria coluber	Snakefish	L	465.8	1067	44	12.5	41.7	30 RBt						
Holothuria edulis	Pinkfish	L	781.1	1180	66	75.0 7.3	250.0 47.6	30 RBt 15 SBt	4.8	33.7	14	10.4 3.4	83.3 10.1	13 MOPt 33 MOPs
Holothuria fuscogilva [4]	White teatfish	H	Noted in deep-water surveys (1 individual)											
Holothuria fuscopunctata	Elephant trunkfish	M	3.5	20.8	4									
Holothuria leucospilota	Black threads fish	H	21.3	108	20	25.6	111.1	46 SBt						
Holothuria nobilis [4]	Black teatfish	H	1.3	30.2	17				1.7	5.9	29			
Holothuria scabra versicolor	Golden sandfish	H	0.2	12.7	1	7.3	95.2	8 SBt						
Stichopus chloronotus	Greenfish	H/M	26.9	53.1	51				20.7	36.2	57	16.5 50.5	66.0 50.5	25 MOPt 100 MOPs
Stichopus hermanni	Curryfish	H/M	8.7	26.8	32									
Stichopus horrens	Peanutfish	M/L	2.8	66.7	4									
Synapta spp.	-	-	0.2	16.7	1	95.2	154.8	62 SBt						
Thelenota ananas	Prickly redfish	H	1.3	18.8	7				0.8	5.7	14			
Thelenota anax	Amberfish	M	1.7	30.0	6									

[1] D = mean density (numbers/ha); [2] DwP = mean density (numbers/ha) for transects or stations where the species was present; [3] PP = percentage presence (units where the species was found); [4] the scientific name of the black teatfish has recently changed from *Holothuria* (*Microthele*) *nobilis* to *H. whitmaei* and the white teatfish (*H. fuscogilva*) may have also changed name before this report is published. [5] L = low value; M = medium value; H= high value; H/M is higher in value than M/H; B-S transects= broad-scale transects; RBt = reef-benthos transect; SBt = soft-benthos transect; RFs = reef-front search; MOPt = mother-of-pearl transect; MOPs = mother-of-pearl search.

2.4.8 Discussion and conclusions: invertebrate resources in Ha’atafu

A summary of environmental, stock status and management factors for the main fisheries is given below. Please note that information on other, smaller fisheries and the status of less prominent species groups can be found within the body of the invertebrate chapter.

In summary, data on giant clam habitat, distribution, density and shell size suggest that:

- The reefs at Ha’atafu provided extensive areas of limestone and coral benthos, with a range of shallow-water lagoon habitats that were suitable for many of the giant clam species group. Water movement was dynamic and there was a range of land- and oceanic-influenced habitat, which afforded giant clam populations a range of exposure grades.

- Only two species of giant clam were recorded at Ha’atafu (the elongate clam *Tridacna maxima* and the fluted clam *T. squamosa*). The smooth clam (*T. derasa*) and the devil’s clam (*T. tevoroa*) are present in Tonga but were not noted in these surveys. Tongatapu is one area that supported the bear’s paw clam (*Hippopus hippopus*) until the mid 1970s, although the species is now extinct in Tonga.

- Giant clam coverage across the study area was noticeably disrupted and there was only a small number of clams close to Ha’atafu. In fact, the total number of clams recorded in both broad-scale and reef-benthos transects was not high. The densities of clams recorded at Ha’atafu are indicative of an impacted clam fishery.

- *T. maxima* displayed a ‘full’ range of size classes, including young clams, which indicates successful spawning and recruitment, but the abundance of large clams was very low, supporting the assumption that clam stocks are largely impacted by fishing.

- As the reef system around Ha’atafu comprises a non-traditional lagoon that is ‘open’ to the east, west and north, fishing is likely to have a greater impact on the sustainability of stocks than in more enclosed lagoon systems, where natural ‘trapping’ of the planktonic larvae of clams is more likely due to longer water residence times (Clam larvae spend up to 12 days in the water column.).

- Giant clams are broadcast spawners that only mature as females at larger size classes (protandric hermaphrodites). This means that, for successful stock management, a percentage of large clams of each species needs to be maintained at high density to ensure that sufficient successful spawning takes place to produce new generations of clams for the fishery. Noting the size profile of clams in Ha’atafu and the generally low concentrations of clams spatially, it is likely that giant clam stocks at this site are in decline.

In summary, data on MOP habitat, presence, distribution, density and shell size suggest that:

- The reefs at Ha’atafu are extensive, largely oceanic-influenced, but with a range of exposure grades and significant land influence in many areas. These characteristics are advantageous for grazing gastropods, as water movement was generally dynamic, and algal food supply on limestone and seagrass surfaces was sufficient for the growth of juveniles and adults.

- The reefs at Ha'atafu are outside the natural range of the commercial topshell, *Trochus niloticus*, but now support this species after successful translocations have been made. Introductions have included the movement of both adults (from Fiji Islands) and juveniles (from the hatchery on Tongatapu). A similar situation exists for green snails, *Turbo marmoratus*, which were also introduced as juveniles from hatchery rearing.

- Trochus (*Trochus niloticus*) and green snails (*Turbo marmoratus*) were both recorded at Ha'atafu. Trochus coverage and density was indicative of a stock that was successfully colonising local reefs. Coverage was good in most relevant surveys, and the density of shells at the better locations had reached an average of over 300 /ha. In the case of MOPt surveys, the average density recorded was 772.6 /ha. No green snails were recorded.

- Size measures of trochus suggest that growth and reproduction of these species is occurring, and that juvenile numbers show good recruitment. At present, juvenile trochus (<7 cm basal width) make up 13% of the population; 54% of the population was in the catch size classes (8–11 cm); and 20% of the population was from large size classes (>11 cm).

- Although there is potential at this time to fish for MOP species in Ha'atafu (Major aggregations should reach 500–600 shells/ha before commercial harvests are considered.), the distribution of trochus reveals that only a few areas (nodes) are well stocked with shells, and it might be useful to allow the numbers to consolidate across the majority of suitable reefs before harvests are considered. It is suggested that ongoing protection is afforded these stocks to allow them to benefit from the increased spawning activity that the high-density base population will provide. Trochus need to be protected to ensure there is a future for this fishery, and stocks may need at least another five years' ongoing protection to allow stocks to build.

- The false trochus or green topshell (*Tectus pyramis*) was noted in Ha'atafu, but were not as common as commercial trochus. This species is also cut for blanks on occasion, but has a far lower value than trochus and produces a much lower grade product and income per shell.

- The blacklip pearl oyster *Pinctada margaritifera* was not uncommon at Ha'atafu. The high-energy environment is likely to have suited the life habit of this species, which is a filter feeder characteristically found in low-nutrient reef environments.

In summary, data on the habitat, distribution and density of sea cucumbers at Ha'atafu reveal that:

- The range of sea cucumber species present at Ha'atafu was high, despite biogeographical influences (the easterly location of Tonga and its relatively isolated position in the Pacific). Protected, shallow-water habitats and more exposed reefs were available in this system, as a range of land and oceanic influences were present.

- Densities of sea cucumbers were greatest in fine-sediment, semi-enclosed lagoonal areas. This was the case to the east of Ha'atafu, where moderate numbers of some species (e.g. leopardfish *Bohadschia argus*) were noted (taking into account the open lagoon, which afforded little protection from periods of rough weather). On the other hand, despite the complete ban on commercial harvesting of holothurians having been in place for seven-to-ten years (depending on when the surveys were completed) some species had not re-built strongly (e.g. black teatfish *Holothuria nobilis* and golden sandfish *H. scabra versicolor*).

- The high-value black teatfish (*H. nobilis*) is usually recorded at lower density (<15 /ha in broad-scale surveys) and after fishing may fall to densities too low for successful reproduction. As sea cucumbers are single-sexed and broadcast spawners, they have to be at high local densities to ensure successful reproduction. A similarly important species, the golden sandfish *H. scabra versicolor*, has also not regained the coverage or density that earlier harvests suggest were present. These two species require careful management to ensure they recover to 'healthy' densities.

- Surf redfish (*Actinopyga mauritiana*) were noted at low density, unlike the situation in Lifuka, Ha'apai, where limestone reef platforms facing the prevailing swell held large numbers. In Ha'atafu, the limestone platform facing west was not holding significant numbers of this species.

- Assessments targeting deeper-water white teatfish stocks (*H. fuscogilva*) were not extensive but, on the one station that was assessed, a single white teatfish was noted. Other deep-water species, such as the lower-value amberfish (*Thelonata anax*), were also noted but at low density.

- Since the 1996 survey, when stocks were shown to be over-fished, the majority of commercial sea cucumber species have again begun to show densities similar to those seen in 1990 (data from serial surveys in Ha'apai). The recovery in density of commercial species since 1996 needs to be tempered with the experience of more highly productive sea-cucumber habitats in other parts of the Pacific, as the low-lying islands and oceanic environment found in areas of Tongatapu present a less-than-optimal and somewhat restricted area for some deposit-feeding resources. Because of these factors, the potential of Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

2.5 Overall recommendations for Ha'atafu

- Ha'atafu and neighbouring communities on Tongatapu be included in the ongoing community-based fisheries management programme.

- Protected zones or no-take marine parks be established to help recovery and maintenance of finfish and invertebrate resources and habitat condition, with appropriate monitoring and enforcement to ensure compliance.

- A monitoring system be set in place to follow any further changes in finfish resources.

- For successful stock management, a percentage of large clams of each species needs to be maintained at high density, to ensure there is sufficient successful spawning taking place to produce new generations of clams for the fishery.

- Ongoing protection be provided to the trochus stocks for at least another five years to enable them to benefit from the increased spawning activity that the high-density base population will provide, thus allowing stocks to rebuild to a minimum of 500–600 shells/ha before commercial harvests are considered.

- The high-value black teatfish (*Holothuria nobilis*) and the golden sandfish (*H. scabra versicolor*) require careful management to ensure they recover to 'healthy' densities.

- The potential of the Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

3. PROFILE AND RESULTS FOR MANUKA

3.1. Site characteristics

Tongatapu is a coral atoll with mean coordinates of 21°10' S and 175°10' W, and a lagoon that has the unusual feature of opening to the north, which gives it the shape of a crescent and should classify it in the 'pseudo lagoon' category. Manuka is located on the eastern side of the lagoon (Figure 3.1). Fishing areas are not clearly defined as the inhabitants conduct 'open-access' fishing. The fishing surface area of the lagoon is about 18.5 km wide and 37 km long and is shared with Ha'atafu and other villages. Around Manuka, a sort of tidal pond bordered by mangroves penetrates the island in an upside-down Y shape. This water is completely filled with microalgae, which indicate poor circulation and give it a greenish hue. Out to sea, a large barrier reef bordered by a few *motu* (small islets) forms an upside-down L over a length of some 22.2 km.

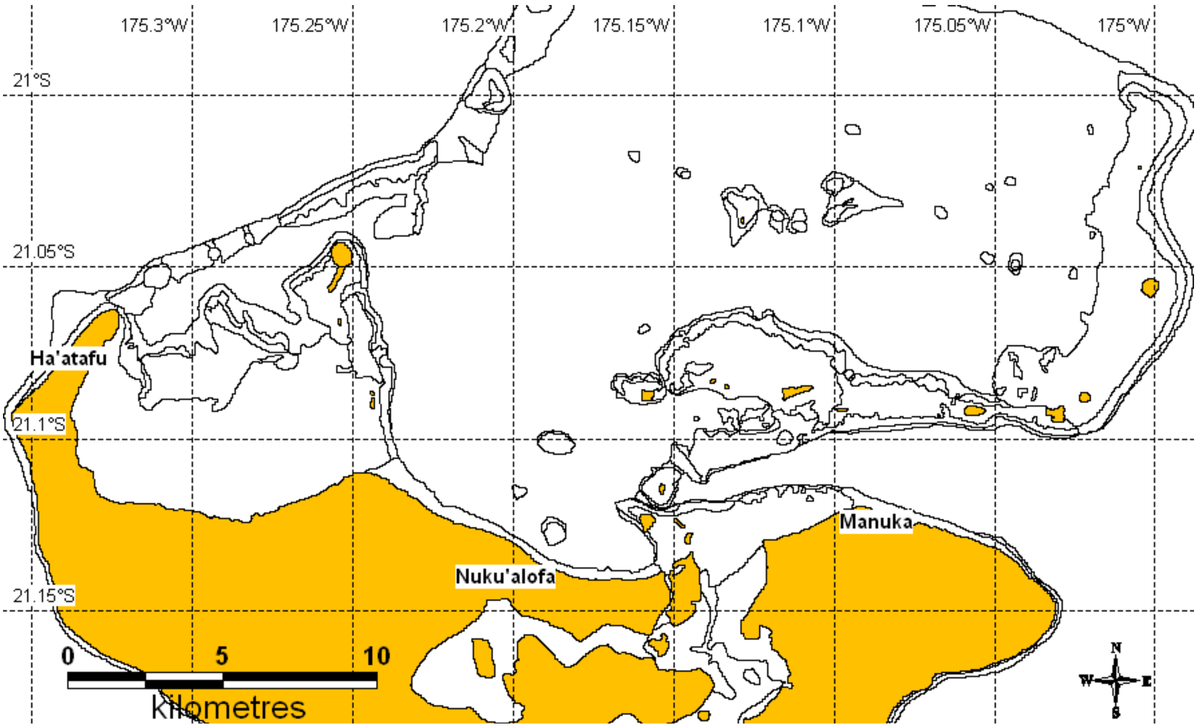

Figure 3.1: Map of Manuka.

3.2. Socioeconomic survey: Manuka

Socioeconomic fieldwork was carried out in Manuka, one of the major fishing communities on Tongatapu in April and September 2008. The survey included households and fishers of the Manuka community only.

The Manuka community has a resident population of 313 people with a total of 44 households. A total of 19 households, which is ~43% of the total households in the community, were surveyed, with most (~84%) of these households being engaged in some form of fishing activities. In addition, a total of 11 finfish fishers (males only) and 13 invertebrate fishers (4 males and 9 females) were interviewed. The average household size is seven people per household. Household interviews focused on the collection of general demographic, socioeconomic and consumption data.

3.2.1 The role of fisheries in the Manuka community: fishery demographics, income and seafood consumption patterns

Our results (Figure 3.2) suggest that fisheries are by far the most important income source for Manuka households (providing 53% of households with first income, and 5% with second income), followed by 'others', i.e. remittances, handicrafts and villages shops (providing 21% of households with first and 5% with second income), while salaries and agriculture play less important roles, providing 16% and 11% of all households with first income, and 21% and 11% with second income respectively. The Manuka community has limited access to agricultural land, which reflects the general scarcity of agricultural land on Tongatapu. However, the community is located at the beach front and has access to a variety of fishing habitats and marine resources. Access to Nuku'alofa's main centre is by road, and travel distance to the market is not far. The majority (63%) of all households have a couple of pigs, and one-third (32%) have chickens, most of which are for home consumption and feasts.

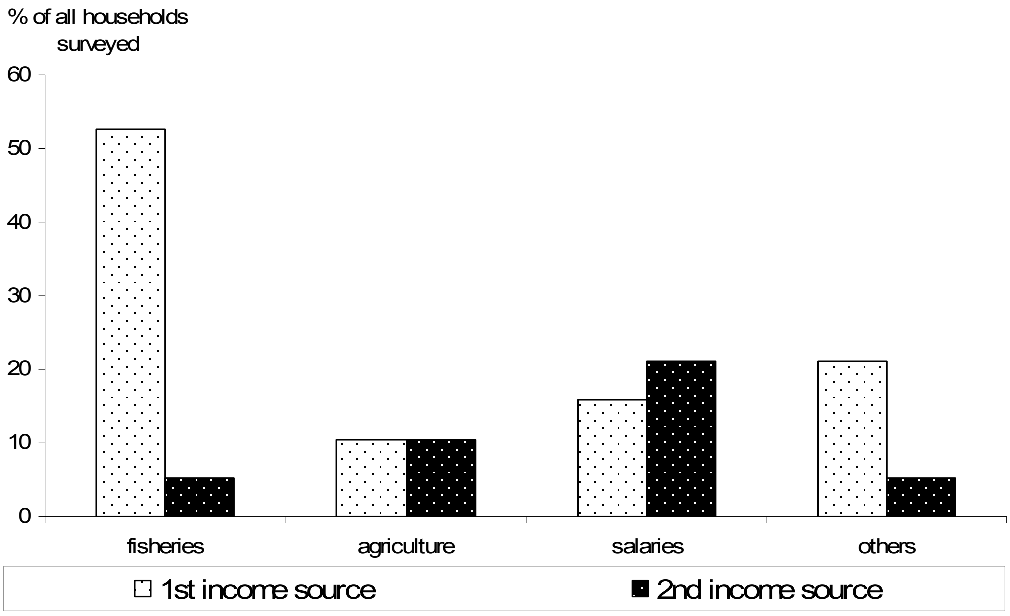

Figure 3.2: Ranked sources of income (%) in Manuka.
Total number of households = 19 = 100%. Some households have more than one income source and those may be of equal importance; thus double quotations for 1st and 2nd incomes are possible.
'Others' are mostly home-based small business.

Our results (Table 3.1) show that the average annual household expenditure is moderate-to-high with an average of USD 2973, reflecting the proximity of this community to the country's capital, as well as its dependency on marine and agricultural products for subsistence. Nevertheless, remittances play an important role for Manuka household incomes, with 78% receiving remittances. Those who receive remittances get an average of USD ~906 /year, corresponding to 31% of the average basic household expenditure.

Survey results indicate an average of one fisher per household and, when extrapolated, the total number of fishers in Manuka is 49. Among these are 23 exclusive finfish fishers (males only), 18 exclusive invertebrate fishers (16 females, 2 males), and seven fishers who fish for both finfish and invertebrates (males only). During this survey, females denied any active participation in finfish fishing, although they do at times catch fish for subsistence purposes and as a side product of gleaning activities. Forty-two per cent of all households own a boat, which are mostly (75%) motorised; a quarter (25%) are non-motorised paddling canoes.

Per capita consumption of fresh fish is high compared to the rural Tonga consumption level, at 78 kg/person/year. This consumption level is also significantly higher than the estimated average given by Preston (2000) of 25.2 kg/person/year, and the regional average of ~35 kg/person/year (Figure 3.3). By comparison, per capita consumption of invertebrates (edible meat weight only) (Figure 3.4) is low, at 3 kg/person/year. Canned fish (Table 3.1) adds another 10 kg/person/year to the annual protein supply from seafood. Canned fish is an established substitute in Tongan nutrition and available even in remote locations. The consumption pattern of seafood found in Manuka highlights the fact that people have a high dependency on marine resources for food, in particular finfish, which is also the most important income source. Due to this importance and the engagement of most households in finfish fishing, purchases and consumption of canned fish are low.

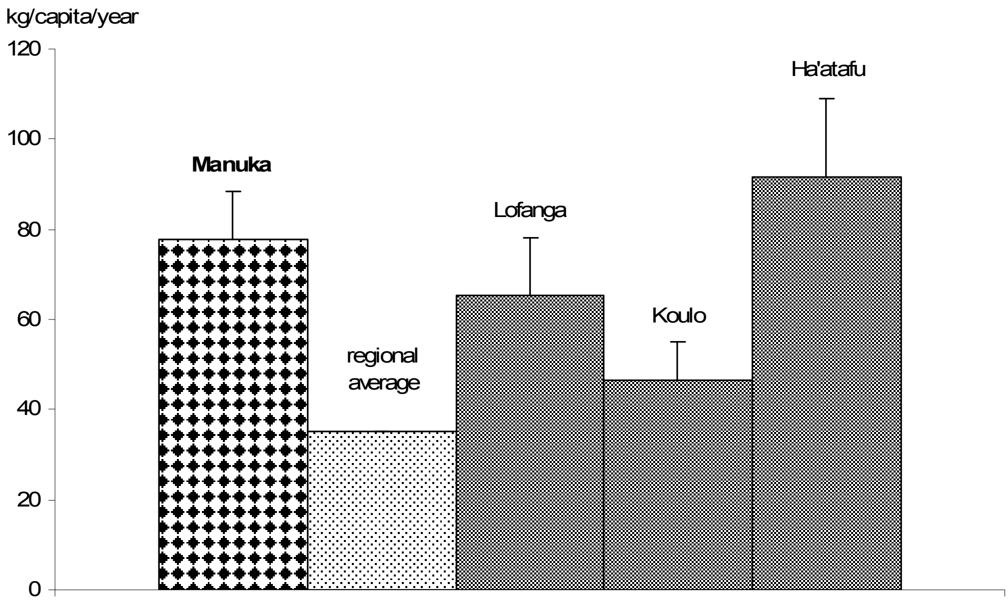

Figure 3.3: Per capita consumption (kg/year) of fresh fish in Manuka (n = 19) compared to the regional average (FAO 2008) and the other three PROCFish sites in Tonga.
Figures are averages from all households interviewed, and take into account age, gender and non-edible parts of fish. Bars represent standard error (+SE).

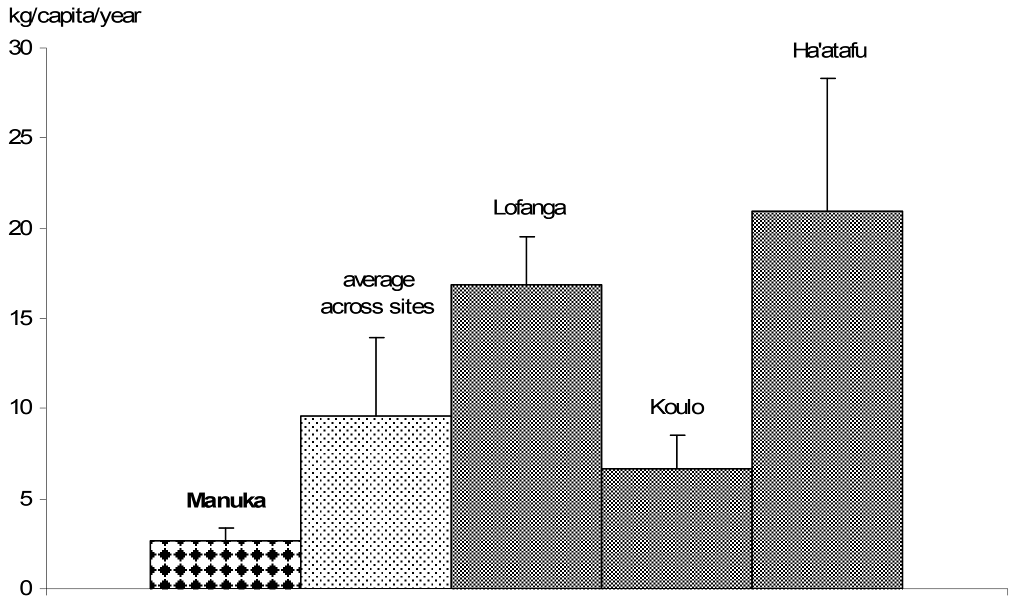

Figure 3.4: Per capita consumption (kg/year) of invertebrates (meat only) in Manuka (n = 19) compared to the average across sites and the other three PROCFish sites in Tonga.
Figures are averages from all households interviewed, and take into account age, gender and non-edible parts of invertebrates. Bars represent standard error (+SE).

Table 3.1: Fishery demography, income and seafood consumption patterns in Manuka

Survey coverage	Site (n = 19 HH)	Average across sites (n = 87 HH)
Demography		
HH involved in reef fisheries (%)	84.2	82.8
Number of fishers per HH	1.11 (±0.15)	1.47 (±0.16)
Male finfish fishers per HH (%)	47.6	43.0
Female finfish fishers per HH (%)	0.0	0.0
Male invertebrate fishers per HH (%)	4.8	2.3
Female invertebrate fishers per HH (%)	33.3	32.0
Male finfish and invertebrate fishers per HH (%)	14.3	22.7
Female finfish and invertebrate fishers per HH (%)	0.0	0.0
Income		
HH with fisheries as 1st income (%)	52.6	39.1
HH with fisheries as 2nd income (%)	5.3	4.6
HH with agriculture as 1st income (%)	10.5	10.3
HH with agriculture as 2nd income (%)	10.5	20.7
HH with salary as 1st income (%)	15.8	21.8
HH with salary as 2nd income (%)	21.1	10.3
HH with other source as 1st income (%)	21.1	29.9
HH with other source as 2nd income (%)	5.3	31.0
Expenditure (USD/year/HH)	2972.90 (±415.77)	3160.33 (±610.10)
Remittance (USD/year/HH) (1)	905.51 (±186.18)	1165.99 (±150.20)
Consumption		
Quantity fresh fish consumed (kg/capita/year)	77.64 (±10.74)	68.57 (±6.36)
Frequency fresh fish consumed (times/week)	4.45 (±0.47)	3.44 (±0.19)
Quantity fresh invertebrate consumed (kg/capita/year)	2.63 (±0.73)	11.58 (±6.36)
Frequency fresh invertebrate consumed (times/week)	0.61 (±0.17)	1.13 (±0.11)
Quantity canned fish consumed (kg/capita/year)	9.99 (±2.23)	16.99 (±1.57)
Frequency canned fish consumed (times/week)	1.42 (±0.22)	2.00 (±0.15)
HH eat fresh fish (%)	100.0	100.0
HH eat invertebrates (%)	73.7	77.0
HH eat canned fish (%)	84.2	89.7
HH eat fresh fish they catch (%)	68.4	76.2
HH eat fresh fish they buy (%)	31.6	42.9
HH eat fresh fish they are given (%)	47.4	81.0
HH eat fresh invertebrates they catch (%)	47.4	71.4
HH eat fresh invertebrates they buy (%)	15.8	14.3
HH eat fresh invertebrates they are given (%)	36.8	52.4

HH = household; (1) average sum for households that receive remittances; numbers in brackets are standard error.

Comparing results obtained for Manuka to the average figures across all four sites surveyed in Tonga, people of the Manuka community eat fresh fish more often and in higher quantities, but eat invertebrates less often and in smaller amounts. They also have a much lower canned fish consumption rate (Table 3.1). In general, however, the proportion of the Manuka population that eats fresh fish, invertebrates and canned fish, is comparative to the average found across all sites studied in Tonga. Manuka people fish, buy and are given fish and invertebrates slightly less than found elsewhere. Sharing seafood among community members on a non-monetary basis is not as common; this may be explained by the fact that most households pursue commercial finfish fishing and thus are pretty self-sufficient in their household fish supply. The dependence on fisheries for income is well above average. The role that agriculture, remittances, mat weaving and small businesses play for income generation is comparative, while salaries are much less important if compared to the average across all sites studied in Tonga. Household expenditure level is high, but below the country average, and Manuka households also benefit from remittances. By comparison, boat ownership is much more common than found elsewhere, and the dominance of motorised boats is less than the overall survey average.

3.2.2 Fishing strategies and gear: Manuka

Degree of specialisation in fishing

Tonga has an open-access system; however, communities may consider certain areas as their own fishing grounds. This observation is partly true for Manuka, where people still consider themselves owners of the lagoon and reef system in front of their village. However, population density on Tongatapu is high and has substantially increased over the past decades. Thus the fishing grounds are shared with fishers external to the community studied. User conflicts are not reported and generally not a subject of major concern. A fisheries management plan has been developed and resource surveys have been undertaken by an AusAID-funded project and Tonga Fisheries working together. However, the survey on Tongatapu only included the two islands of ‘Atata and ‘Eueiki, not the community of Manuka.

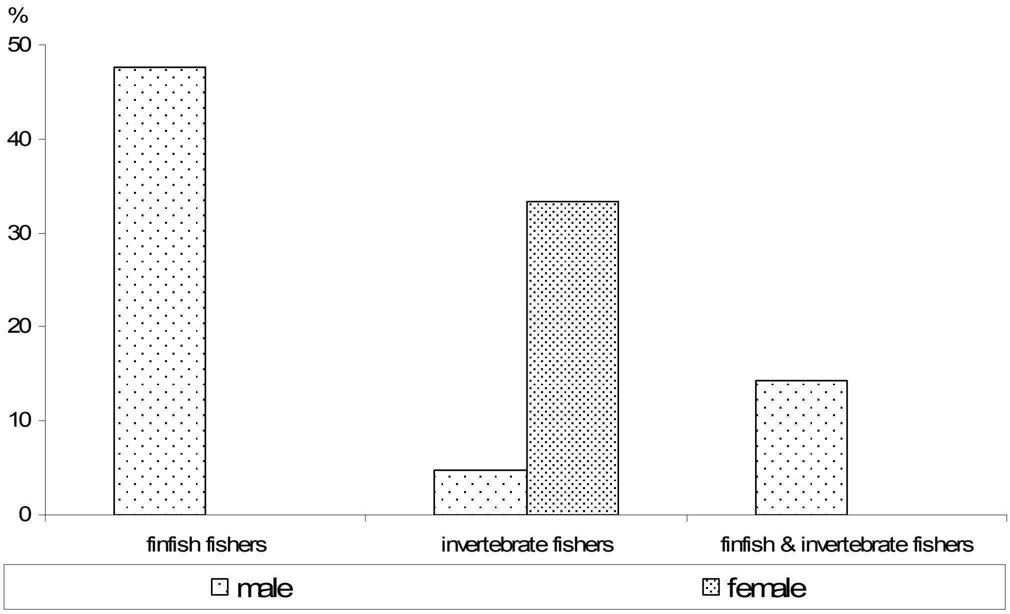

Figure 3.5: Proportion (%) of fishers who target finfish or invertebrates exclusively, and those who target both finfish and invertebrates in Manuka.
All fishers = 100%.

As previously mentioned, Manuka fishers follow the traditional gender differentiation in roles, with males being the major finfish fishers, while females take the lead in invertebrate collection. However, as shown in an earlier study (Kronen 2004b, Kronen and Bender 2006), gender roles have changed over time and females also catch finfish at times, while males actively participate in the collection of invertebrates. Nevertheless, due to the traditional *tabu* and the diverse lifestyle of Manuka people, there is not much incentive or need for Manuka females to engage in finfish fisheries. Females contribute mainly to household income by weaving mats for sale locally and for the tourism industry.

Targeted stocks/habitat

Because Manuka is located at the seafront of Tongatapu, several habitats can be targeted. Fishing in the sheltered coastal reef and lagoon does not necessarily require boat transport. However, respondents indicated that in 71% of all trips boats are used. Male fishers targeting the outer reef need motorised boats to reach the fishing ground. No respondent targets the sheltered coastal reef or the lagoon exclusively, they all fish both habitats in one fishing trip. In contrast, if the outer reef is targeted, no fishing in other habitats is done during the same trip. The relationship of major impact on the sheltered coastal reef and lagoon and less impact on the outer-reef resources is shown in Table 3.2. Interviews showed that invertebrate collection targets mainly the combined soft-benthos and reeftop habitats. Male fishers also engage in lobster fishing, which may at the same time render giant clams and octopus catches (Figure 3.6). Soft-benthos and reeftop gleaning is a female domain, but males also actively participate in invertebrate harvesting on soft-benthos and reeftops or dive for reef-associated species. Lobster fishing is only done by male fishers (Figure 3.7).

Table 3.2: Proportion (%) of interviewed male and female fishers harvesting finfish and invertebrate stocks across a range of habitats (reported catch) in Manuka

Resource	Fishery / Habitat	% of male fishers interviewed	% of female fishers interviewed
Finfish	Sheltered coastal reef & lagoon	63.6	0.0
	Outer reef	45.5	0.0
Invertebrates	Soft benthos	0.0	33.3
	Soft benthos & other	25.0	0.0
	Soft benthos & reeftop	50.0	66.7
	Lobster & other	25.0	0.0

'Other' refers to octopus fishery.
Finfish fisher interviews, males: n = 11; females: n = 0. Invertebrate fisher interviews, males: n = 4; females: n = 9.

Fishing patterns and strategies

The number of fishers, the frequency of fishing trips and the average catch per fishing trip are the basic factors used to estimate the fishing pressure imposed by fishers from Manuka on their fishing grounds (Tables 3.2 and 3.3).

Our survey sample suggests that fishers from Manuka have a good choice of types of fishing ground that they can target. Basically, they can choose whether to fish close to shore and in the lagoon, or to venture out on a much longer fishing trip to the outer reef. The same observation is true for invertebrate fisheries as the coastline offers soft-benthos and reeftop habitats; however, reefs within the lagoon system or at the outer reef may be exploited if free-diving is practised (Figures 3.6 and 3.7).

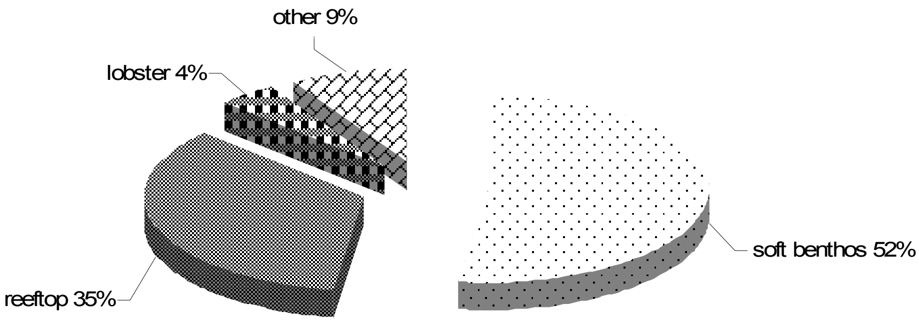

Figure 3.6: Proportion (%) of fishers targeting the four primary invertebrate habitats found in Manuka.
Data based on individual fisher surveys; data for combined fisheries are disaggregated; 'other' refers to octopus fishery.

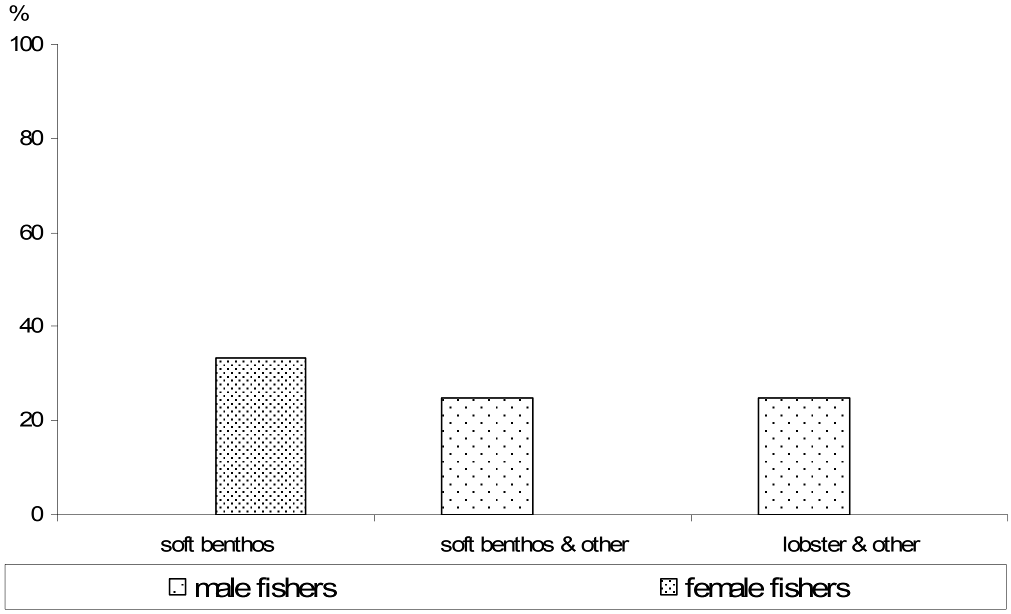

Figure 3.7: Proportion (%) of male and female fishers targeting various invertebrate habitats in Manuka.
Data based on individual fisher surveys; data for combined fisheries are disaggregated; fishers commonly target more than one habitat; figures refer to the proportion of all fishers who target each habitat: n = 4 for males, n = 9 for females.

Gear

Figure 3.8 shows that Manuka fishers use a variety of fishing gear. For sheltered coastal reef and lagoon fishing, spear diving is the main method, and very little handlining or cast netting are used. Handlining, however, dominates the fishing at the outer reef. Fishers may also use deep-bottom lining. Fish fences were not reported for Manuka village.

To collect invertebrates, most fishers use very simple techniques, such as digging, collecting by hand or poking with sticks, iron rods and knives in tidal pools and crevasses. Hand-woven baskets and plastic buckets are used to collect the catch and carry it back home for processing or cooking. Free-diving is done by males using mask, snorkel and fins, often while spear diving for finfish or in combination with finfish fishing trips.

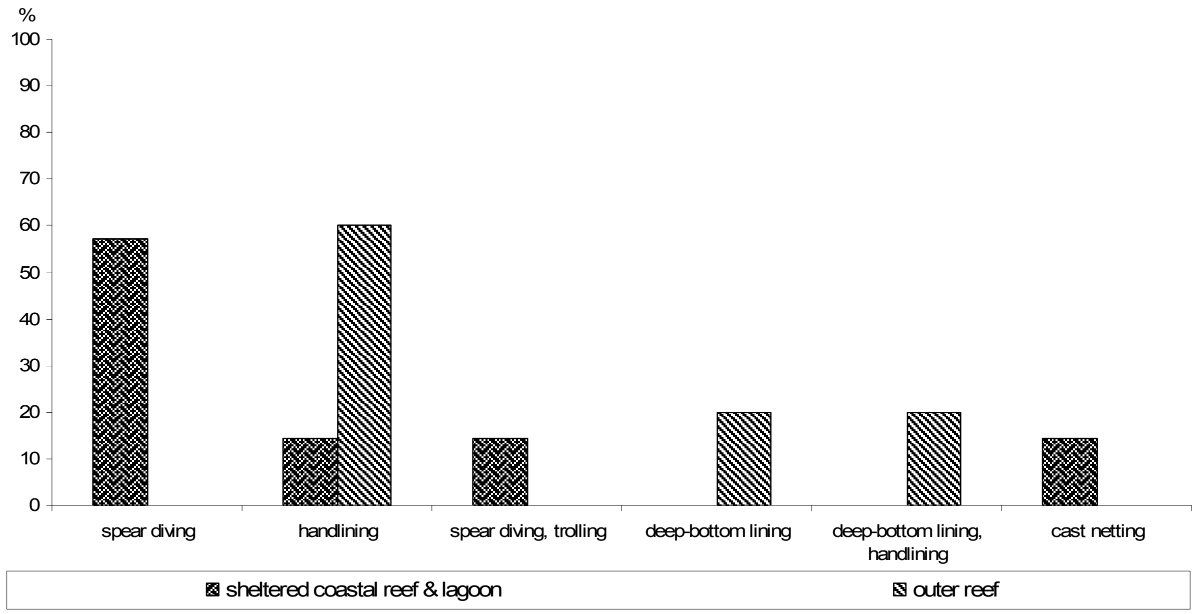

Figure 3.8: Fishing methods commonly used in different habitat types in Manuka.
Proportions are expressed in % of total number of trips to each habitat. One fisher may use more than one technique per habitat and target more than one habitat in one trip.

Frequency and duration of fishing trips

Male fishers go out to catch finfish about 2 to 2.5 times per week regardless of which habitat they choose. As shown in Table 3.3, an average fishing trip targeting the outer reef takes longer (7 hours) because of the long travel distances to these habitats. This may also explain why these habitats are less targeted than the sheltered coastal reef and lagoon areas. Sheltered coastal reef and lagoon fishing trips take on average about four hours.

Invertebrate fishers go fishing about as often as finfish fishers, on average about two times per week for the major fisheries. The average fishing trip by female and male fishers gleaning the reeftops or male fishers free-diving lasts ~2.5–3 hours (Table 3.3).

Finfish fishing and invertebrate collection are practised throughout the year. Half of all finfish fishing trips to the sheltered coastal reef and lagoon are scheduled either only at day or at night time. Trips to the outer reef are mostly planned according to tidal conditions, and less often undertaken exclusively at night time. Ice is less used during fishing trips if targeting the sheltered coastal reef and lagoon, where fishers reported ‘always’ using ice in 29% of trips, and ‘sometimes’ in 43% of all trips. However, during fishing trips to the outer reef, ice is ‘always’ used in 80% of trips and ‘sometimes’ used in 20% of trips.

Most invertebrate collecting is done by walking, and all but the lobster fishery is performed exclusively at day time. Lobsters are targeted at night and this fishery depends on motorised-boat transport. Boat transport is rarely used for any other invertebrate fishery. Most invertebrate fisheries are performed continuously throughout the year.

Table 3.3: Average frequency and duration of fishing trips reported by male and female fishers in Manuka

Resource	Fishery / Habitat	Trip frequency (trips/week)		Trip duration (hours/trip)	
		Male fishers	Female fishers	Male fishers	Female fishers
Finfish	Sheltered coastal reef & lagoon	2.43 (±0.28)		4.14 (±0.86)	
	Outer reef	2.00 (±0.16)	0	7.20 (±0.92)	0
Invertebrates	Soft benthos	0	2.00 (±0.00)	0	3.00 (±0.00)
	Soft benthos & other	0.04 (n/a)	0	3.00 (n/a)	0
	Soft benthos & reeftop	2.00 (±0.00)	2.17 (±0.17)	1.50 (±0.50)	2.50 (±0.22)
	Lobster & other	2.00 (n/a)	0	3.00 (n/a)	0

Figures in brackets denote standard error; n/a = standard error not calculated; 'other' refers to octopus fishery.
Finfish fisher interviews, males: n = 11; females: n = 0. Invertebrate fisher interviews, males: n = 4; females: n = 9.

3.2.3 Catch composition and volume – finfish: Manuka

The catches reported from the sheltered coastal reef and lagoon, and from outer-reef and passage fishing in Manuka contain various species and species groups. Acanthuridae and Scaridae make up the major proportion of catches from the sheltered coastal reef and lagoon, followed by Lethrinidae and several others. The reported catch composition from the outer reef differs, as it is determined by Lethrinidae, Serranidae, Lutjanidae and others. Scaridae and Acanthuridae were not reported, which may be explained by the major use of spear diving in the sheltered coastal reef and lagoon and handlines and deep-bottom lines at the outer reef. Overall, the reported variety of catches from any of the habitats targeted and as expressed by vernacular names is not very diverse compared to catches reported from the other sites studied in Tonga. Detailed information on catch composition by species, species groups and habitats is reported in Appendix 2.2.1.

Figure 3.9 confirms the findings from the socioeconomic survey reported earlier, that finfish fishing serves both subsistence and income purposes. While 57% of the total annual catch serves the demand of the Manuka community itself, 43% is sold on the island and at the Nuku'alofa market. Although the number of fishers targeting the sheltered coastal reef and lagoon is much higher than the number of those fishing at the outer reef, in terms of total annual weight caught, impact on both habitats is the same (50%).

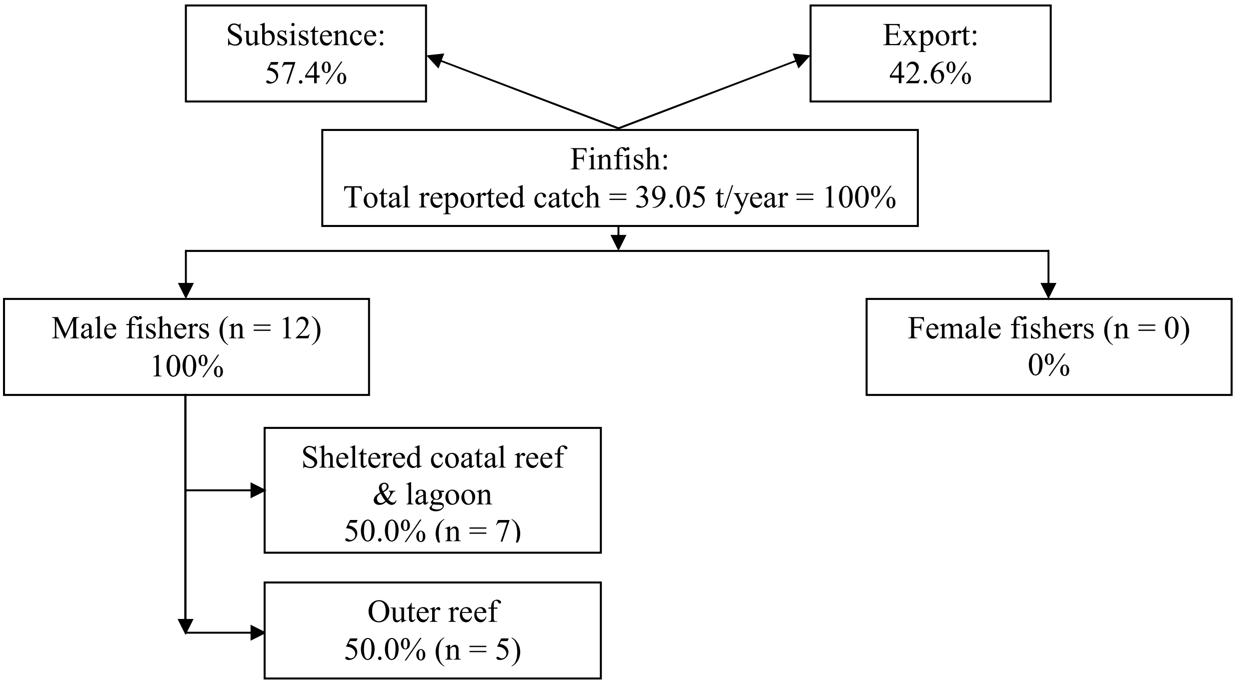

Figure 3.9: Total annual finfish catch (tonnes) and proportion (%) by fishery and gender (reported catch) in Manuka.
n is the total number of interviews conducted per each fishery; total number of interviews may exceed total number of fishers surveyed as one fisher may target more than one fishery and thus respond to more than one fishery survey.

The distribution of annual catch weight between the more accessible sheltered coastal reef and lagoon, and the more further distant outer reef is a consequence of the number of fishers and the catch per unit effort (CPUE) rather than the average annual productivity. As shown in Figure 3.10, the average annual catch per fisher is 40% higher for fishers targeting the outer reef than for those fishing in the sheltered coastal reef and lagoon.

Comparing productivity rates between genders and habitats (Figure 3.11), the picture is inverse: fishers targeting the sheltered coastal reef and lagoon catch about 2.8 kg/hour fishing trip as compared to 2.4 kg/hour fishing trip achieved on average at the outer reef. The difference may be due to a number of factors: resource status, but also different fishing strategies and techniques used, i.e. spear diving in the inshore habitats and handlining at the outer reef.

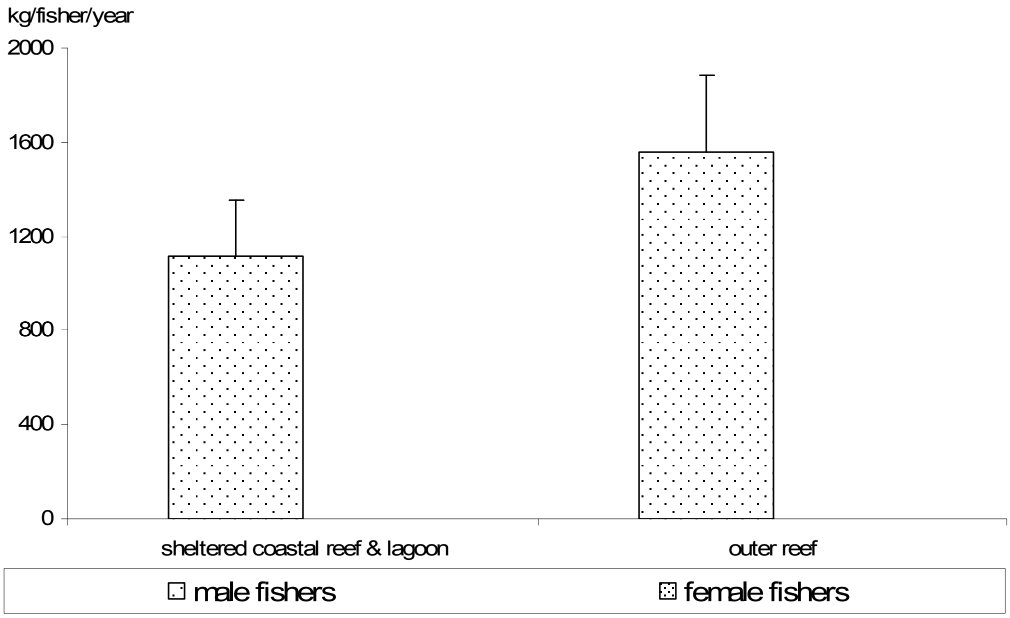

Figure 3.10: Average annual catch (kg/year, +SE) per fisher by gender and habitat in Manuka (based on reported catch only).

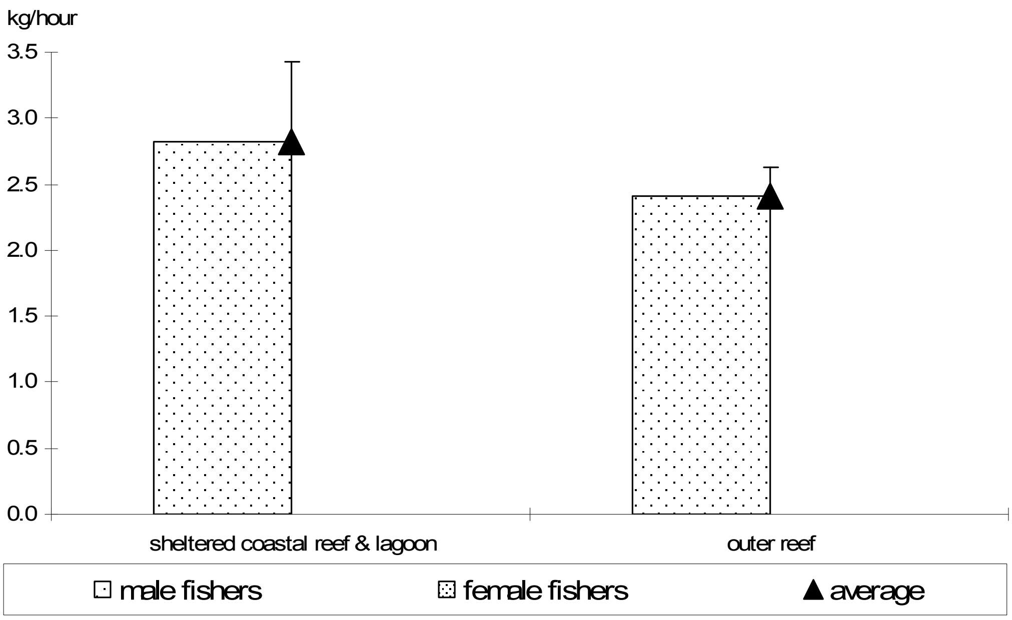

Figure 3.11: Catch per unit effort (kg/hour of total fishing trip) for male and female fishers by habitat type in Manuka.
Effort includes time spent transporting, fishing and landing catch. Bars represent standard error (+SE).

The high importance of commercial fishing for Manuka fishers clearly shows in Figure 3.12. Male fishers targeting the sheltered coastal reef and lagoon may fish slightly more for subsistence but also mainly for sale; fishers targeting the outer reef fish with an even stronger commercial interest.

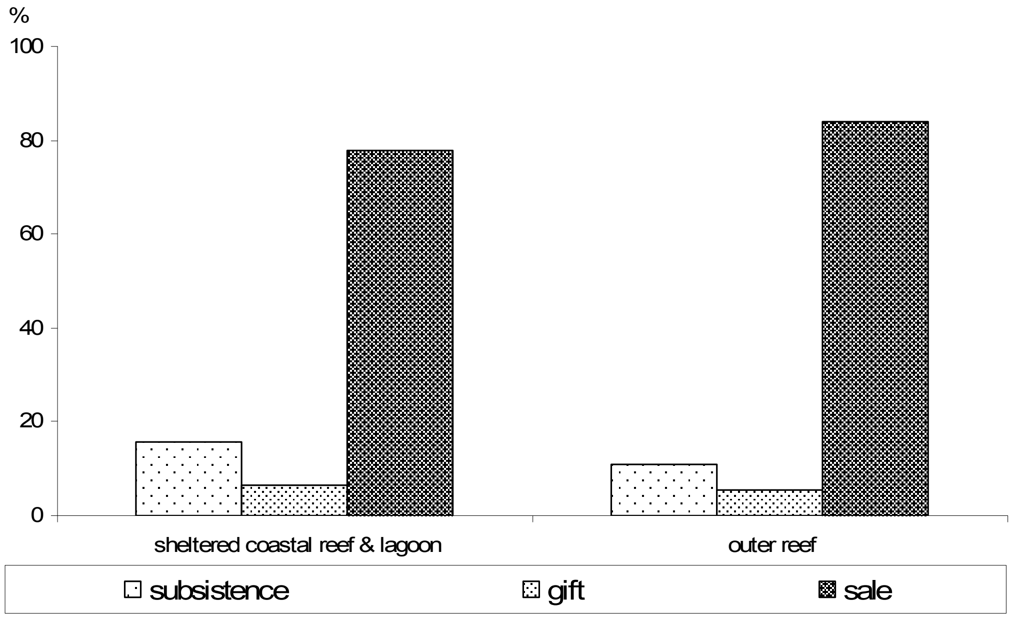

Figure 3.12: The use of finfish catches for subsistence, gifts and sale, by habitat in Manuka. Proportions are expressed in % of the total number of trips per habitat.

The overall finfish fishing productivity per habitat may be affected by a number of possible factors. The usual and expected trend that average fish size increases with distance from shore is confirmed for Lethrinidae and Serranidae. Holocentridae do not show any difference in size between catches reported from the two habitats. Wider comparison of average fish size length between habitats fished, however, is not possible due to the different catch composition and thus absence of comparative data across all families (Figure 3.13). Overall, reported average fish lengths are medium, and range from 20 to 30 cm.

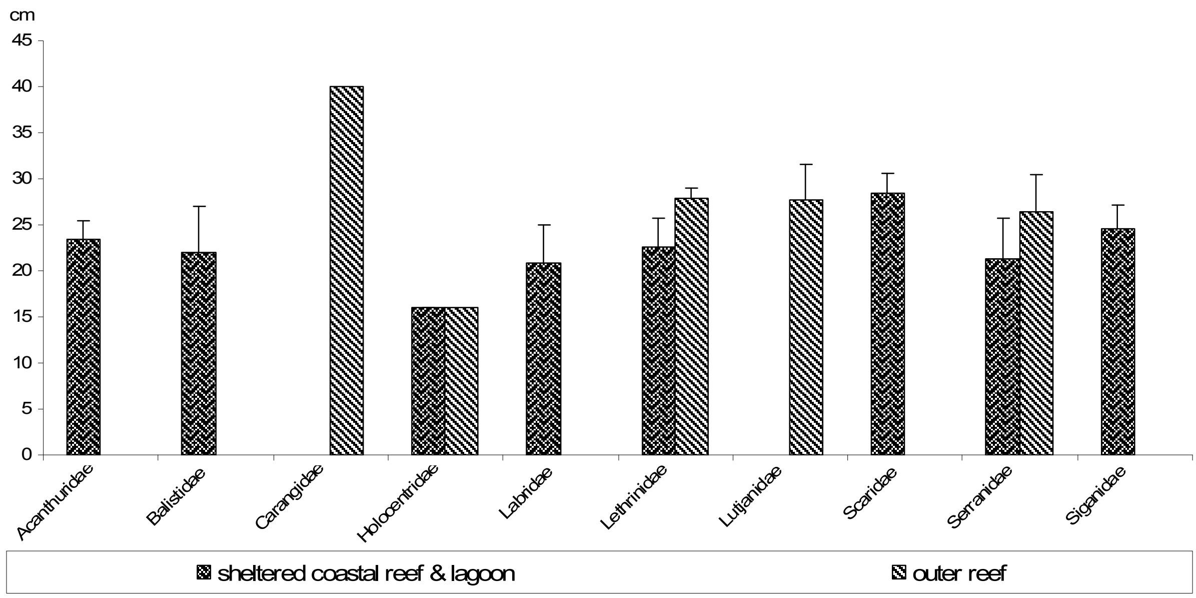

Figure 3.13: Average sizes (cm fork length) of fish caught by family and habitat in Manuka. Bars represent standard error (+SE).

The parameters selected to assess current fishing pressure on Manuka's reef and lagoon resources are shown in Table 3.4. Overall, all parameters calculated for fishing pressure are low. This applies to finfish fisher density in all habitats considered, population density for total reef and fishing ground areas, and the impact due to subsistence fish catch. Even if we consider the annual export catch, which accounts for 43% of the total annual catch, catch rates remain very low. Thus, overall, there is no indication that Manuka's fishing community currently catches finfish at a rate which is detrimental to resource levels. However, it must be borne in mind that the open-access system in the Tongatapu lagoon and the high population density on the island is likely to add considerable pressure on the resources, here allocated to the Manuka community only. Underwater resource survey results revealed that, in fact, fish resources in the Manuka reef and lagoon areas are the poorest of all the other sites studied in Tonga. Therefore, it is concluded that the current low finfish catch rates are a response to the poor resource status. Furthermore, it is concluded that the current low resource status is a result of past and current fishing pressure imposed by fishers not only from Manuka but also from elsewhere in Tongatapu.

Table 3.4: Parameters used in assessing fishing pressure on finfish resources in Manuka

Parameters	Habitat			
	Sheltered coastal reef & lagoon	Outer reef	Total reef area	Total fishing ground
Fishing ground area (km^2)	224.88	5.10	94.94	255.64
Density of fishers (number of fishers/km^2 fishing ground) (1)	0.1	2.7	0.3	0.1
Population density (people/km^2) (2)			3.3	1.2
Average annual finfish catch (kg/fisher/year) (3)	1112.5 (±239.7)	1555.7 (±325.9)		
Total fishing pressure of subsistence catches (t/km^2)			0.2	0.1
Total number of fishers	19	14	30	30

Figures in brackets denote standard error; total lagoon surface area is 201.9 km^2; mangrove area = 25.66 km^2; (1) total number of fishers is extrapolated from household surveys; (2) total population = 313; total number of fishers = 30; total subsistence demand = 22.42 t/year; (3) catch figures are based on recorded data from survey respondents only.

3.2.4 Catch composition and volume – invertebrates: Manuka

Analysis of catches reported by invertebrate fishers by wet weight shows that holothurian catches account for the highest impact, followed by *Strombus* spp. All other catches are comparatively unimportant. This observation includes lobsters, sea urchins, *Turbo crassus*, *Dolabella* spp. and others (Figure 3.14).

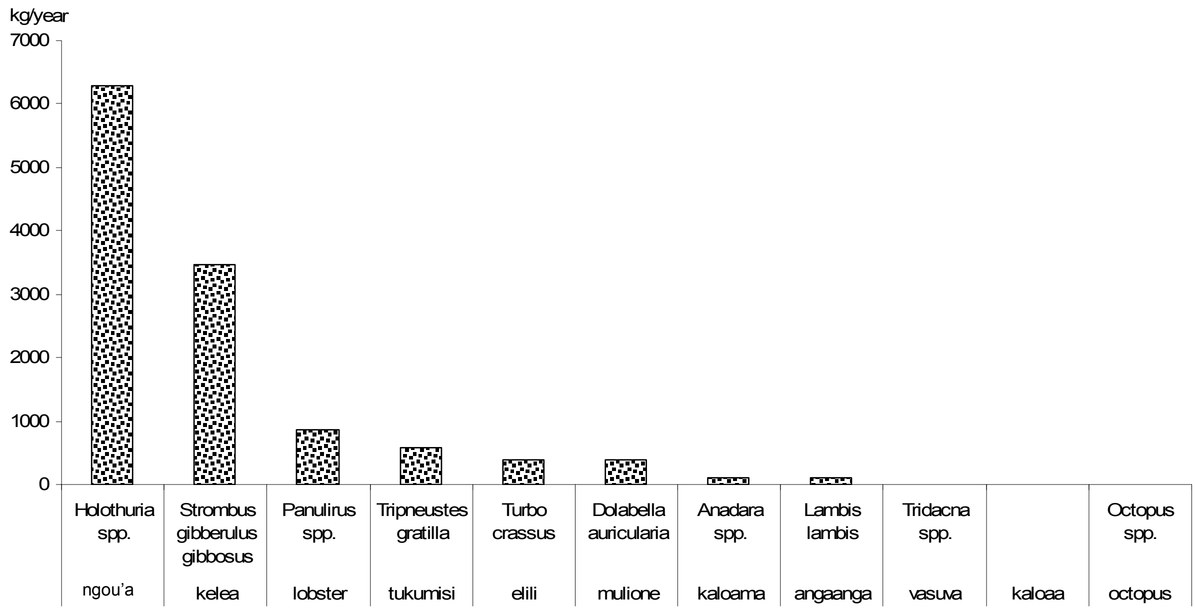

Figure 3.14: Total annual invertebrate catch (kg wet weight/year) by species (reported catch) in Manuka.

The fact that most impact is due to a few species only also shows in the number of vernacular names that have been registered from respondents. Soft-benthos and reeftop gleaning, which is often combined in one fishing trip, is represented by a maximum of seven vernacular names; soft-benthos species alone include about five different targets identified by vernacular names; and lobsters are represented by one vernacular name, while 'others' are mainly octopus catches (Figure 3.15).

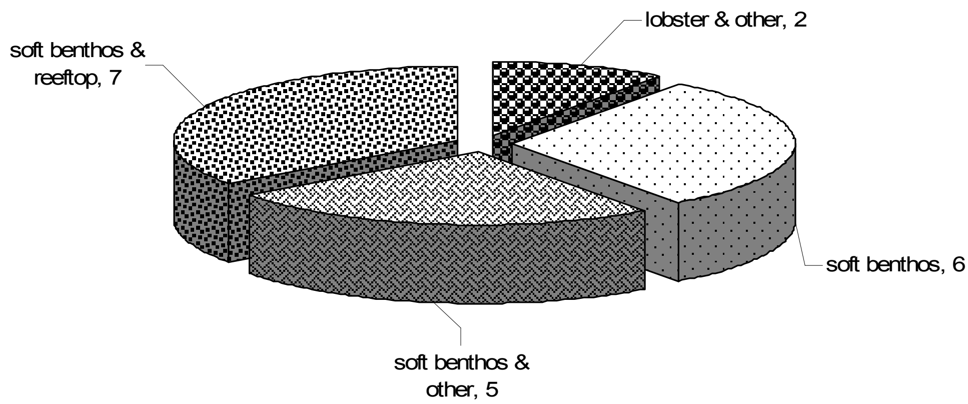

Figure 3.15: Number of vernacular names recorded for each invertebrate fishery in Manuka.

The average annual catch per fisher by gender and fishery (Figure 3.16) reveals substantial differences among fisheries and confirms, as reported earlier, that soft-benthos and reeftop gleaning are the major fisheries. Highest average annual catches are obtained by female fishers gleaning soft benthos, and male fishers gleaning soft benthos and reeftops combined. By comparison, the average annual catches by male fishers are much lower for both fisheries that they are mainly engaged in, i.e. lobster diving and soft-benthos and reeftop gleaning. Average annual catches per fisher indicate that invertebrates serve mainly subsistence purposes and do not represent any major commercial fishery.

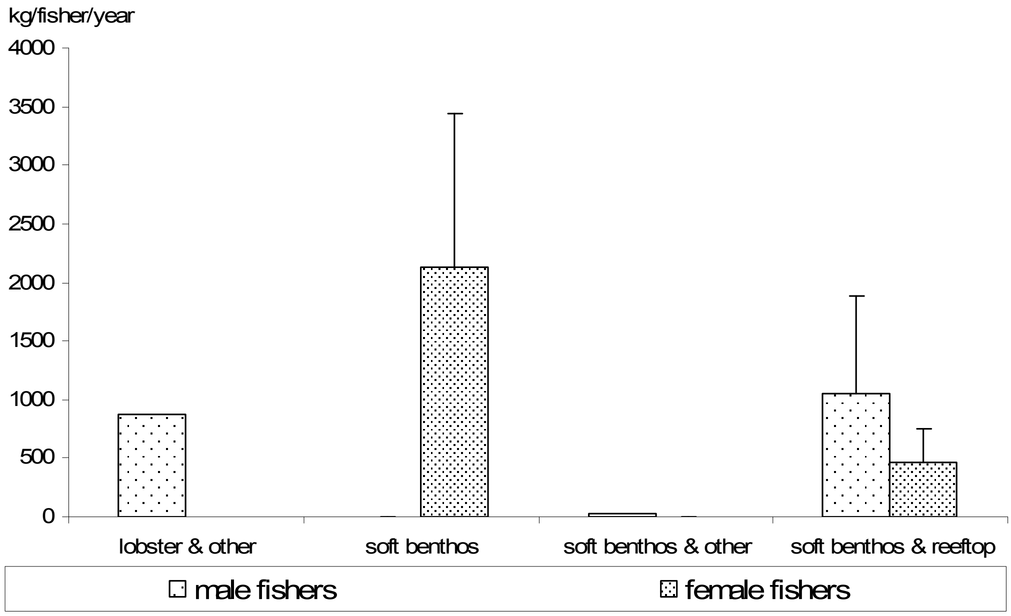

Figure 3.16: Average annual invertebrate catch (kg wet weight/year) by fisher and gender in Manuka.
Data based on individual fisher surveys. Figures refer to the proportion of all fishers who target each habitat (n = 4 for males, n = 9 for females).

This finding is further supported by Figure 3.17, which shows that most of the invertebrate catches are used for subsistence purposes, and a maximum of 4% may be sold, assuming that half of the catch reported for consumption and sale may indeed be sold. No fisher reported collecting invertebrates only for sale.

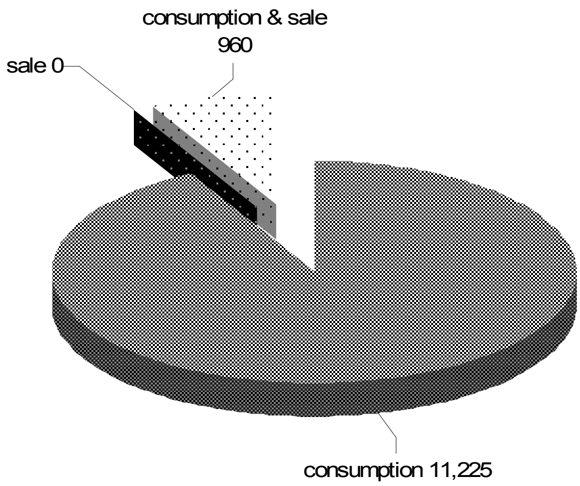

Figure 3.17: Total annual invertebrate biomass (kg wet weight/year) used for consumption, sale, and consumption and sale combined (reported catch) in Manuka.

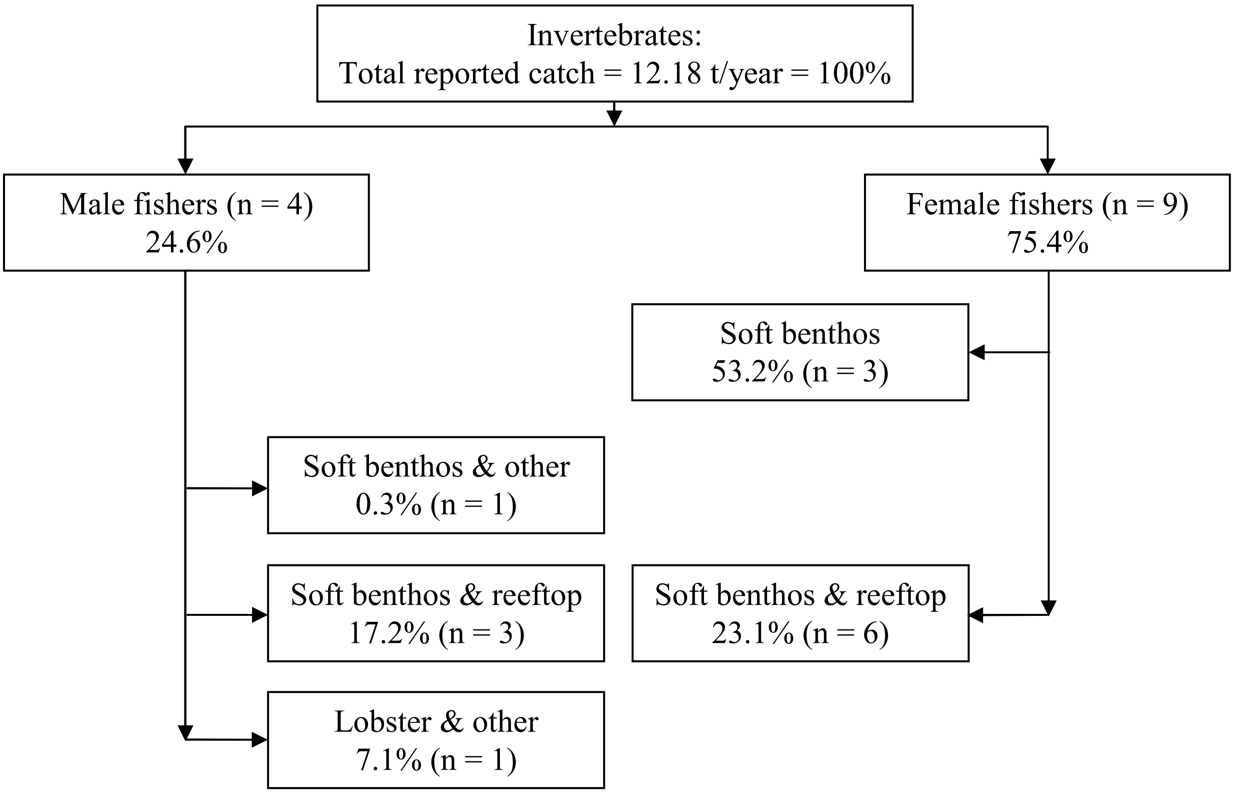

Figure 3.18: Total annual invertebrate catch (tonnes) and proportion (%) by fishery and gender (reported catch) in Manuka.
n is the total number of interviews conducted per each fishery; total number of interviews may exceed total number of fishers surveyed as one fisher may target more than one fishery and thus respond to more than one fishery survey.

As mentioned earlier, male and female fishers from Manuka are both engaged in invertebrate collection but it is not surprising that female fishers account for the largest proportion in wet weight (Figure 3.18). This observation confirms that female fishers take higher average annual catches and participate more in invertebrate fishing. Also, as stated earlier, the highest pressure is on soft-benthos and the combined soft-benthos and reeftop habitats, i.e. a total of 53% and 40% respectively of the annual reported catch, with 17% taken by male fishers and 76% due to female fishers' gleaning activities.

Table 3.5: Parameters used in assessing fishing pressure on invertebrate resources in Manuka

Parameters	Fishery / Habitat			
	Lobster & other	Soft benthos	Soft benthos & other	Soft benthos & reeftop
Fishing ground area (km^2)				22.98
Number of fishers (per fishery) [(1)]	2	5	2	15
Density of fishers (number of fishers/km^2 fishing ground)				0.7
Average annual invertebrate catch (kg/fisher/year) [(2)]	868.6 (n/a)	2124.2 (±1310.8)	32.7 (n/a)	613.9 (±275.1)

Figures in brackets denote standard error; [(1)] total number of fishers is extrapolated from household surveys; [(2)] catch figures are based on recorded data from survey respondents only.

Taking into account figures on the available reeftop surface, reeftop fisheries have, as expected, a low fisher density, i.e. <1 fisher/km² of reeftop surface. Even though invertebrate fisheries are relatively important for Manuka, in particular for home consumption, and focus on a few target species only, the average annual catch rates, fisher numbers and the available reef area all suggest a low fishing pressure and thus no detrimental effect from current fishing levels (Table 3.5). However, again it must be noted that the open-access system coupled with a high population density on Tongatapu may add considerable stress on the resources, here allocated to the Manuka community only. Thus, final conclusions on resource status and possible visible impacts need verification with results from the invertebrate resource survey.

3.2.5 Fisheries management: Manuka

Manuka is a community that is located relatively close to Nuku'alofa and is part of a close network of villages at the northeastern part of Tongatapu island. The Manuka population has, undoubtedly, access to urban market facilities and products and enjoys an elevated living standard with electricity and public water supply. However, the amount of remittances received and the high seafood consumption figures suggest that the community still follows a rather traditional and self-sustained lifestyle. This is also supported by the fact that the community is still managed in parts by traditional social institutions. As elsewhere in Tonga, fishing is governed by the open-access system, which does not restrict people from fishing wherever they wish. While no conflicts are reported, results from the underwater resource survey suggest that external fishers have added in the past and continue to add considerable pressure on the marine resources that are located around the Manuka community. This is made easier by the fact that "their" fishing grounds are relatively easily accessible by the capital's populations and neighbouring villages. Marketing of fishery produce is not limited as transport is easy and the costs involved are low, making Manuka fishers competitive in the market (Kronen 2004).

Manuka has not benefited from the fisheries management planning and resource surveys undertaken by Tonga Fisheries in cooperation with a former AusAID project.

3.2.6 Discussion and conclusions: socioeconomics in Manuka

Manuka is a rural coastal community on the northeastern coast of Tongatapu, in close proximity to the capital's market. It has therefore good access to urban and market facilities by road. The living standard is relatively high with electricity and public water supply; however, a considerable amount of income is generated by finfish fisheries and complemented by remittances received from overseas. Community life is still determined to some extent by traditional and, perhaps, religious institutions, but Manuka is not yet included in the ongoing governmental community management programme. People have limited access to agricultural land and depend primarily on marine resources.

Due to the low population and fisher density, and the large size of appropriated fishing grounds and reef surfaces, fishing pressure is relatively low. However, the marine resources allocated in this study to the Manuka community are also subject to presumably significant external impact due to the open-access fisheries system, the considerable population density on Tongatapu and the easy accessibility of Manuka's fishing grounds by people from the capital and the neighbouring villages.

In summary, survey results suggest:

- The Manuka population has a significant dependence on marine resources (mainly finfish) for home consumption and revenue. Marketing of finfish fisheries produce is by far the most important source of income, complemented by remittances, mat weaving done by females, and salaries.

- Per capita finfish consumption is high, while invertebrates and canned fish are consumed far less than the average rate across all communities studied in Tonga.

- Tradition demands different gender roles in fisheries and these are still apparent in Manuka. Male fishers are the only official and commercial finfish fishers, while females take the lead in invertebrate collection. Although females also catch fish at times, it is difficult to obtain any information on female finfish fishing activities. Males are increasingly involved in invertebrate harvesting and account for one-quarter of the total annual invertebrate catch (wet weight).

- Most fishers target the sheltered coastal reef and lagoon habitats and less the outer reef, but the total annual catch from either habitat is comparative.

- Overall, CPUEs are moderate, and lowest for outer reef fishing. Differences may be explained by the fishing techniques used (spearfishing at the sheltered coastal reef and lagoon, handlining at outer reef) rather than the resource status alone.

- Spearfishing, handlining and deep-bottom lining are the most common techniques used; cast netting and trolling are rarely used. Invertebrates are collected using very low-cost equipment. Male fishers may free-dive to collect invertebrates using mask, snorkel and fins. The average reported fish sizes are small-to-medium and range between 20 and 30 cm. Conclusions on effects of habitats on average reported fish sizes are limited due to the lack of comparative data across the various families reported.

- Results from the invertebrate fisher survey show that catches of holothurians and *Strombus* spp. account for most of the annual harvest (wet weight). By comparison, catches of lobsters, sea urchins, *Turbo* spp., *Dolabella* spp. and all other species are of low importance.

- Average annual finfish catches show considerably higher productivity for fishers targeting the outer reef as compared to most fishers who catch fish in the sheltered coastal reef and lagoon. This is due not to fisher numbers or CPUE as both factors are higher for the closer-to-shore habitats, but to the time spent and frequency of fishing by the individual fisher. Also, for both habitats targeted, similar interests in catching fish for commercial purposes apply. Significant differences were also found in the average annual catches per invertebrate fishery. Annual average catches reported for the gleaning of soft-benthos and the combination of soft benthos and reeftops are far higher than all other catch rates reported. Highest average annual catches are taken by female fishers gleaning soft benthos habitats.

- Fishing pressure parameters calculated for finfish fisheries suggest that finfish fishing pressure is low, due to the large available reef and overall fishing ground area, low fisher and population densities and low catch rates. The same conclusion is suggested for the invertebrate catch, reef area and fisher-density data. In summary, the current exploitation level imposed on finfish and invertebrates for subsistence and commercial purposes does not give any reason to assume any detrimental effect on resources. However, the results from the underwater finfish resource survey highlight the fact that Manuka's finfish resource status is the worst of all the other sites studied in Tonga. Hence, past and present fishing effort, including fishing by external fishers from outside the Manuka community has imposed substantial fishing pressure on resources, and detrimental effects are clearly visible.

3.3 Finfish resource surveys: Manuka

This report aims at presenting a preliminary assessment of the finfish resources of the coral reefs of Tongatapu (Figure 3.19). The two villages of Manuka and Ha'atafu are treated separately, although the fishing grounds are mostly shared by the two fisher communities.

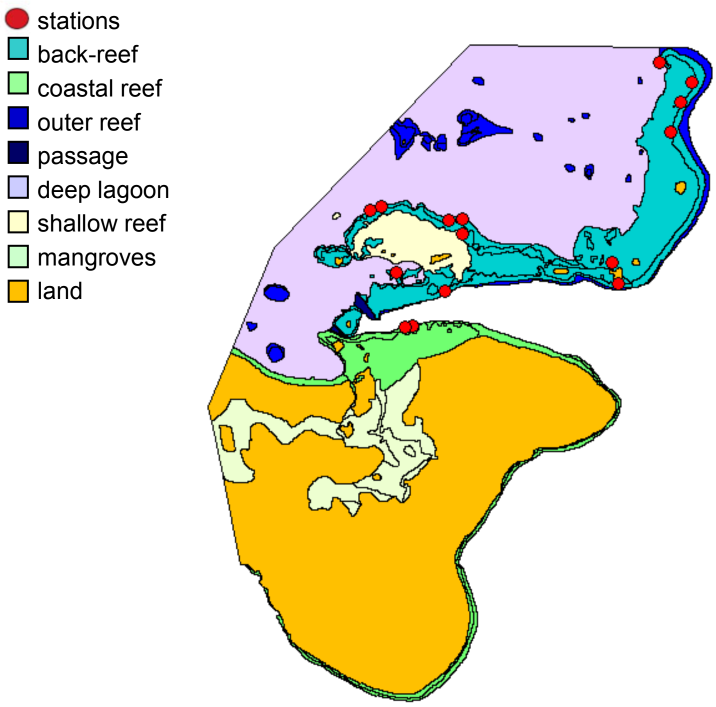

Figure 3.19: Habitat types and transect locations for finfish assessment in Manuka.

3.3.1 Finfish assessment results: Manuka

Finfish resources and associated habitats were assessed between 23 and 27 September 2008 for a total of 12 transects (8 back-reef, 1 coastal reef, 3 outer reef). Other coastal areas were not diveable.

A total of 14 families, 35 genera, 93 species and 2243 fish were recorded in the 12 transects (See Appendix 3.2.2 for list of species.). Only data on the 13 most dominant families (See Appendix 1.2 for species selection.) are presented below, representing 34 genera, 92 species and 2166 individuals.

Finfish resources varied greatly among the three reef environments found in Manuka (Table 3.6). The coastal reef (1 station) contained the greatest number of fish (0.4 fish/m^2) and highest biomass (36 g/m^2) compared to the outer and back-reefs. However, this could be an effect of having sampled only one station. Lowest density (0.1 fish/m^2), size (13 cm FL), size ratio (54%), biomass (10 g/m^2) and biodiversity (26 species/transect) were recorded in the back-reefs, while size and biodiversity were highest in the outer reefs (14 cm FL and 31 species/transect respectively).

Table 3.7: Primary finfish habitat and resource parameters recorded in Manuka (average values ±SE)

Parameters	Habitat			
	Sheltered coastal reef (1)	Back-reef (1)	Outer reef (1)	All reefs (2)
Number of transects	1	8	3	12
Total habitat area (km^2)	18.57	49.73	15.49	83.79
Depth (m)	9 (6–10) (3)	4 (1–10) (3)	6 (5–7) (3)	6 (1–10) (3)
Soft bottom (% cover)	8 ±0	20 ±7	11 ±6	16
Rubble & boulders (% cover)	14 ±0	12 ±3	6 ±1	12
Hard bottom (% cover)	31 ±0	36 ±6	52 ±8	37
Live coral (% cover)	43 ±0	25 ±7	19 ±3	29
Soft coral (% cover)	3 ±0	3 ±1	9 ±2	4
Biodiversity (species/transect)	29 ±0	26 ±3	31 ±2	28 ±2
Density (fish/m^2)	0.4 ±0.0	0.1 ±0.0	0.2 ±0.0	0.2
Size (cm FL) (4)	14 ±2	13 ±1	14 ±1	14
Size ratio (%)	52 ±6	54 ±3	57 ±5	54
Biomass (g/m^2)	36.1 ±0.0	10.6 ±1.6	15.4 ±2.9	17.2

(1) Unweighted average; (2) weighted average that takes into account relative proportion of habitat in the study area; (3) depth range; (4) FL = fork length.

Sheltered coastal reef environment: Manuka

The coastal reef environment of Manuka was dominated by two major families of herbivores: Acanthuridae and Scaridae (Figure 3.20, Table 3.8). These two families were represented by nine species; particularly high biomass and abundance were recorded for *Ctenochaetus striatus*, *Scarus rivulatus*, *Chlorurus sordidus* and *Scarus psittacus* (Table 3.8). This reef environment was composed of mostly hard corals (43%), a high cover of hard bottom (31%) and an average cover of soft bottom and rubble (22% Table 3.7, Figure 3.20).

Table 3.8: Finfish species contributing most to main families in terms of densities and biomass in the sheltered coastal reef environment of Manuka

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.07 ±0.00	6.7 ±0.0
Scaridae	*Scarus rivulatus*	Rivulated parrotfish	0.05 ±0.00	7.6 ±0.0
	Chlorurus sordidus	Daisy parrotfish	0.04 ±0.00	4.2 ±0.0
	Scarus psittacus	Palenose parrotfish	0.04 ±0.00	2.7 ±0.0

The density, size and biomass of finfish in the coastal reefs of Manuka were higher than the outer-reef and back-reef values. Biodiversity was intermediate between values at the back- and outer reefs. The trophic structure of fish in Manuka coastal reefs was highly dominated by herbivorous fish, here mainly represented by Acanthuridae and Scaridae. Carnivores were represented mainly by Lutjanidae and Mullidae.

Size ratio was below 50% for Labridae, but it was especially low for Scaridae, suggesting an impact from heavy fishing.

These reefs displayed a substrate dominated by a high percentage of hard coral and hard bottom and only 22% composed of soft bottom and rubble, normally more favourable to some carnivorous species. The most important species in terms of biomass and density were Acanthuridae *Ctenochaetus striatus*, and Scaridae *Chlorurus sordidus* and *Scarus psittacus*, all small-sized species of herbivores.

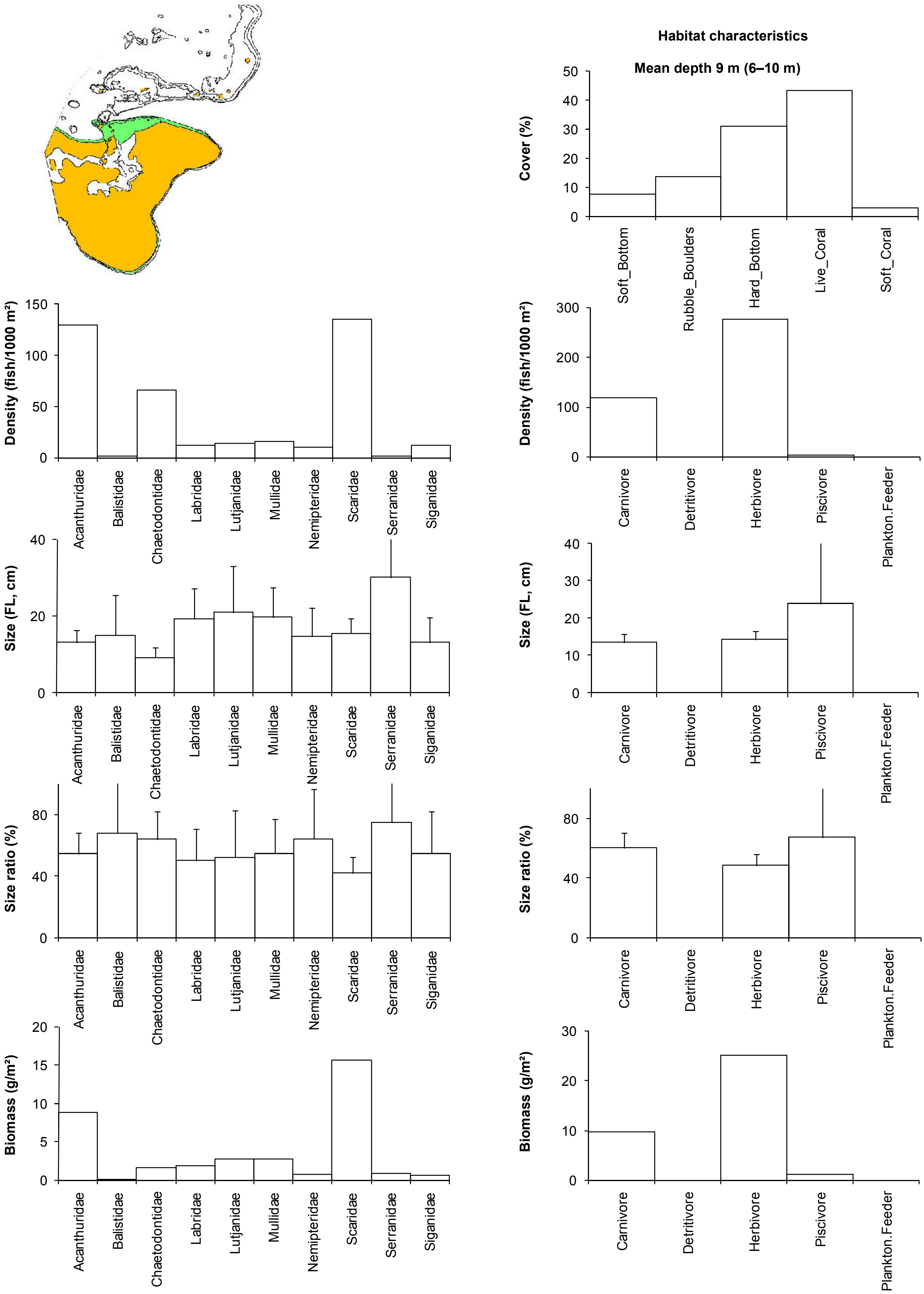

Figure 3.20: Profile of finfish resources in the sheltered coastal reef environment of Manuka.
Bars represent standard error (+SE); FL = fork length.

Back-reef environment: Manuka

The back-reef environment of Manuka was dominated by two major families of herbivores: mainly Acanthuridae, followed by Scaridae (Figure 3.21, Table 3.9). These two families were represented by 18 species; particularly high biomass and abundance were recorded for *Ctenochaetus striatus*, *Zebrasoma scopas* and *Chlorurus sordidus* (Table 3.9). This reef environment was composed of mostly hard bottom (36%), a high cover of hard coral (25%), and soft bottom and rubbles (32% Table 3.7, Figure 3.21).

Table 3.9: Finfish species contributing most to main families in terms of densities and biomass in the back-reef environment of Manuka

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.04 ±0.00	4.2 ±1.1
	Zebrasoma scopas	Two-tone tang	0.02 ±0.00	0.7 ±0.3
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.01 ±0.00	1.0 ±0.4

The density, size, biomass and biodiversity of finfish in the back-reefs of Manuka were the lowest compared to the outer-reef and costal-reef values. The trophic structure of fish was highly dominated by herbivores, especially in terms of biomass. Herbivores were mainly represented by Acanthuridae. Carnivores were almost absent and mainly represented by Labridae and Mullidae. Size ratio was below 50% values for most families (Balistidae, Labridae, Lethrinidae, Lutjanidae, Mullidae, Scaridae and Siganidae), suggesting, together with the values of the other biological parameters, a very high stress from fishing impact.

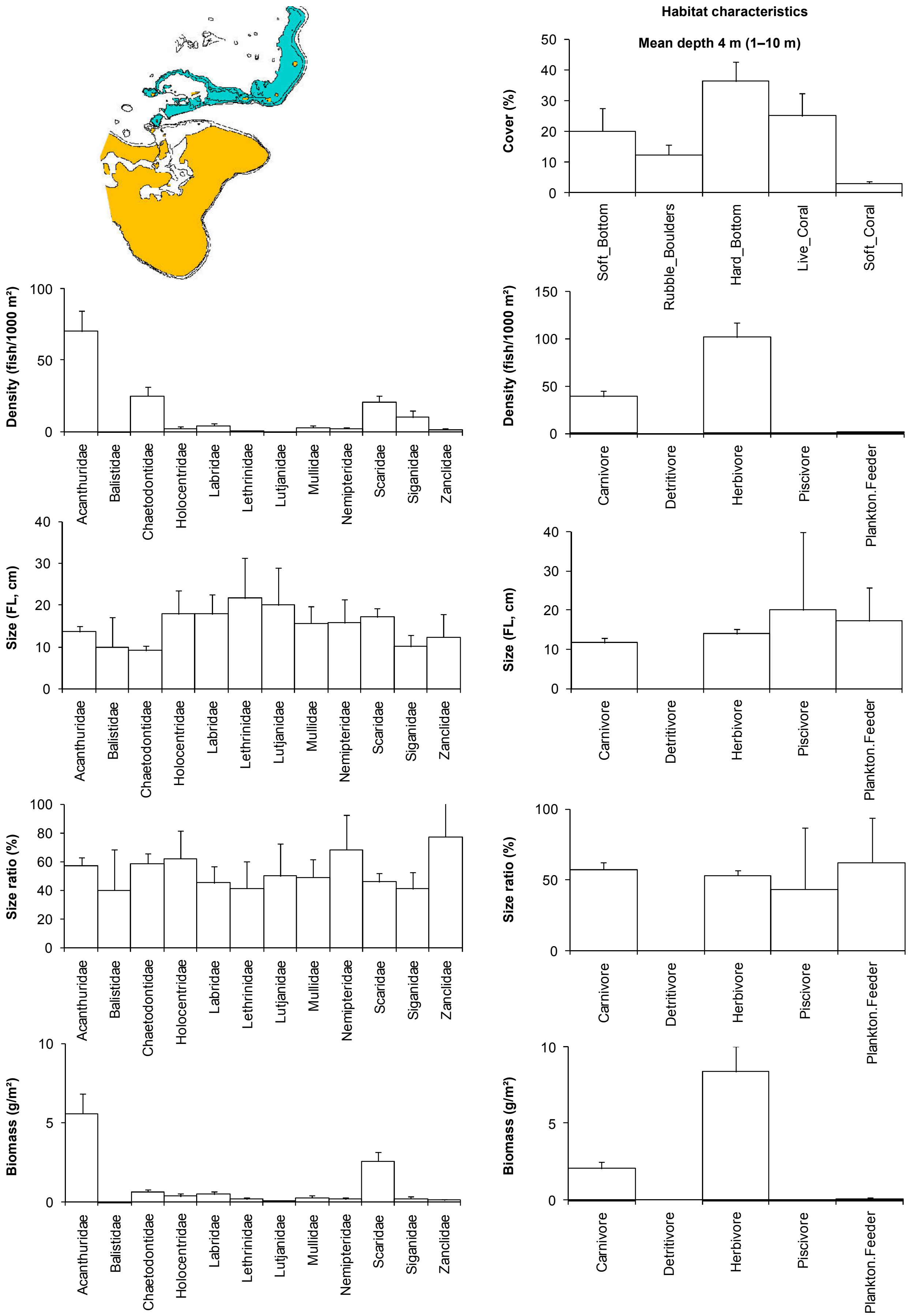

Figure 3.21: Profile of finfish resources in the back-reef environment of Manuka.
Bars represent standard error (+SE); FL = fork length.

Outer-reef environment: Manuka

The outer-reef environment of Manuka was dominated by one major family of herbivorous fish, Acanthuridae, followed in much lower importance by Scaridae (Figure 3.22, Table 3.10). These two families were represented by 12 species; particularly high biomass and abundance were recorded for *Ctenochaetus striatus*, *Acanthurus nigrofuscus* and *Zebrasoma scopas* (Table 3.10). This reef environment was composed of mainly hard bottom (52%), the lowest cover of hard coral among all reefs (19%), and very little soft bottom and rubble (17%, Table 3.10, Figure 3.22).

Table 3.10: Finfish species contributing most to main families in terms of densities and biomass in the outer-reef environment of Manuka

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.08 ±0.00	7.7 ±1.2
	Acanthurus nigrofuscus	Brown surgeonfish	0.02 ±0.01	1.4 ±0.7
	Zebrasoma scopas	Two-tone tang	0.01 ±0.00	0.8 ±0.5

The size, size ratio and biodiversity of finfish in the outer reefs of Manuka were the highest compared to the coastal-reef and back-reef values. Density and biomass were lower than at the coastal reefs; however, only one site was sampled in that environment. The trophic structure of fish was highly dominated by herbivores, mainly Acanthuridae. Carnivores were almost absent and mainly represented by Labridae. Size ratio was below 50% values for the families Labridae, Lutjanidae, Scaridae and Siganidae, suggesting a very high stress from fishing impact.

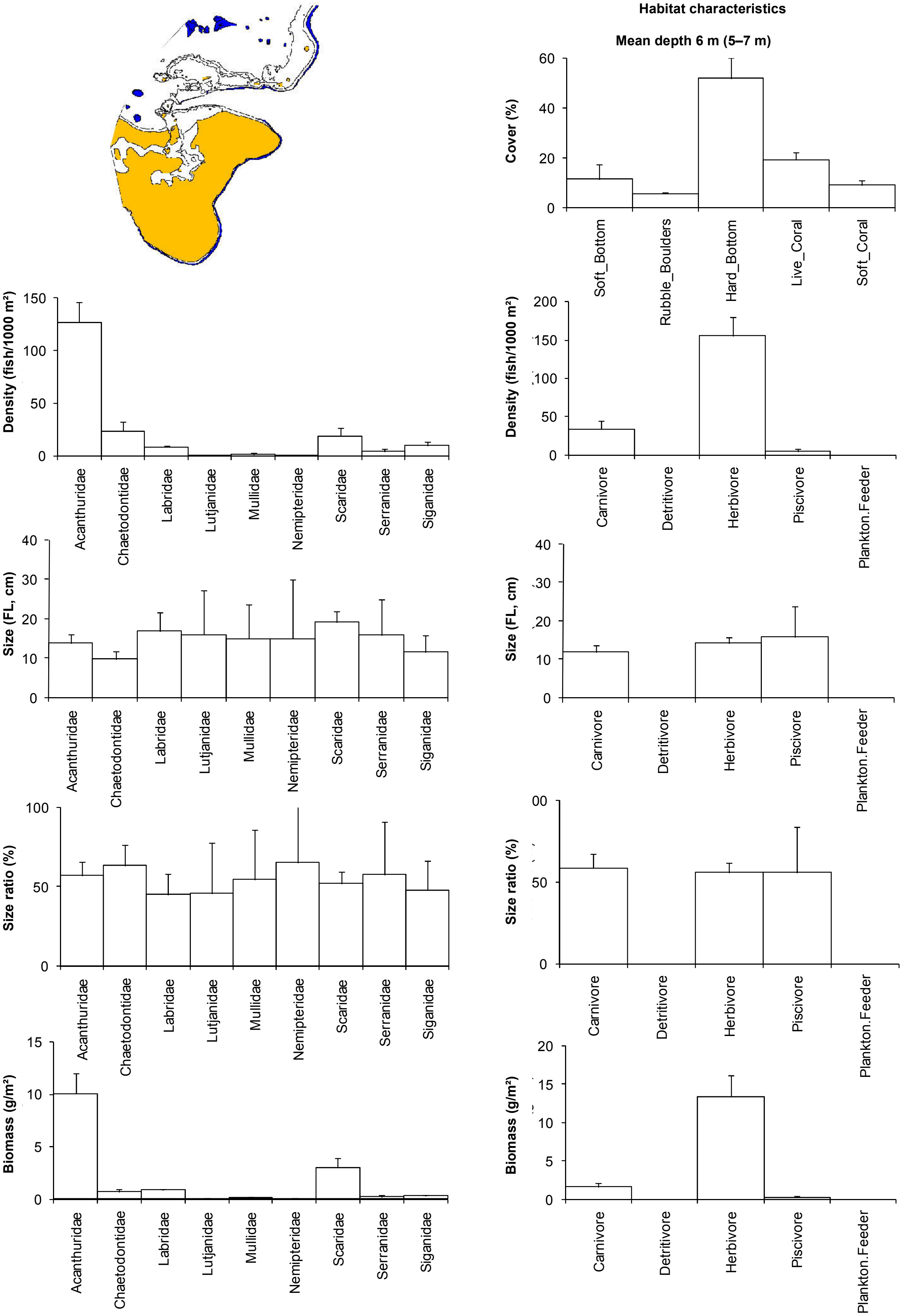

Figure 3.22: Profile of finfish resources in the outer-reef environment of Manuka.
Bars represent standard error (+SE); FL = fork length.

Overall reef environment: Manuka

Overall, the reefs of Manuka were heavily dominated by two main herbivorous families, Acanthuridae and Scaridae (Figure 3.23). These two families were represented by a total of 22 species, dominated by *Ctenochaetus striatus*, *Scarus rivulatus*, *Chlorurus sordidus*, *Scarus psittacus*, *Zebrasoma scopas* and *Acanthurus nigrofuscus* (Table 3.11). Overall, hard-bottom cover dominated the habitat (37%) and cover of live coral was relatively good (29%, Table 3.7 and Figure 3.23). The overall fish assemblage in Manuka shared characteristics of primarily back-reefs (59.5% of total habitat), then coastal reefs (22%) and finally outer reefs (18.5%).

Table 3.11: Finfish species contributing most to main families in terms of densities and biomass across all reefs of Manuka (weighted average)

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.06	5.5
	Zebrasoma scopas	Two-tone tang	0.02	0.8
	Acanthurus nigrofuscus	Brown surgeonfish	0.01	0.7
Scaridae	*Scarus rivulatus*	Rivulated parrotfish	0.01	2.1
	Chlorurus sordidus	Daisy parrotfish	0.01	1.8
	Scarus psittacus	Common parrotfish	0.01	0.9

Overall, Manuka appeared to have a very poor finfish resource, with lowest density, biomass and biodiversity among all sites visited in Tonga. The detailed assessment at the fish community composition level revealed much poorer density and biomass allocated to carnivore and piscivore species compared to herbivores, which strongly dominated the fish community. The biomass of herbivores was on average more than four times higher than the biomass of carnivores, while piscivores were practically absent. Few families dominated the community and a general lack or serious poverty of carnivores was the dominant profile: Labridae, Lutjanidae and Mullidae were present in extremely low numbers and mostly in coastal reefs, while Lethrinidae and Serranidae were practically non-existent. The dominance of herbivores can be partially explained by the composition of the habitat, mainly composed of hard rock and live coral, with little percentage of soft substrate, which normally favours most invertebrate-feeding carnivores. The composition of the major families was made of small-sized species, a further indication of fishing impact. From the analysis of size and size ratio, fish were present only with small or very small individuals, clearly indicating an impact on all fish groups.

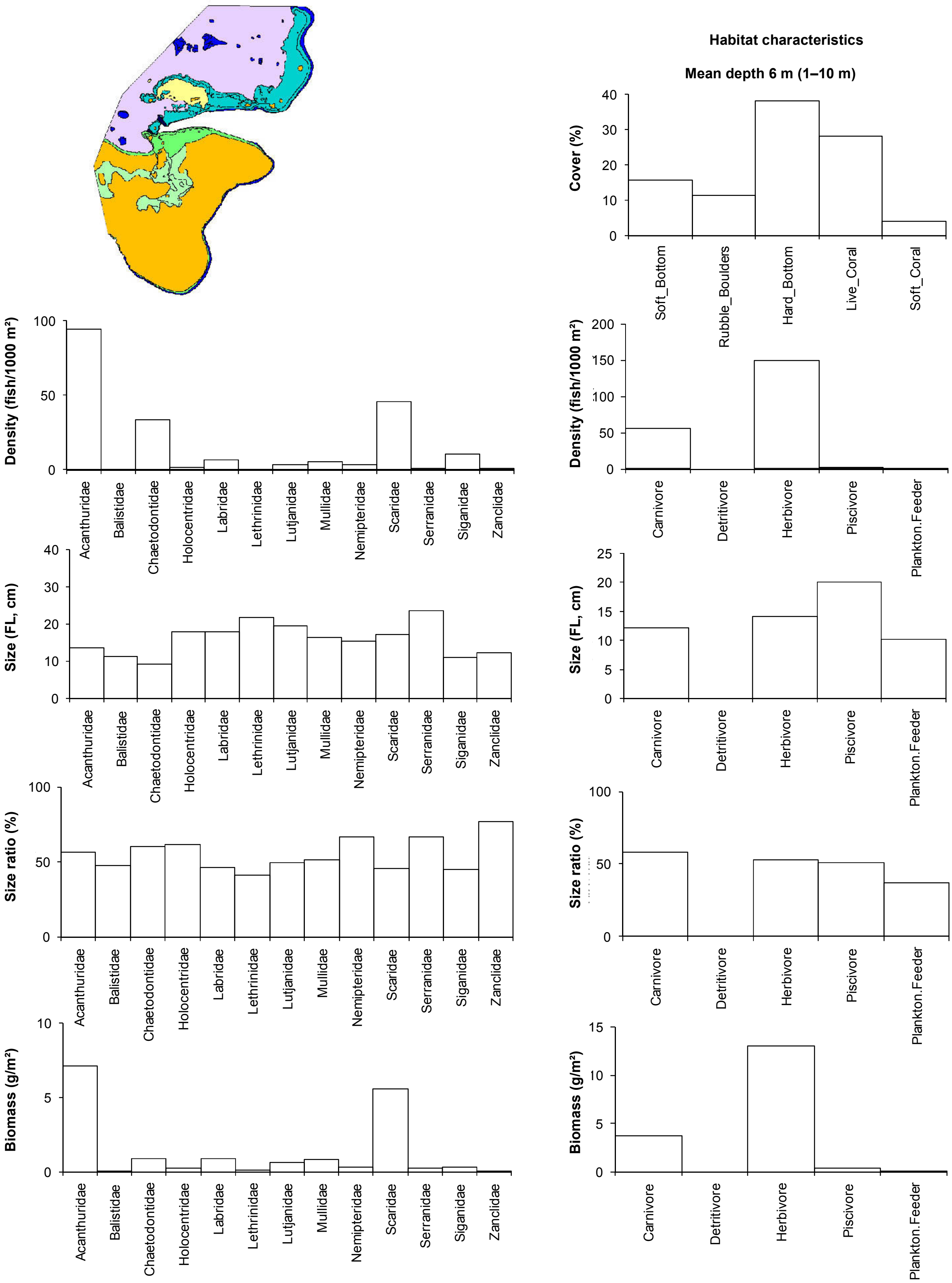

Figure 3.23: Profile of finfish resources in the combined reef habitats of Manuka (weighted average).
FL = fork length.

Comparisons with 2002 survey

The four PROCFish sites of Tonga surveyed in 2008 were previously surveyed in 2002. It is therefore possible to draw some comparisons between the two data sets in terms of average values of the biological parameters.

Average density and biomass were lower in 2008, while size and size ratio did not appear to show important changes. Therefore, the decrease in biomass was mainly due to a decrease in number of fish (Figure 3.24). Biodiversity was also significantly lower in 2008 (28 species/transect) compared to 2002 (32 species/transect). The trend of trophic composition did not change between the two surveys except for a strong decrease in the biomass of herbivores (Figure 3.25). The most important change was in species composition: *Chlorurus sordidus* and *Scarus psittacus*, the two most important species in 2002 (Table 3.13), displayed much lower density and biomass in 2008 (Table 3.11), and were replaced by *Ctenochaetus striatus*, which had much higher density and biomass in 2008 (Table 3.11). All the main species had much lower density and biomass in 2008 compared to 2002.

Table 3.12: Primary finfish habitat and resource parameters recorded in Manuka in 2002 and 2008

Parameters	Year of survey	
	2002	2008
Number of transects	16	12
Total habitat area (km^2)	68.3	83.79
Depth (m)	3 (0–12) (1)	6 (1–10) (1)
Soft bottom (% cover)	17.9	15.7
Rubble & boulders (% cover)	10.8	11.4
Hard bottom (% cover)	31.3	38.1
Live coral (% cover)	21.4	28.1
Soft coral (% cover)	3.1	4.2
Biodiversity (species/transect)	32 ±2	28 ±2
Density (fish/m^2)	0.31	0.21
Size (cm FL) (2)	15	14
Size ratio (%)	46	54
Biomass (g/m^2)	32.1	17.2

(1) depth range; (2) FL = fork length.

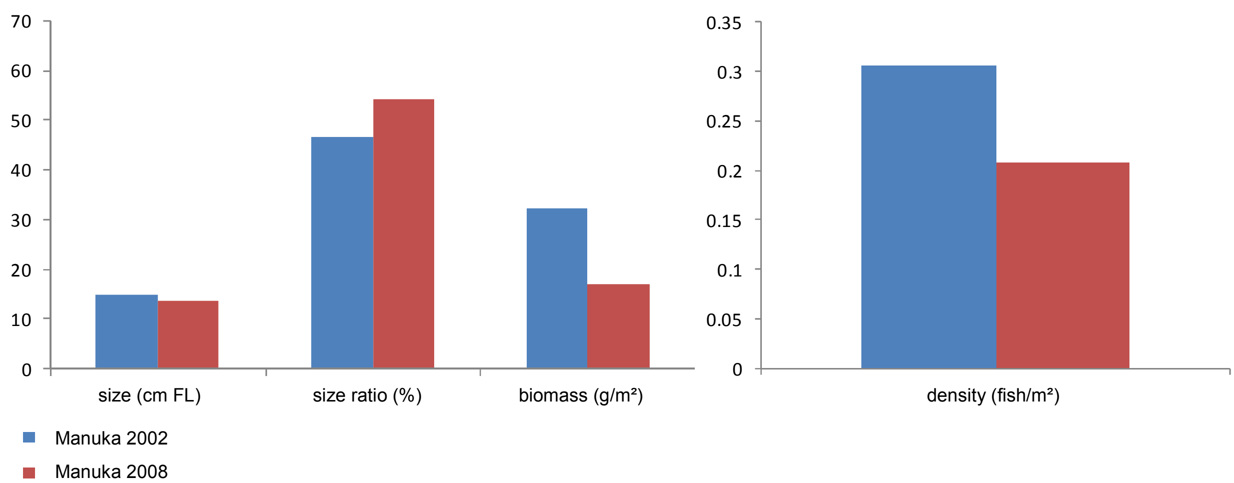

Figure 3.24: Variation in average size, size ratio, biomass and density of finfish in Manuka between 2002 and 2008.

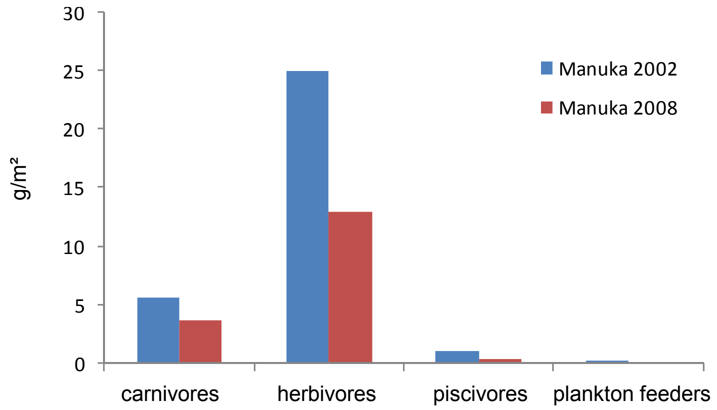

Figure 3.25: Trophic composition in terms of biomass in Manuka in 2002 and 2008.

Table 3.13: Finfish species contributing most to main families in terms of densities and biomass across all reefs of Manuka in 2002 (weighted average)

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Scaridae	*Scarus psittacus*	Common parrotfish	0.05	6.2
	Scarus schlegeli	Schlegel's parrotfish	0.02	2.2
	Chlorurus sordidus	Daisy parrotfish	0.04	4.2
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.04	4.1

3.3.2 Discussion and conclusions: finfish resources in Manuka

- Fishing in Manuka is open-access. People from the village of Manuka and Ha'atafu fish in the same area and fishing ground.

- The assessment indicated that the status of finfish resources at this site at the time of surveys was very poor. Density was low in terms of the regional average but sizes and biomass values especially were very low. Biodiversity was also very poor, poorer than in countries to the east of Tonga, therefore suggesting a response not only to the distance from the centre of biodiversity but also to the impact from heavy fishing. The two most important families were the herbivores Acanthuridae and Scaridae, while carnivores were very scarce. Some carnivore families were practically absent, e.g. Serranidae and Lethrinidae. The most representative fish in terms of density and biomass were small-sized fish displaying average sizes much lower than the maximum reported from the literature. We suggest that this overall poverty is due to high fishing impact. Back-reefs were the poorest habitats with the lowest density, small sizes, very poor biomass and low biodiversity. Outer reefs displayed a higher number of species but very low density and biomass as well. Coastal reefs, of difficult access, were sampled only at one station. They displayed higher density than the other habitats, but this could be an effect of the sampling bias.

- In 2002 conditions of finfish were better than in 2008, with higher biodiversity, density, size, size ratio and biomass than in 2008.

- The Atata island reserve was recently created and two transects were surveyed windward and leeward of this zone. It is interesting to note that the reaction of fish there was completely different from the other sectors since observation distances were smaller and there was almost no fleeing reaction. This proves that fishers respect this reserve and suggests that more protected areas are needed.

- Resources were, overall, in very poor condition, and much poorer than in 2002. The back-reefs were the poorest habitat sampled.
- Density and biomass of fish were highest in the only station sampled for coastal reefs.
- Finfish biodiversity was highest at the outer reefs but still very poor compared to other sites and countries.
- Fish size was particularly small at all reefs.
- The fish community composition was heavily dominated by the two herbivorous families Acanthuridae and Scaridae, represented only by a few small-sized species.
- The use of spearfishing should be controlled and a ban on night spearfishing be imposed.
- Net mesh size should be regulated.
- A monitoring system should be set in place to follow any further changes in finfish resources.
- More community-managed reserves such as the Atata island reserve should quickly be established to restore the exploited resources and should be followed by patrolling to enforce compliance and allow finfish stocks to recover.

3.4 Invertebrate resources: Manuka

The diversity and abundance of invertebrate species at Manuka were independently determined using a range of survey techniques (Table 3.14), broad-scale assessment (using the 'manta-tow' technique; locations shown in Figure 3.26) and finer-scale assessment of specific reef and benthic habitats (Figures 3.27 and 3.28).

The main objective of the broad-scale assessment is to describe the distribution pattern of invertebrates (rareness/commonness, patchiness) at large scale and, importantly, to identify target areas for further, fine-scale assessment. Then, fine-scale assessment is conducted in targeted areas to specifically describe the status of resource in those areas of naturally higher abundance and/or most suitable habitat.

The in-water work completed at the two sites at Tongatapu were not all standard PROCFish surveys, as we used the opportunity of this scheduled work to respond to a specific request by the Government of Tonga. This request was to assess the sea cucumber resources linked with surveys in Ha'apai, and to conduct in-water work to train staff and advise on the colonisation of trochus, *Trochus niloticus*, following the concerted effort made by the authorities to introduce mother-of-pearl resources to local reefs.

Table 3.14: Number of stations and replicate measures completed at Manuka

Survey method	Stations	Replicate measures
Broad-scale transects (B-S)	12	70 transects
Slope 'manta' transects (10–20 m)		12 transects (2)
Deep 'manta' transects (20–30 m)		12 transects (2)
Reef-benthos transects (RBt)	19	117 transects
Soft-benthos transects (SBt)	11	50 transects
Soft-benthos infaunal quadrats (SBq)	6	48 quadrat groups
Mother-of-pearl transects (MOPt)	8	54 transects
Mother-of-pearl searches (MOPs)	2	12 search periods
Reef-front searches (RFs) (1)	13	102 search periods
Reef-front search by walking (RFs_w)	0	0 search period
Sea cucumber day searches (Ds)	See slope and deep 'manta' transects	24 search periods (2)
Sea cucumber night searches (Ns)	0	0 search period

(1) Reef-front search stations were completed with more than the normal two officers and therefore each station can have more than six replicates; (2) search periods for deep-water work were 100 m in length and 4 m swathe.

Figure 3.26: Broad-scale survey stations for invertebrates in Manuka.
Data from broad-scale surveys conducted using 'manta-tow' board;
black triangles: transect start waypoints.

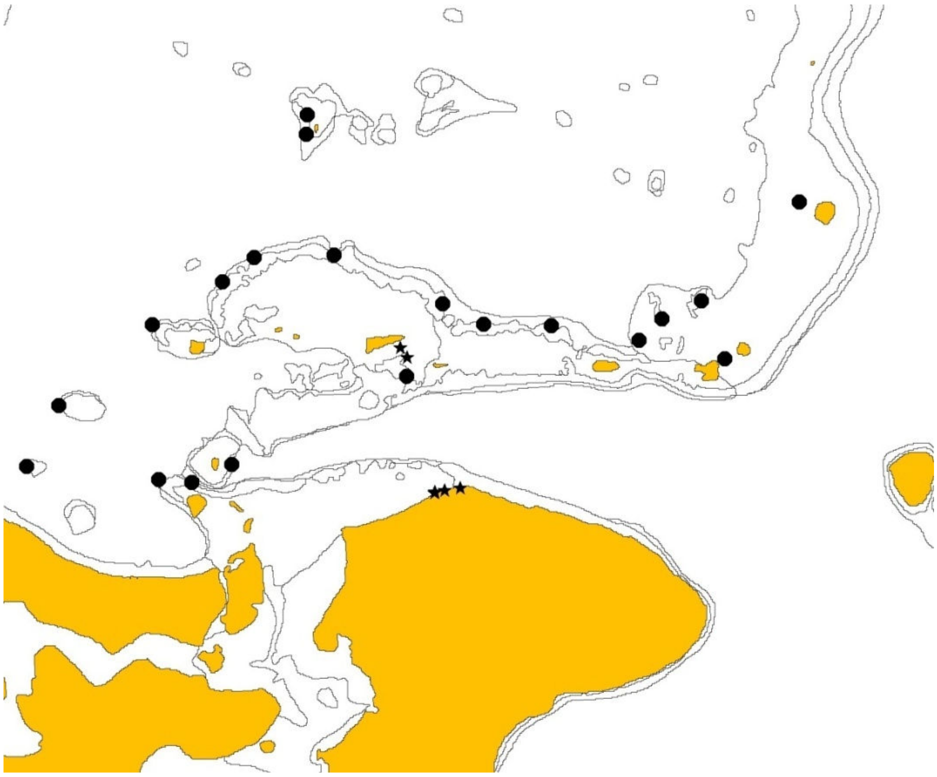

Figure 3.27: Fine-scale reef-benthos transect survey stations and soft-benthos transect stations for invertebrates in Manuka.
Black circles: reef-benthos transect stations (RBt);
Black stars: soft-benthos transect stations (SBt).

Figure 3.28: Fine-scale survey stations for invertebrates in Manuka.
Inverted black triangles: reef-front search stations (RFs);
black squares: mother-of-pearl transect stations (MOPt);
grey squares: mother-of-pearl search stations (MOPs).

Seventy-eight species or species groupings (groups of species within a genus) were recorded in the invertebrate surveys at Manuka. These included 13 bivalves, 32 gastropods, 18 sea cucumbers, 6 urchins, 6 sea stars and 1 cnidarian (Appendix 4.2.1). Information on key families and species is detailed below.

3.4.1 Giant clams: Manuka

Shallow-reef habitat that is suitable for giant clams on the fringing, intermediate and offshore reefs associated with Manuka was extensive. The main access to hard-bottom invertebrate fishing areas is through the gleaning of boulder, patch-reef and broken limestone-pavement areas within and at the edge of seagrass beds, although a more extensive reef system exists offshore from Manuka (but needs boat access). This type of submerged reef for gleaning is known in Tongan as *hakau*. Fishing is generally open-access in Tonga and no set fishing area is noted in this report (Shallow-water reef area was calculated from satellite images of Tongatapu to be 82.0 km^2.).

The environment at Manuka was a mix of land- and oceanic-influenced habitats. As there was no enclosed lagoon and significant through-flow of oceanic water the benthos was relatively well flushed. However, seagrass areas did exist on the extended flats in front of Manuka and south of the offshore island facing Manuka (Onevai island).

Reefs at this site held two species of giant clam: the elongate clam *Tridacna maxima* and the fluted clam *T. squamosa*. The smooth clam *T. derasa* has, on occasion, been introduced to the waters of Tongatapu (from hatchery spawnings). One individual clam was noted that might have been a *T. derasa* or a *T. tevoroa* that was 15 cm in length (west of Atata Island, near the small islands on the barrier), but no clear identification could be made. The devil's clam *T. tevoroa*, which was found in deeper-water surveys in Ha'apai, was not found in these surveys.

Shallow-water broad-scale sampling provided an overview of giant clam distribution and density; *T. maxima* had the widest distribution (found in 7 of 12 stations and 14 of 70 transects), followed by *T. squamosa* (2 stations and 3 transects). The average station density of *T. maxima* in broad-scale, shallow-water surveys was 11.7 /ha ±6.9, see Figure 3.29).

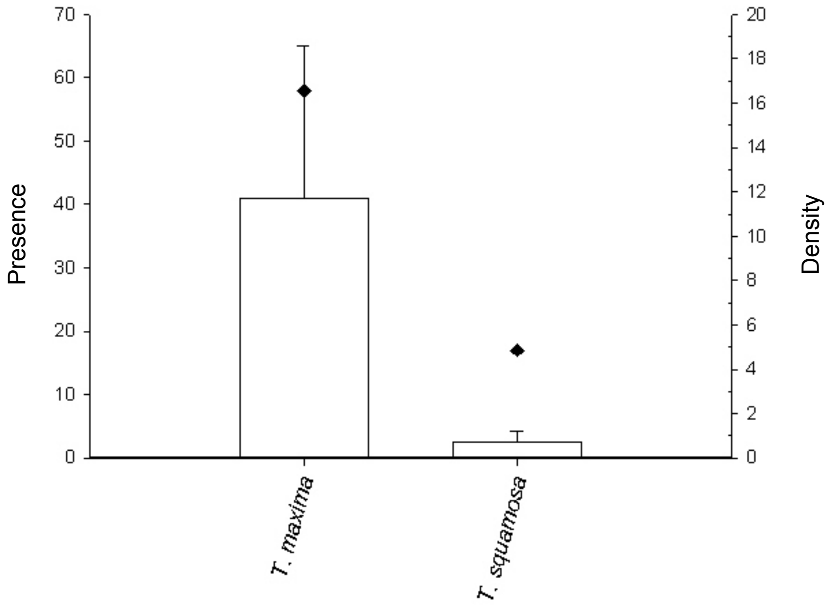

Figure 3.29: Presence and mean density of giant clam species in Manuka based on broad-scale survey.
Presence is measured as % of stations surveyed where clams were present and denoted by black diamonds; density is measured in numbers per hectare and is represented by bars (+SE).

Based on the findings of the broad-scale survey, finer-scale surveys targeted specific areas of clam habitat (Figure 3.30). In these reef-benthos assessments (RBt), *T. maxima* was present in 42% of stations at a mean density of 28.5 /ha ±10.1.

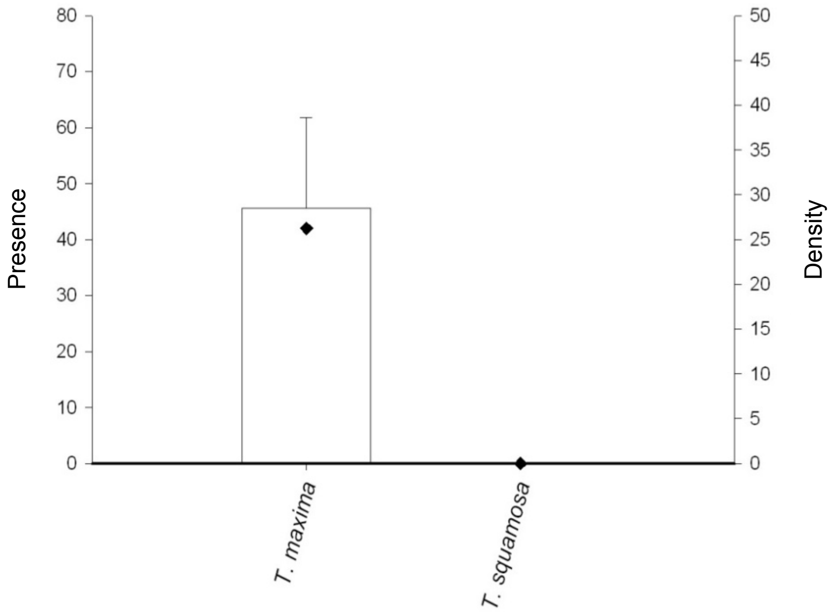

Figure 3.30: Presence and mean density of giant clam species in Manuka based on fine-scale survey.
Presence is measured as % of stations surveyed where clams were present and denoted by black diamonds; density is measured in numbers per hectare and is represented by bars (+SE).

In general, clams were quite uncommon at Manuka, with 11 RBt stations holding no records of clam and the highest station average density being just 167 /ha. At best, this represents just four clams in six transects of 40 m².

From a total of 105 clams recorded from all assessment techniques at Manuka, 18 length recordings were made. The average length of *T. maxima* clams taken in surveys was 14.7 cm ±1.9 (n = 18), which represents a clam of greater than 7–8 years old (See Figure 3.31.). Only four *T. squamosa* (which grow to an asymptotic length L_∞ of 40 cm) were noted and the average length from the three measured was 17.7 cm ±5.9. These clams are faster growing; a 17 cm *T. squamosa* is probably around four years of age.

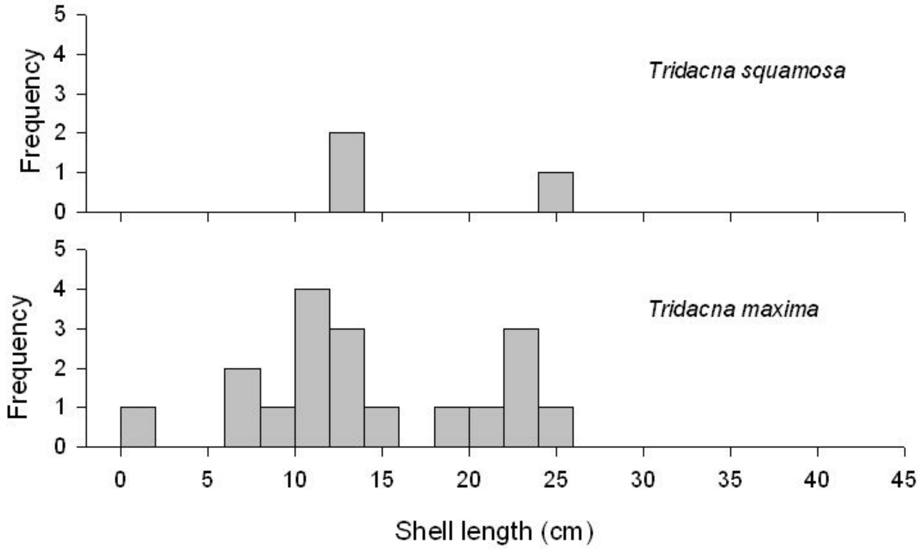

Figure 3.31: Size frequency histograms of giant clam shell length (cm) for Manuka.

Small *T. maxima* (<10 cm in length) were recorded at Manuka, which shows that recruitment is still occurring, although large *T. maxima* clams (≥16 cm) were not common (See Figure 3.31). Size records for *T. squamosa* were too few to make any useful comment.

3.4.2 Mother-of-pearl species (MOP) – trochus and pearl oysters: Manuka

Tongatapu is the largest and main island of the Tonga archipelago. Tongatapu lies 21°S and 175°E, which is outside the east–west range of the commercial topshell, *Trochus niloticus* (found naturally on islands as far east as Wallis). As in other eastern Pacific islands, commercial mother-of-pearl shells have been introduced to Tongatapu.

After the successful translocation and establishment of trochus and green snail (*Turbo marmoratus*) into Cook Islands and French Polynesia in the 1950s, the Tongan government requested assistance for the introduction of these species. The first translocation was carried out in August 1992, when 250 wild trochus broodstock were brought in from Fiji Islands Lau Group and released on Tabana Island in the Vava'u Group (Gillett 2002). In May 1994, another 1092 trochus shells were donated to Tonga again by Fiji Islands; these were released on Tongatapu, although some were retained for breeding purposes in the hatchery (Table 3.15).

Prior to the releasing of the shells, a habitat-suitability assessment survey was conducted at 17 sites around Tongatapu (Sone 1992). Eighty per cent of the sites assessed on the north-facing side of Tongatapu, which covered fringing reefs, islet reefs, patch reefs, barrier reefs and the island of Eueiki all recorded presence of potential index species, such as *Turbo argyrostomus*, *T. setosus* and *T. crassus* (Sone 1992). The presence of *Turbo* and *Tectus* species was used as an index for trochus habitability and sites were selected as release areas for the introduced adult trochus and green snail (Sone 1992).

In May 1994, 500 trochus shells were released at the front of the barrier reef at Fukave island. The other 400 shells were released at Eueiki island, an offshore island off Fukave island. The records of adult trochus releases are summarised in Tables 2.14 and 2.15.

The reefs at the lagoon front of Manuka constitute an extensive benthos for *T. niloticus* and records show (Table 3.15) that introductions of adult shells have been sufficient to build up a moderate-level stock and create the conditions suitable for the formation of a fishery in the medium-term future.

Table 3.15: Presence and mean density of *Trochus niloticus*, *Tectus pyramis*, *Turbo marmoratus* and *Pinctada margaritifera* in Manuka
Based on various assessment techniques; mean density measured in numbers per ha (±SE)

	Density	SE	% of stations with species	% of transects or search periods with species
Trochus niloticus				
B-S	0	0	0/12 = 0	0/70 = 0
RBt	149.1	48.7	12/19 = 63	30/117 = 26
RFs	26.5	7.3	5/13 = 38	5/102 = 5
MOPt	301.2	69.3	8/8 = 100	42/54 = 78
MOPs	30.3	30.3	1/2 = 50	3/12 = 25
Tectus pyramis				
B-S	1.8	0.8	3/12 = 25	5/70 = 7
RBt	39.5	11.7	9/19 = 47	16/117 = 14
RFs	13.8	5.5	10/13 = 77	29/102 = 28
MOPt	0	0	0/8 = 0	0/54 = 0
MOPs	0	0	0/2 = 0	0/12 = 0
Turbo marmoratus				
B-S	0	0	0/12 = 0	0/70 = 0
RBt	0	0	0/19 = 0	0/117 = 0
RFs	0	0	0/13 = 0	0/102 = 0
MOPt	2.6	2.6	1/8 = 13	1/54 = 2
MOPs	0	0	0/2 = 0	0/12 = 0
Pinctada margaritifera				
B-S	3.4	1.8	4/12 = 33	7/70 = 10
RBt	6.9	4.9	2/19 = 11	3/117 = 3
RFs	0.6	0.5	2/13 = 15	2/102 = 2
MOPt	2.6	2.6	1/8 = 13	1/54 = 2
MOPs	11.4	11.4	1/2 = 50	3/12 = 25

B-S = broad-scale survey; RBt = reef-benthos transect; RFs = reef-front search; MOPt = mother-of-pearl transect; MOPs = mother-of-pearl search.

PROCFish survey work located 328 live *T. niloticus* at Manuka (Table 3.15). The mean size (basal width) of *T. niloticus* was 9.9 cm ±0.1 (n = 216 individuals). Interestingly, shells recorded at sites in Manuka had very few small-sized trochus (<7 cm basal width). For this cryptic species, younger shells are normally only picked up in surveys from the size of about 5.5 cm, when small trochus are emerging from a cryptic phase of life and joining the main stock. Therefore, it is normal to find only a few of these smaller-sized trochus; however, when Manuka results are compared with results from the whole of Tongatapu, the complement of small shells is still low. This indicates that the bulk of stocks at Manuka is within the capture size classes or larger; there was no large recruitment pulse of young trochus evident (First maturity of trochus is at 7–8 cm, approximately three years old; see Figure 3.32).

Tectus pyramis, a closely related gastropod, was also recorded (n = 77 individuals) at a mean size of 8.1 cm ±0.3 (n = 12 individuals). This less valuable species of topshell (also an algal grazer, with a similar life history to trochus) was not as common as trochus at Manuka.

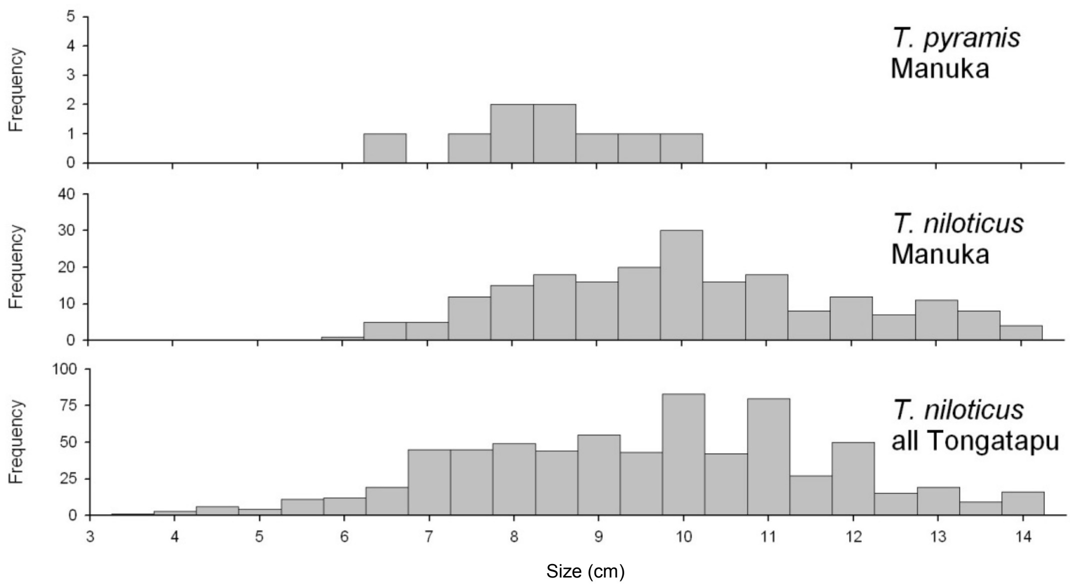

Figure 3.32: Size frequency histograms of *Tectus pyramis* and *Trochus niloticus* shell base diameter (cm) for Manuka.

Green snail (*Turbo marmoratus*) juveniles were also stocked on to reefs in Tongatapu, although there is little information on the locations where they were released. In these surveys only a single *T. marmoratus* was recorded in MOPt station surveys. The average density was low at 2.6 /ha, and this recording was taken from Fukave reef, which is not far distant from Eueiki island and a reef where previous translocations had been made. The green snail noted on Fukave reef was 14 cm in size.

Blacklip pearl oysters (*Pinctada margaritifera*) are normally cryptic and sparsely distributed in open lagoon systems. However, the dynamic through-flow of water at the complex reef system in front of Manuka presented suitable shallow-water reef for this species (a total of n = 23 individuals recorded). The average density of this species was 35.5 /ha for one broad-scale station (Maximum 300 m transect density was 109.2 /ha, south of Onevai island at the margin of the channel.). The mean size of these shells was 12.3 cm ±2.2 (dorso–ventral measure).

3.4.3 Infaunal species and groups: Manuka

Fine-scale infaunal stations on soft benthos (quadrat surveys) were made at Manuka to assess species groups within the ground. Soft-benthos coastal margins were common in front of the village at Manuka and extensive areas of seagrass and coral rubble were noted there and also south of Onevai island. Concentrations of in-ground resources (shell 'beds'), such as arc shells (*Anadara* spp. called *kaloa'a*), were not identified, despite fishers ranging widely to collect them. Locations sampled for in-ground species showed that arc shells were not common in Manuka (1 of 6 stations held *Anadara*). This species was recorded at a mean station density of 0.1 ±0.1 individuals/m^2. A single station recorded *Anadara* spp., and shells were only noted in one of the eight quadrat groupings tested (See Methods.). Arc shells were also present in most catches, but again did not comprise a large part of the catch. They were only specifically targeted in small, shallow-water sand patches in the seagrass. Catch rates at Manuka and Onevai averaged 1.1 individual/hour ±0.6 (n = 4) and 4.9 individuals/hour ±1 (n = 4 fishers) respectively.

The average shell length of *kaloa'a* in front of the village was 7.2 cm ±0.2 (n = 7) and 6.0 cm ±0.2 at Onevai (n = 7). The average length of all gleaned *Anadara* spp. significantly exceeded those sold in the Nuku'alofa market (mean 4.9 cm ±0.07, n = 128), which were generally sourced from the Patangata and Popua areas.

Although infaunal species were not assessed within soft-benthos transect surveys, some adult *Anadara* spp. were also noted on the surface of the substratum. Detection rates in this style of survey are undoubtedly an underestimate – but the average recorded for Onevai was 32 individuals/ha ±16 (n = 3 SBt stations).

The main invertebrate species collected by fishers at Manuka was typically the dolabellid sea cat *Dollabella auricularia* (locally called *mulione*, or *ngou'a* when small). *D. auricularia* is herbivorous and well camouflaged, remaining cryptic during the day, burrowed just under the surface of the substrate or under rubble or within indentations and hollows. Although part of its dorsal surface (the inhalent siphon-opening in the mantle folds) remains partially emerged, its visibility is usually obscured by seagrass or debris around the burrowed animal.

Average catch rates for this species were 10–16 pieces/hour (13.8 ±3.3, n = 14 fishers) although dedicated dollabellid fishing yielded an average of 35 pieces/hour (at more distant sites in Ha'atafu, n = 2 fishers). As a point of comparison, Quinn and Davis (1997) recorded catch rates of approximately 24 pieces/hour for non-replicated observations in Fiji Islands. Manuka creel surveys had the lowest average CPUE rates of those noted at Tongatapu (5.0 /hour ±1.5, n = 4 fishers). The rate was higher at Onevai, the collection site offshore of Manuka (9.6 /hour ±4.95, n = 4 fishers), where seagrass beds were the most extensive. There was no significant variation in CPUE between Ha'atafu and Onevai, although CPUE at Manuka was significantly lower than at Ha'atafu.

Detection rates of *D. auricularia* in survey transects were typically low, as infaunal assessments were not part of the soft-benthos transect surveys (found in 36% of soft-benthos transect stations, at a mean density of 23.8 individuals/ha ±10.6). However, in some areas of Ha'atafu, possibly where the hard base was closer to the surface of the sandy substrate, densities were recorded at an average of 289.4 individuals/ha ±69.4 (n = 13 stations), with a maximum average density at one site of 761.9 individuals/ha ±95 for a single station (n = 6 transects). These would be minimum densities due to the fact that fully buried individuals would not have been detected by this type of assessment. At Manuka and Onevai the detection rate was lower, yielding an average survey density of 8.9 individuals/ha ±9 (n = 8 sets) and 63.5 individuals/ha ±16 (n = 3 sets) respectively.

Mussels, *Modiolus* spp. (*kuku*), were only found at low density throughout all seagrass patches, with fishers collecting 0.12 and 0.36 individuals/hour at Ha'atafu and Manuka. The offshore seagrass patch south of Onevai held high-density patches of *Modiolus* in the shallows and, although gleaners did not preferentially target this species, the catch rate recorded was 37.2 individuals/hour ±8 (n = 4 fishers). The average shell length of *Modiolus* fished was 5.2 cm ±0.1 (n = 51) with an average unprocessed weight of 16.4 g/individual ±1 (n = 51).

Close to the low-tide mark near the village of Manuka, among the sand and coral stone/limestone platform can be found *Tellina* (*quidnipagus*) *palatam* (*mehingo*). This species is also not preferentially targeted in Tongatapu, possibly due to the difficulty in finding patches of clear sand (without stone pieces to hamper digging). *Tellina palatam* was not fished by any gleaners at the time of this study; however, in experimental digging with a full-sized garden pitchfork, 270 individuals/hour were collected. The shell length was between 2.8 and 4.9 cm, averaging 3.9 cm ±0.1 (n = 49). They were delicious baked in the *umu* (earth oven) with coconut milk.

A gastropod, *Strombus gibberulus*, was found with *S. labiatus* (both called *kele'a*) at Manuka, particularly inshore on sparse grass and algal-mat patches. *S. gibberulus* is the most targeted species as it grows to a larger size than *S. labiatus*; *S. gibberulus* grows to a maximum of 7 cm shell length, while *S. labiatus* grows to a maximum of only 5 cm. Large numbers of *S. gibberulus* could be collected rapidly by fishers, although this species requires significant post-harvest processing to retrieve the edible portion and is therefore not preferentially targeted.

One fisher was recorded collecting *S. gibberulus* at a rate of 127 individuals/hour, although she was not making dedicated collections of this species and preferentially targeted the largest sizes. Anecdotal information suggests this species is preferentially targeted during prolonged periods of bad weather and for feeding to young children during weaning. Survey of the denser, inshore algal-mat patches yielded densities of *S. gibberulus* of 10.8 individuals/m^2 ±3.1 (n = 6 stations using six 1 m^2 quadrats/station) with a single station maximum of 29 individuals/m^2, whereas *S. labiatus* was found at lower densities. The average shell length and weight of *S. gibberulus* was 3.3 cm ±0.1, and 4.3 g ±0.2 (n = 62). The maximum shell length for *S. gibberulus* was 4.5 cm. The length and weight of *S. labiatus* was 2.5 cm ±0.02 and 2.1 g ±0.2 (n = 20).

Other species were also collected during soft-benthos gleaning (Table 3.16). These included *Pitar proha* (mean density of 6.8 individuals/m^2 ±5.1) and *Tellina scobinata* (mean density of 0.2 individuals/m^2 ±0.2), which were also recorded in infaunal assessments. Octopus (*Octopus cyanea*) was also much sought after by gleaners, but collection rates were not high on regularly fished seagrass areas near villages. From the observed gleaning of seagrass (total of 42 hours 40 mins fisher time) only one octopus was taken.

Table 3.16: Species data from invertebrate gleaners taken in Manuka and Onevai

Species	CPUE - individuals/hour ($\bar{x}$, SE, n)		Length - mm ($\bar{x}$, SE, n)		Comments
	Manuka	Onevai	Manuka	Onevai	
Conus spp.	0.4, 0.2, 4	0	46, 62, 68		Shell length, *C. leopardus*, *C. miles*
Cerithium nodulosum	0.4, 0.4, 4	0.4, 0.2, 4		58, 62,	
Cypraea	0.2, 0.2, 4	0.4, 0.2, 4	75	90, 85, 92	*C. tigris*
Trochus niloticus	0.2, 0.2, 4	0.1, 0.1, 4		64	
Turbo chrysostomus	0	0.1, 0.1, 4			
Strombus luhuanus	0	0			One patch
Cymatium spp.	0	0			Possibly *C. pileare*
Polinices spp.	0	0			*P. flemingatus*
Tellina scobinata	0.5, 0.3, 4	0.1, 0.1, 4	67	70	
Pharaonella tongana	0.2, 0.2, 4	0			
Gafrarium pectinatum	0	0.5, 0.3, 4		32	Average length
Fimbria fimbria	0.2, 0.2, 4	0.1, 0.1, 4	43	50, 50	
Pinctada margaritifera	0	0.1, 0.1, 4		116	
Fragum spp.	0	0			*F. unedo* and *F. fragum*
Pitar prora	0	0.1, 0.1, 4			
Cassiopea andromeda	0	0			Eaten raw
Caulerpa spp.	collected	0			
Calappa spp.	0.7, 0, 4	0.1, 0.1, 4	66, 64, 46, 52	68, 61	Carapace width
Hermit crab	0.2, 0.2, 4	0			
Acanthopleura spp.	0	2, 2, 4		65, 5, 38	Curled – so average weight in g, SE, n
Onchidium spp.	0	0.2, 0.2, 4			
Eel	0.4, 0.2, 4	0.3, 0.2, 4		196–450	Length range

3.4.4 Other gastropods and bivalves: Manuka

Tongan fishers have over 203 names for marine invertebrates and 87 for molluscs (Malm 1999). Seba's spider conch, *Lambis truncata* (the larger of the two common spider conchs) was recorded at low density (n = 3 individuals) in 3% of broad-scale transects. In Manuka, *Lambis lambis* (n = 44) was relatively common (recorded in B-S, RBt and SBt stations) and this species is often the first on the list of primary *fingota* (shellfish) taxa (called *anga anga* locally, Malm 1999). At Manuka and Onevai, the average CPUE was between 3 individuals/hour ±0.3 and 3.3 individuals/hour ±0.6 (n = 4 fishers). In-water surveys at Manuka yielded an average density of 53.5 individuals/ha ± 29 (n = 8 SBt stations). Average density of *L. lambis* at Onevai was 63.5 individuals/ha ±42 (n = 3 SBt stations). Another important resource species, the strawberry or red lipped conch (*Strombus luhuanus*) was also recorded at Manuka (n = 12 individuals) (Appendices 4.2.1 to 4.2.7).

In addition to the single *Turbo marmoratus* found, a full range of small turban shells were recorded (e.g. *Turbo chrysostomus*, *T. crassus* and *T. setosus*). In quantity, only a small number of *Turbo* spp. were noted, with *T. crassus* and *T. setosus* limited to one MOPt station each. It was not possible to closely inspect the surf zone on the eastern shores of Fukave reef, where the density of turban species may have been greater, although the area had very high live-coral cover, which limits the space for algal grazers.

Other gastropod resource species targeted by fishers (e.g. *Astralium*, *Cerithium*, *Charonia*, *Chicoreus*, *Conus*, *Cymatium*, *Cypraea*, *Dolabella*, *Latirolagena*, *Mitra*, *Ovula*, *Pleuroploca*, *Polinices*, *Thais*, *Tutufa* and *Vasum*) were also recorded during independent surveys (Appendices 4.2.1 to 4.2.7). Data on other bivalves in broad-scale and fine-scale benthos surveys, such as *Atrina*, *Fragum*, *Hyotissa*, *Modiolus*, *Periglypta*, *Pinna*, *Spondylus* and *Tellina*, are also in Appendices 4.2.1 to 4.2.7.

Creel surveys were conducted at Manuka, both on soft and mixed benthos in front of the village (4 fishers, 84 minutes each) and on soft benthos south of Onevai island (4 fishers, 290 minutes each, see Table 3.16).

3.4.5 Lobsters: Manuka

Manuka had extensive areas of exposed reef front (barrier reef). This exposed reef, with exposed reef platforms and submerged reef slopes, provides a large amount of habitat for lobsters.

Although there was no dedicated night reef-front assessment of lobsters (See Methods.), surveys of the shallow and deep water (searching for sea cucumbers) afforded a potential source of lobster recordings. Despite the large amount of time spent surveying Tongatapu, however, no lobsters were noted.

3.4.6 Sea cucumbers[7]: Manuka

Manuka had extensive areas of shallow-water lagoon with complex reef structure and a range of soft-benthos areas bordering the large land mass of Tongatapu. A full range of protected, richer depositional areas (land influence) were found within the lagoon and exposed, oceanic-influenced areas were also present. Fringing reef margins, reef slopes and areas of shallow, mixed hard- and soft-benthos habitat were largely suitable for commercial sea cucumbers, which are generally deposit feeders (which eat organic matter in the upper few mm of bottom substrates).

Species presence and density were determined through broad-scale and fine-scale methods (Table 3.17, Appendices 4.2.2 to 4.2.8, also see Methods). In addition to the standard protocol for sampling, a special additional sampling protocol was initiated in Manuka in response to a request from the Tonga Government. To assist in this endeavour extra staff from Solomon Islands and PNG took part in the surveys and extra deep-water surveys (outside the general scope of PROCFish) were completed on SCUBA.

A short history shows that Tonga fisheries authority in 1997 recommended a zero quota (moratorium) on sea cucumber exports when it became clear that the fishery was in serious decline in the early 1990s. The Act provided for a 10-year moratorium, but also called for a five-year review of stocks to advise on their recovery and status. This extra work constitutes part of this review and provides extra information in addition to the three-point time series assessment of the sea cucumber fishery of Ha'apai.

Results from most of the individual survey methods are separated for the two PROCFish sites in Tongatapu (Manuka and Ha'atafu). The species list for Manuka returned 18 commercial species of sea cucumber from all in-water assessments (plus one indicator species, see Table 3.17). A further two species were noted in surveys concentrating on the western, Ha'atafu side of the system. The range of sea cucumber species recorded reflects both the variable nature of the habitats present and the level of management control that has been enforced over the fishery.

Sea cucumber species associated with shallow-reef areas, such as the medium-value leopardfish (*Bohadschia argus*), were common (found in 73% of broad-scale transects and 74% of reef-benthos transect stations). The average density recorded was also high (>50 /ha). In shallow reefs, the average density at two of the highest-density RBt stations was >400 /ha.

Stocks of high-value sea cucumbers, such as the black teatfish (*Holothuria nobilis*[6]), which is also found in shallow reefs, and is therefore easily targeted by fishers, were not commonly noted at Manuka. Although they were only recorded in 1% of broad-scale transects, they were also noted in RBT, RFs and MOPs stations. Wherever they were noted, black teatfish were at low average density (<4 /ha). There is some evidence that this species is highly susceptible to fishing pressure and, once depleted, can take years to recover to reasonable densities of >10 /ha. It is possible that previous heavy fishing around Tongatapu could still be impacting the viability of stocks at Manuka. Sea cucumbers are single-sexed, and release their eggs and sperm into the water column for fertilisation (broadcast spawners). Stocks such

[7] There has been a recent change to sea cucumber taxonomy that has changed the name of the black teatfish in the Pacific from *Holothuria* (*Microthele*) *nobilis* to *H. whitmaei*. It is possible that the scientific name for white teatfish may also change in the future. This should be noted when comparing texts, as in this report the 'original' taxonomic names are used.

as black teatfish, which are generally found at lower-density ranges, are susceptible to the negative effects that occur when overfishing decreases stock densities further, because reproduction success can be decreased when individuals become too widely dispersed for fertilisation of gametes to be maximised (See Figure 2.35).

The faster-growing and medium/high-value greenfish (*Stichopus chloronotus*) was more common (in 29% of broad-scale transects), being recorded in most assessments (B-S, RBt and RFs) and at reasonably high density in shallow-water reefs (mean density in RBt was 213.5 /ha ±85.2).

Surf redfish (*Actinopyga mauritiana*), which were recorded at high density in Ha'apai, were noted across the site. This species can be recorded at commercial densities of 500–600 /ha in oceanic-influenced and atoll islands in French Polynesia and Solomon Islands, but the densities at reefs in Manuka were not high (<30 /ha). The eastern arm of Fukave looked to be predominantly live coral, which is not very suitable for this species, which likes a reef of high complexity but is generally found at higher density where epiphytic algae is rich.

More protected areas of reef and soft benthos in depositional lagoon embayments were seen south of Onevai and just outside Manuka village. We recorded reasonable coverage but low numbers of blackfish (*Actinopyga miliaris*), stonefish (*A. lecanora*), elephant trunkfish (*Holothuria fuscopunctata*) and curryfish (*Stichopus hermanni*) across the site; they were generally at moderate density.

One higher-value species of great importance to Tonga is the golden sandfish, which is presently called *Holothuria scabra versicolor* (This scientific name has changed recently to *Holothuria lessoni* but, to maintain consistency in the PROCFish reports, we have kept the former name.). This species is concentrated at only a few locations in the shallow-water seagrass fringing the harbour areas of Tongatapu. It is unknown how this coverage reflects the original range for this species before large-scale harvest severely depleted stocks in the early 1990s. However, despite its often cryptic nature in the seagrass and rubble, it was still noted in 9% of broad-scale transects, at a low average density of 5.2 /ha.

Anecdotal reports from a marine produce agent who was buying product in Tongatapu at the time the fishery was most active state that product was exported in large tonnages during the peak of the fishing activity. Initial survey results suggest that stocks of this species have not recovered to anywhere near the previous numbers suggested from these reports.

Some lower-value species, e.g. lollyfish (*Holothuria atra*), pinkfish (*H. edulis*) and brown sandfish (*Bohadschia vitiensis*), were noted at moderate-to-high density at Manuka. Lollyfish is likely even more common in very shallow water not targeted by the surveys, on the margins of the main island Tongatapu and in the internal brackish lagoon.

Gleaners fished five holothurian species in the seagrass areas around Manuka. The species most regularly taken was a white species with brown markings, *Bohadschia similis*, which was regularly found in aggregations partially or fully buried in the substrate. This species and brown sandfish (also known as 'chalky fish'), *B. vitiensis* (*mula*), was cut and processed on capture, the body wall of these species being retained. This was also true for the lollyfish, *H. atra*, which was occasionally retained, although the body wall was thoroughly scrubbed on capture (removing most of the red colouration and holothurine chemical). *Stichopus horrens* was immediately cut on capture to remove the tubules from the viscera (Lambeth 2000 – this author defined the species as *S. hermanni*, although it is more similar to *S. horrens* or, perhaps, *S. monotuberculatus*). These threads were usually kept in a container or plastic drink bottle by the fisher and the sea cucumber was returned to the shallows. On some occasions, large numbers were accumulated in buckets to be processed in the shallows. It is doubtful whether these holothurians would regenerate as successfully as those returned immediately to the water after processing (Indeed, a number were seen washed up on the beach by the falling tide.). Lastly, the black-fringed sea cucumber, *Holothuria leucospilota* (*te'epupulu*), is also cut on capture to remove tubules for consumption. This practice usually only occurs late in the year when these tubules are large enough to warrant collection.

The catch rate for *Bohadschia similis* in this study was recorded at 2 individuals/hour ±0.7 (n = 4 fishers) at Manuka, with none collected at Onevai. Collection rates of brown sandfish and lollyfish were low, with only one *B. marmorata* collected (at Manuka) and 28 *H. atra* (1.4 individuals/hour ±0.8, n = 4 fishers) collected at Onevai. Although *B. similis* burrows into the substrate, individuals often form a visible mound as they are half-submerged, and therefore were recorded in soft-benthos transect surveys (mean density of 197.0 individuals/ha ±74.3, n = 11 stations). Interestingly, this species was also found in surveys at Onevai, despite none being fished. *B. marmorata* was not found in surveys. Lollyfish were found at surprisingly low density in surveys at Manuka (500 /ha, 8 stations) but were found in reasonable densities at Onevai (2079.4 /ha, 3 stations). *Stichopus horrens* was actively targeted at more western sites in the lagoon, at Atata island, with high catch rates (138.2 individuals/hour ±37, n = 3 fishers) for individual animals <11 cm in length.

Mid-water and deep-water assessments were conducted using a broad-scale system on SCUBA to extend the main survey work conducted in Ha'apai (Friedman *et al.* 2004). In these surveys, 12 medium-depth water transects (100 m length, 4 m width, depth range 10–20 m, average depth 12.8 m) and 12 deep-water transects (100 m length, 4 m width, depth range 20–40 m, average depth 20 m) were completed to obtain a preliminary abundance estimate for white teatfish (*Holothuria fuscogilva*), prickly redfish (*Thelenota ananas*), amberfish (*T. anax*) and partially for elephant trunkfish (*H. fuscopunctata*). Oceanic-influenced benthos in the areas between reefs, at the foot of reef slopes and in passages had suitably dynamic water movement for these species. These surveys did not record white teatfish but did note *Bohadschia argus*, *B. vitiensis*, *Holothuria atra*, *H. edulis*, *H. fuscopunctata*, *Stichopus hermanni* and *Thelenota anax* to depths of ~13 m and *B. vitiensis*, *H. edulis*, *H. scabra versicolor*, *S. hermanni* and *T. anax* to depths of ~20 m.

3.4.7 Other echinoderms: Manuka

The edible collector urchin, *Tripneustes gratilla*, was present and recorded in small numbers in independent surveys (n = 13 individuals). This urchin, also known as the pincushion or hairy urchin (*tukimisi*), is generally cryptic, covered with pieces of seagrass, and only located by feel (foot, metal rod) and by recognition of the unusual clumping of seagrass fronds that can characterise its position. The spines on *T. gratilla* are short and sufficiently blunt to allow handling. Collection rates generally ranged between 0.7 and 13 individuals/hour but were higher at Onevai (5.53 individuals/hour ±0.9, n = 4 fishers) than at Manuka (1.07 individuals/hour ±0.2, n = 4 fishers). The difference between Manuka and Onevai collection rates was significant ($F_{2.10}$ = 7.7, P = 0.01). Average densities of pincushion urchins recorded in transect surveys ranged between 17.9 and 98.9 individuals/ha. The inshore site at Manuka again recorded the lowest average density, 17.9 individuals/ha ±33 (n = 8 sets) whereas the survey of Onevai returned higher average densities (63.5 individuals/ha ±63 (n = 3 sets)). Data collected on the size of *Tripneustes* reveal that urchins were larger at Onevai (8.4 cm test ±0.1, n = 106) than at Manuka (7.7 cm test ±0.2, n = 5). There did not seem to be any selectivity in the size of urchins for collection; there was no significant difference in size between pincushion urchins collected by fishers and those found in independent surveys.

Slate urchins, *Heterocentrotus mammillatus*, were more common (n = 377), being recorded in 42% of broad-scale stations and 58% of RBt stations, at a moderately high average density of 189.3 ±64 /ha. Other urchins that can be used as a food source or potential indicators of habitat condition (*Diadema* spp., *Echinothrix* spp. and *Echinometra mathaei*) were also recorded, with *E. mathaei* noted at high density in some locations, with one station reaching a mean density of 8994 /ha (overall RBt station average 739.5 ±498 /ha). The large black *Echinothrix* species (*E. diadema* and *E. calamaris*) were not as common (21% of RBt stations, with a mean station density of 46.1 ±24.9 /ha, see Appendices 4.2.1 to 4.2.7).

Starfish were well represented at Manuka. The common blue starfish, *Linckia laevigata*, was recorded in 27% of broad-scale transects and the pincushion star, *Culcita novaeguineae*, had a similar coverage (29% of broad-scale transects). *L. laevigata* was at moderate density (mean of 62.9 /ha for broad-scale stations) and was very common at a station close to Onevai (mean of 550.9 /ha). *C. novaeguineae* was at far lower density (10 /ha in broad-scale survey) as was another coralivore (coral eating) starfish, the crown-of-thorns starfish (*Acanthaster planci*), which was rare (n = 7 individuals) and at low density, <1 /ha (See presence and density estimates in Appendices 4.2.1 to 4.2.7.). Other starfish recorded included *Archaster typicus*, a star found in shallow-water sandy areas, and *Choriaster granulatus* and *Protoreaster nodosus*, which are both found in deeper and shallow water.

Table 3.17: Sea cucumber species records for Manuka

Species	Common name	Commercial value [6]	B-S transects n = 70			Other stations RBt = 19, SBt = 11			Other stations RFs = 13			Other stations MOPt = 8, MOPs = 2		
			D [1]	DwP [2]	PP [3]	D	DwP	PP	D	DwP	PP	D	DwP	PP
Actinopyga echinites	Deep-water redfish	M/H	0.2	16.7	1									
Actinopyga lecanora	Stonefish	M/H	1.9	19.0	10	2.2	41.7	5 RBt	0.5	6.2	8	2.6 3.8	20.8 7.6	13 MOPt 50 MOPs
Actinopyga mauritiana	Surf redfish	M/H				27.8	88.0	32 RBt	1.9	4.1	46	18.2	145.8	13 MOPt
Actinopyga miliaris	Blackfish	M/H	0.7	16.7	4	6.5	71.4	9 SBt				5.2	20.8	25 MOPt
Actinopyga palauensis	Blackfish	M/H												
Bohadschia argus	Leopardfish	M	53.7	73.8	73	98.3	133.4	74 RBt	8.1	17.6	46	34.1	68.2	50 MOPs
Bohadschia similis	False sandfish	L	2.1	50.0	4	2.5 197.0	47.6 361.1	5 RBt 55 SBt						
Bohadschia vitiensis	Brown sandfish	L	141.4	202.0	70	14.9	70.9	21 RBt	0.4	2.7	15			
Holothuria atra	Lollyfish	L	329.7	398.0	83	453.7 930.7	478.9 1024	95 RBt 91 SBt	25.6	27.8	92	41.7	41.7	100 MOPs
Holothuria coluber	Snakefish	L	1393	2268	61	152.9	2905	5 RBt	1.7	5.5	31			
Holothuria edulis	Pinkfish	L	111.8	195.6	57	12.2	116.1	11 RBt				18.9	37.9	50 MOPs
Holothuria fuscogilva [4]	White teatfish	H	Noted in deep-water surveys											
Holothuria fuscopunctata	Elephant trunkfish	M	4.7	23.6	20				0.5	6.2	8	26.5	26.5	100 MOPs
Holothuria leucospilota	Black threads fish	H	49.6	216.8	23	71.7 6.5	272.6 71.4	26 RBt 9 SBt	3.3	43.5	8			
Holothuria nobilis [4]	Black teatfish	H	0.2	16.7	1	6.6	125.0	5 RBt	0.7	3.2	23	3.8	7.6	50 MOPs
Holothuria scabra versicolor	Golden sandfish	H	5.2	61.1	9									
Stichopus chloronotus	Greenfish	H/M	10.4	36.5	29	213.5	338.0	63 RBt	27.8	40.2	69			
Stichopus hermanni	Curryfish	H/M	5.5	29.5	19									
Stichopus horrens	Peanutfish	M/L							0.2	2.9	8			
Synapta spp.	-	-	3.6	41.7	9									
Thelenota ananas	Prickly redfish	H	0.8	17.8	4				0.3	2.0	15			
Thelenota anax	Amberfish	M	2.6	91.7	3									

[1] D = mean density (numbers/ha); [2] DwP = mean density (numbers/ha) for transects or stations where the species was present; [3] PP = percentage presence (units where the species was found); [4] the scientific name of the black teatfish has recently changed from *Holothuria* (*Microthele*) *nobilis* to *H. whitmaei* and the white teatfish (*H. fuscogilva*) may have also changed name before this report is published. [5] L = low value; M = medium value; H = high value; H/M is higher in value than M/H; B-S transects = broad-scale transects; RBt = reef-benthos transect; SBt = soft-benthos transect; RFs = reef-front search; MOPs = mother-of-pearl search; MOPt = mother-of-pearl transect.

3.4.8 Discussion and conclusions: invertebrate resources in Manuka

A summary of environmental, stock status and management factors for the main fisheries is given below. Please note that information on other, smaller fisheries and the status of less prominent species groups can be found within the body of the invertebrate chapter.

In summary, data on giant clam habitat, distribution, density and shell size suggest that:

- Reefs at Manuka provided extensive areas of limestone and coral benthos, with shallow-water sheltered lagoon areas that were suitable for a range of giant clam species. Water movement was dynamic and there was a range of land- and oceanic-influenced habitat, which afforded giant clam populations a range of exposure grades.

- Only two species of giant clam were recorded at Manuka (the elongate clam *Tridacna maxima* and the fluted clam *T. squamosa*). The smooth derasa clam (*T. derasa*) and the devil's clam (*T. tevoroa*) are present in Tonga but were not noted in these surveys. Tongatapu is one area that supported the bear's paw clam (*Hippopus hippopus*) until the mid 1970s, although the species is now extinct in Tonga.

- Giant clam coverage across the study area was noticeably disrupted and there was only a small number of clams close to Manuka. In fact, the total number of clams recorded in both broad-scale and reef-benthos transects was not high. The densities of clams recorded at Manuka indicate that the clam fishery is impacted.

- *Tridacna maxima* displayed a 'full' range of size classes, including young clams, which indicate successful spawning and recruitment, although the abundance of large clams was relatively low, supporting the assumption that clam stocks are moderately impacted by fishing.

- As the reef system around Manuka comprises a non-traditional lagoon, which is 'open' to the east, west and north, fishing is likely to have a greater impact on the sustainability of stocks than in more enclosed lagoon systems, where natural 'trapping' of planktonic larvae is more likely due to the longer water residence times.

- Giant clams are broadcast spawners that only mature as females at larger size classes (protandric hermaphrodites). This means that, for successful stock management, a percentage of large clams of each species needs to be maintained at high density to ensure that sufficient successful spawning takes place to produce new generations of clams for the fishery. Noting the size profile of clams in Manuka and the generally low concentrations of clams spatially, it is likely that these clam stocks are in decline.

In summary, data on MOP habitat, presence, distribution, density and shell size suggest that:

- The reefs facing Manuka are extensive, largely oceanic-influenced, but with a range of exposure grades and significant land influence in many areas. These characteristics are advantageous for grazing gastropods, as water movement was generally dynamic, but algal food supply on limestone and seagrass surfaces was sufficient for the growth of juveniles and adults.

- The reefs at Manuka are outside the natural range of the commercial topshell, *Trochus niloticus*, but now support this species after successful introductions. Introductions have included the movement of both adults (from Fiji Islands) and juveniles (from the hatchery on Tongatapu). A similar situation exists for green snails, *Turbo marmoratus*, which were also introduced as juveniles from hatchery rearing.

- Trochus, *Trochus niloticus*, and green snails, *Turbo marmoratus*, were both recorded at Manuka. Trochus coverage and density were indicative of a stock that was colonising the local reefs. Coverage was good in most relevant surveys, and the density of shells at the better locations had reached an average of over 300 /ha. Only a single green snail was recorded.

- Size measures of trochus suggest that growth and reproduction of this species are occurring, despite a slightly greater number of adult sizes in Manuka reefs compared to Ha'atafu the other PROCFish site further west.

- There is no potential at this time to fish for mother-of-pearl species in Manuka. The presence and density records suggest that mother-of-pearl stocks are below the level at which commercial fishing is recommended, and are in need of ongoing protection to allow time for stocks to build. Trochus need to be protected to ensure there is a future for this fishery, and stocks may need at least another 5–>10 years, or at least enough time for the density at the major aggregations to reach 500–600 shells/ha before commercial harvests can be considered.

- The false trochus or green topshell (*Tectus pyramis*) was noted in Manuka, but was not as common as commercial trochus. This species is also cut for blanks on occasion, but has a far lower value and produces a much lower grade product and income per shell.

- The blacklip pearl oyster, *Pinctada margaritifera*, was not uncommon at Manuka. The high-energy environment is likely to have suited the life habit of this species, which is a filter feeder characteristically found in low-nutrient reef environments.

In summary, data on the habitat, distribution and density of sea cucumbers at Manuka reveal that:

- The range of sea cucumber species present at Manuka was high, despite biogeographical influences (the easterly location of Tonga and its relatively isolated position in the Pacific). Protected, shallow-water habitats and more exposed reefs were available in this reef system as a range of land- and oceanic-influenced environments.

- Densities of sea cucumbers were greatest in fine-sediment, semi-enclosed lagoonal areas. This was the case south of Onevai and east of Toke Toke, where large numbers of *Holothuria atra* and *H. coluber*, both low-value species, were recorded. Otherwise, the open lagoon had a more oceanic influence and held lower densities of commercial holothurians. The complete ban on commercial harvesting of holothurians for production has been in place for long enough for stocks of some species to have re-built strongly (e.g. tigerfish, *Bohadschia argus*), while others do not seem to have recovered much (e.g. black teatfish, *H. nobilis*).

- The high-value black teatfish (*H. nobilis*) is usually recorded at lower density and, after fishing, may fall to densities too low for successful reproduction, because sea cucumbers are single-sexed and broadcast spawners. This means they have to be at high local densities to ensure successful reproduction. A similarly important species, the golden sandfish (*H. scabra versicolor*) has also not regained the coverage or density that earlier harvests suggest were present. These two species require careful management to ensure they recover to 'healthy' densities.
- Surf redfish (*Actinopyga mauritiana*) were noted at low density, unlike the situation in Lifuka, Ha'apai, where limestone reef platforms facing prevailing swell held large numbers.

- Assessments targeting deeper-water white teatfish stocks (*Holothuria fuscogilva*) were not extensive but, on the one station that was accessed, this high-value species was not recorded. Other deep-water species, such as the lower-value amberfish (*Thelonata anax*), were at moderate density at Manuka.

- Since the 1996 survey, when stocks were shown to be over-fished, the majority of commercial sea cucumber species have again begun to show densities similar to those seen in 1990 (data from serial surveys in Ha'apai). The recovery in density of commercial species since 1996 needs to be tempered with the experience of more highly productive sea-cucumber habitats in other parts of the Pacific, as the low-lying islands and oceanic environment found in areas of Tongatapu present a less-than-optimal and somewhat restricted area for some deposit-feeding resources. Because of these factors, the potential of Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

3.5 Overall recommendations for Manuka

- Manuka and neighbouring communities on Tongatapu be included in the ongoing community-based fisheries management programme.

- Protected zones or no-take marine parks be established to help the recovery and maintenance of finfish and invertebrate resources and habitat condition, with appropriate monitoring and enforcement to ensure compliance.

- Spearfishing be controlled in the Manuka area, with a ban on night spearfishing imposed.

- Regulations be put in place to control the mesh size of nets.

- A monitoring system be set in place to follow any further changes in finfish resources.

- For successful stock management, a percentage of large clams of each species needs to be maintained at high density, to ensure there is sufficient successful spawning taking place to produce new generations of clams for the fishery.

- Ongoing protection be provided to the trochus stocks for at least another five-to-ten years to enable them to benefit from the increased spawning activity that the high-density base population will provide, thus allowing stocks to rebuild to a minimum of 500–600 shells/ha before commercial harvests are considered.

- The high-value black teatfish (*Holothuria nobilis*) and the golden sandfish (*H. scabra versicolor*) require careful management to ensure they recover to 'healthy' densities.

- The potential of the Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

4. PROFILE AND RESULTS FOR KOULO

4.1. Site characteristics

Koulo (Figure 4.1) is a village located at the northern end of the coral island of Lifuka at the mean coordinates of 19°46' S; 174°20' W. Lifuka is the main island of the Ha'apai Island group. In the eastern part, a barrier reef exposed to the prevailing winds is not accessible by sea, whereas the northern part of the island is linked to the island of Foa by backfill and a road. The village of Koulo is divided by the airport. The back-reef, which is very shallow, can only be fished on foot and does not seem to be very rich. The west coast is bordered by a beach and reef flat, a small part of which is made up of a seagrass bed and the rest of coral patches, sand and coral debris. Further out to sea, coral structures of various sizes are fished by fishers using poles and lines or diving. The fishing system is open-access.

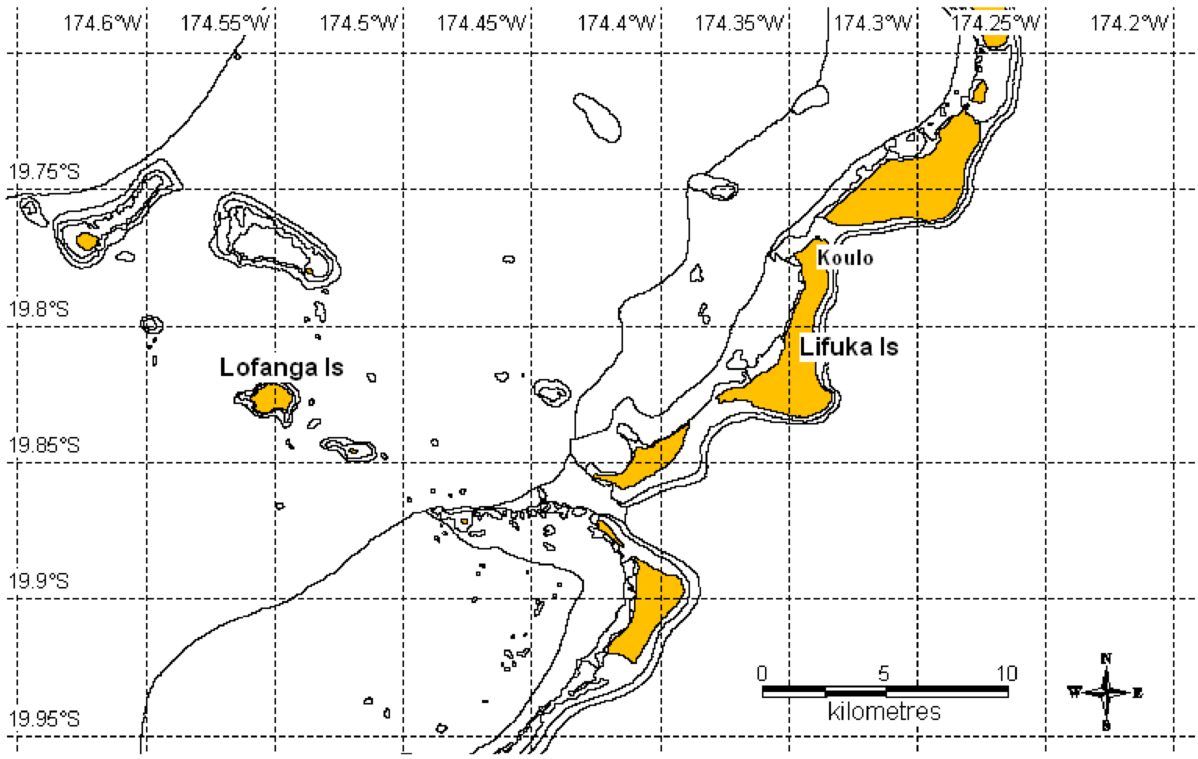

Figure 4.1: Map of Koulo.

4.2. Socioeconomic survey: Koulo

Socioeconomic fieldwork was carried out in Koulo, one of the major communities on Lifuka, the main island in the Ha'apai Island group, in May–June 2008. The survey included households and fishers of the Koulo community only.

The Koulo community has a resident population of 200 people with a total of 32 households. A total of 27 households, which is >84% of the total households in the community, were surveyed, with 74% of these households being engaged in some form of fishing activities. In addition, a total of 16 finfish fishers (males only) and 12 invertebrate fishers (3 males and 9 females) were interviewed. The average household size is six people per household. Household interviews focused on the collection of general demographic, socioeconomic and consumption data.

4.2.1 The role of fisheries in the Koulo community: fishery demographics, income and seafood consumption patterns

Our results (Figure 4.2) suggest that 'other' income sources, mainly representing mat weaving done by females, provide by far the most important income source for the Koulo households. Salaries, which provide about 30% of households with first income, are also much more important than agriculture (providing ~18% of households with first income) and fisheries (providing ~15% of households with first income). Mat weaving is also the most important secondary income source, followed by agriculture (~15%). The Koulo community has good access to agricultural land and to marine resources. However, the proximity to the airport and the Lifuka urban centre explains why income is mainly derived from other sources, i.e. mat weaving for local and tourist sales, and salaries. Also, almost all (93%) households have a couple of pigs and most (85%) have chickens, most of which are for home consumption and feasts.

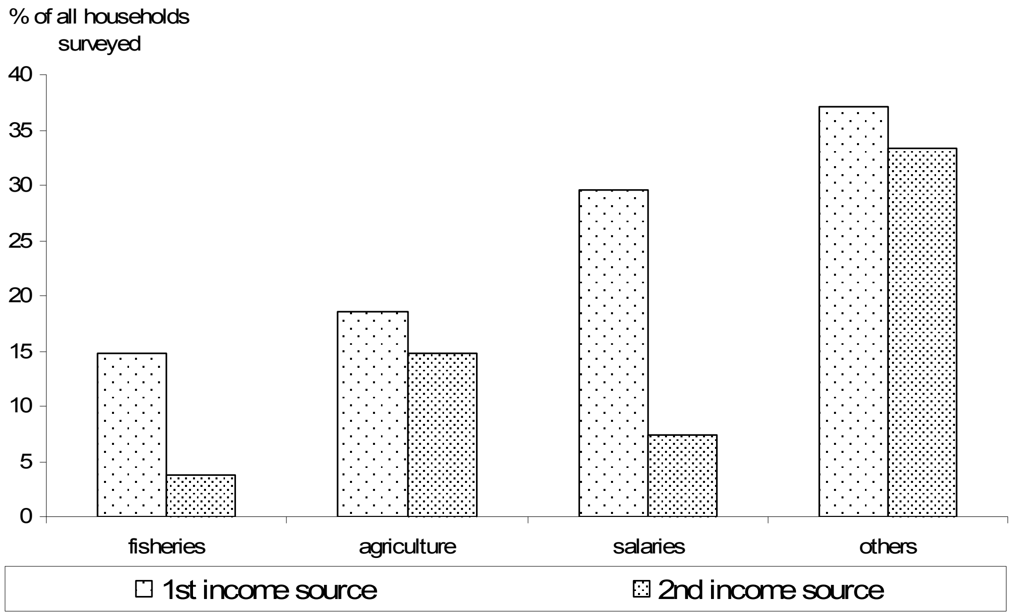

Figure 4.2: Ranked sources of income (%) in Koulo.
Total number of households = 27 = 100%. Some households have more than one income source and those may be of equal importance; thus double quotations for 1st and 2nd incomes are possible. 'Others' are mostly home-based small business.

Our results (Table 4.1) show that annual household expenditures are high, with an average of USD 3780, and reflect the more urban character of the community as well as its access to cash income. Nevertheless, remittances do play an important role for Koulo households' income with 92% receiving remittances; those that receive remittances get an average of USD ~713 /year, corresponding to almost one-fifth of the average basic household expenditure.

Table 4.1: Fishery demography, income and seafood consumption patterns in Koulo

Survey coverage	Site (n = 27 HH)	Average across sites (n = 87 HH)
Demography		
HH involved in reef fisheries (%)	74.1	82.8
Number of fishers per HH	1.56 (±0.45)	1.47 (±0.16)
Male finfish fishers per HH (%)	61.9	43.0
Female finfish fishers per HH (%)	0.0	0.0
Male invertebrate fishers per HH (%)	0.0	2.3
Female invertebrate fishers per HH (%)	26.2	32.0
Male finfish and invertebrate fishers per HH (%)	11.9	22.7
Female finfish and invertebrate fishers per HH (%)	0.0	0.0
Income		
HH with fisheries as 1st income (%)	14.8	39.1
HH with fisheries as 2nd income (%)	3.7	4.6
HH with agriculture as 1st income (%)	18.5	10.3
HH with agriculture as 2nd income (%)	14.8	20.7
HH with salary as 1st income (%)	29.6	21.8
HH with salary as 2nd income (%)	7.4	10.3
HH with other source as 1st income (%)	37.0	29.9
HH with other source as 2nd income (%)	33.3	31.0
Expenditure (USD/year/HH)	3779.76 (±1952.03)	3160.33 (±610.10)
Remittance (USD/year/HH) (1)	713.37 (±132.52)	1165.99 (±150.20)
Consumption		
Quantity fresh fish consumed (kg/capita/year)	46.60 (±8.46)	68.57 (±6.36)
Frequency fresh fish consumed (times/week)	2.81 (±0.35)	3.44 (±0.19)
Quantity fresh invertebrate consumed (kg/capita/year)	6.68 (±1.85)	11.58 (±6.36)
Frequency fresh invertebrate consumed (times/week)	0.86 (±0.22)	1.13 (±0.11)
Quantity canned fish consumed (kg/capita/year)	18.59 (±2.88)	16.99 (±1.57)
Frequency canned fish consumed (times/week)	2.31 (±0.33)	2.00 (±0.15)
HH eat fresh fish (%)	100.0	100.0
HH eat invertebrates (%)	51.9	77.0
HH eat canned fish (%)	92.6	89.7
HH eat fresh fish they catch (%)	66.7	76.2
HH eat fresh fish they buy (%)	40.7	42.9
HH eat fresh fish they are given (%)	77.8	81.0
HH eat fresh invertebrates they catch (%)	44.4	71.4
HH eat fresh invertebrates they buy (%)	7.4	14.3
HH eat fresh invertebrates they are given (%)	33.3	52.4

HH = household; n/a = standard error not calculated; (1) average sum for households that receive remittances; numbers in brackets are standard error.

Survey results indicate an average of 1–2 fishers per household and, when extrapolated, the total number of fishers in Koulo is 50. Among these are 31 exclusive finfish fishers (males only), 13 exclusive invertebrate fishers (females only), and 6 fishers who fish for both finfish and invertebrates (males only). During this survey females denied any active participation in finfish fishing, although they do at times catch fish for subsistence purposes and as a side product of gleaning activities. Only 11% of all households own a motorised boat.

Per capita consumption of fresh fish is, by comparison to the rural Tonga consumption level, relatively low, at 46.6 kg/year. However, this consumption level is still significantly higher than the estimated average given by Preston (2000) of 25.2 kg/year, or the regional average of ~35 kg/year (Figure 4.3). By comparison, per capita consumption of invertebrates (edible meat weight only) (Figure 4.4) is much lower, at 6.7 kg/year. Canned fish (Table 4.1) adds a considerable amount (18.6 kg/year) to the annual protein supply from seafood. Canned fish is an established substitute in Tongan nutrition and available even in remote locations. The consumption pattern of seafood found in Koulo highlights the fact that people have good access to the urban market, are self-reliant in agricultural produce and hence are less dependent on seafood.

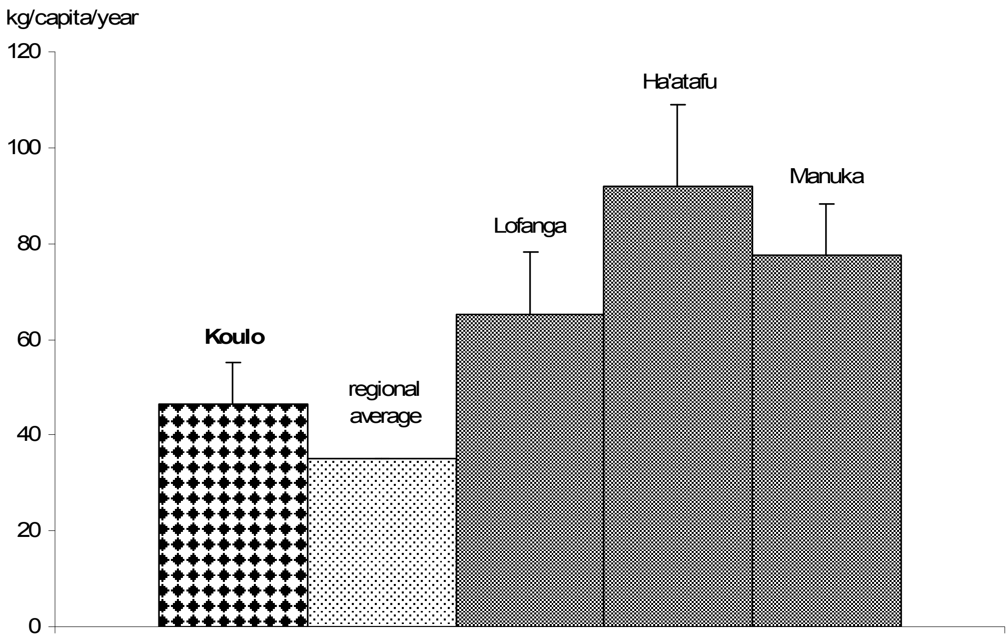

Figure 4.3: Per capita consumption (kg/year) of fresh fish in Koulo (n = 27) compared to the regional average (FAO 2008) and the other three PROCFish sites in Tonga.
Figures are averages from all households interviewed, and take into account age, gender and non-edible parts of fish. Bars represent standard error (+SE).

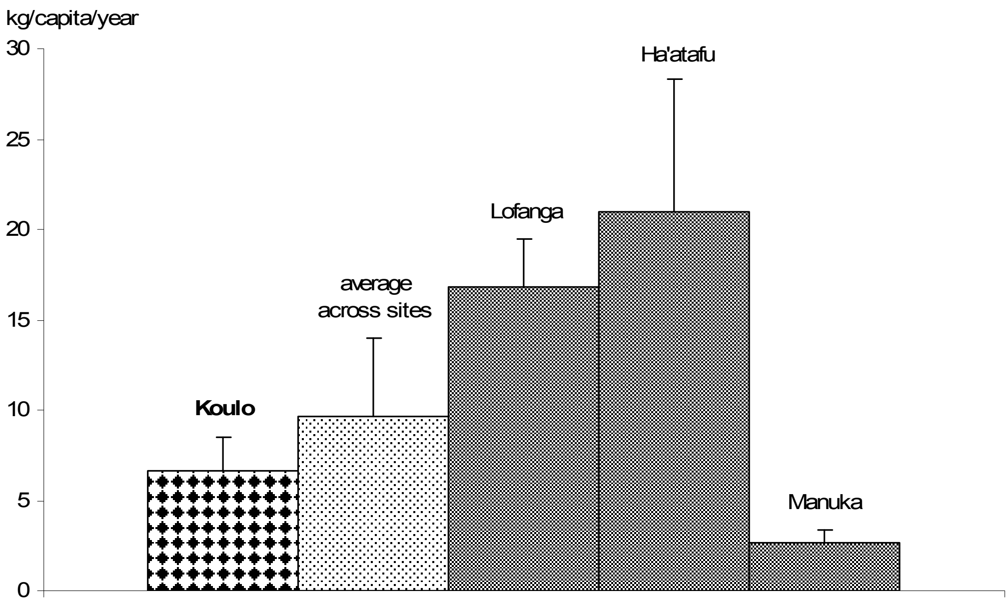

Figure 4.4: Per capita consumption (kg/year) of invertebrates (meat only) in Koulo (n = 27) compared to the other three PROCFish sites in Tonga.
Figures are averages from all households interviewed, and take into account age, gender and non-edible parts of invertebrates. Bars represent standard error (+SE).

Comparing results obtained for Koulo to the average figures across all four study sites in Tonga, people of the Koulo community eat fresh fish and invertebrates less often and in considerably smaller quantities; however, they consume canned fish more often and in higher quantities. In general, the proportion of the Koulo population that eats fresh fish is similar to the average found across all sites studied in Tonga; however, fewer people eat invertebrates and more people consume canned fish. Koulo people catch less fish and invertebrates themselves, but they often (41%) buy fresh fish. Sharing seafood among community members on a non-monetary basis is very common, but perhaps a little less common than found elsewhere in Tonga. Mat weaving and salaries are the most important income sources, more than the average found across all sites, while income from fisheries is less than average. Agriculture is more important as first income in Koulo than elsewhere. Household expenditure level is far higher than the average across all sites studied in Tonga, but Koulo's households receive less remittances. By comparison, boat ownership is not as common as found elsewhere; however, the dominance of motorised boats is consistent with the overall survey results.

4.2.2 Fishing strategies and gear: Koulo

Degree of specialisation in fishing

Tonga has an open-access system; however, communities may consider certain areas as their own fishing grounds. This observation is partly true for Koulo; however, population density on Lifuka has increased over the past decades and fishing grounds may be shared with fishers from neighbouring communities. User conflicts are still rare and not a subject of major concern. While, so far, no marine management interventions have been initiated for or with the Koulo fishing community, a fisheries management plan has been developed and resource surveys have been undertaken jointly by an AusAID-funded project and Tonga Fisheries in three communities in Ha'apai.

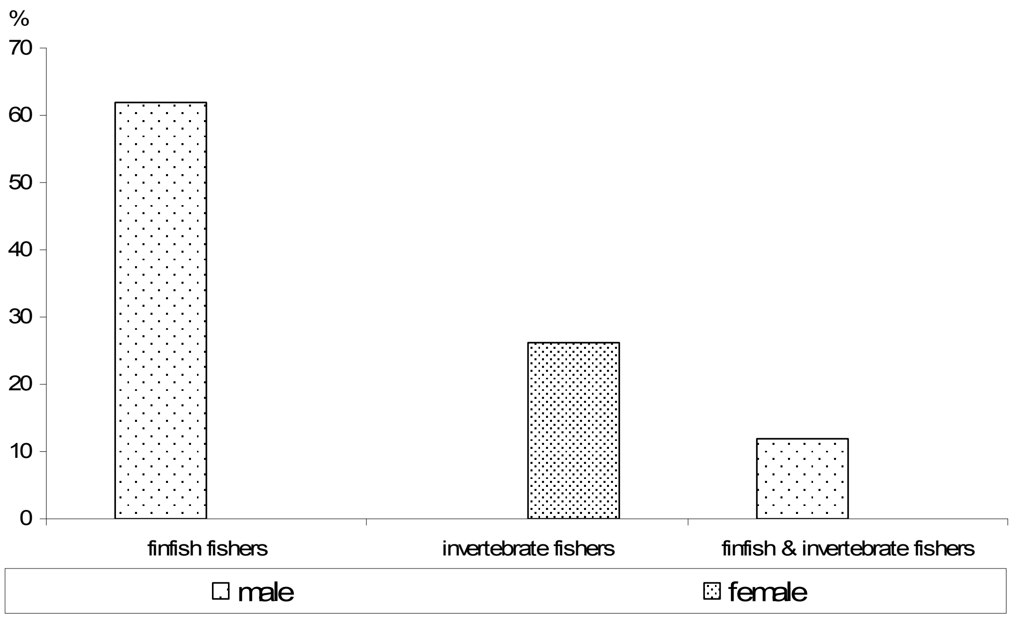

Figure 4.5: Proportion (%) of fishers who target finfish or invertebrates exclusively, and those who target both finfish and invertebrates in Koulo.
All fishers = 100%.

As mentioned earlier, Koulo people follow traditional gender roles, with males being the major finfish fishers, while females take the lead in invertebrate collection. However, as shown in an earlier study (Kronen and Bender 2006), gender roles have changed over time and females also do catch finfish at times, while males actively participate in the collection of invertebrates, particularly if for sale or while spearfishing. Nevertheless, due to the traditional *tabu* and the diverse lifestyle of Koulo's people, there is not much incentive or need for Koulo females to engage in finfish fisheries. Females contribute mainly to household income by weaving mats for sale locally, on Tongatapu, and to the tourism industry.

Fishing patterns and strategies

The number of fishers, the frequency of fishing trips and the average catch per fishing trip are the basic factors used to estimate the fishing pressure imposed by people from Koulo on their fishing grounds (Tables 4.2 and 4.3).

Our survey sample suggests that fishers from Koulo do not have a great deal of choice in the type of fishing ground that they can target. Basically, the choice is between fishing close inshore along the coastline, or venturing out on a much longer fishing trip, using motorised boat transport and targeting the isolated coral reefs located in the deep lagoon some distance from Koulo and Lifuka island. The same observation is true for invertebrate fisheries as the island has reeftop habitats but little else. Free-diving may be done on the top of the exposed, isolated coral reefs within the deep-lagoon area and in certain spots close to the village itself. There are no mangroves, seagrass or any important soft-benthos habitats available (Figures 4.6 and 4.7).

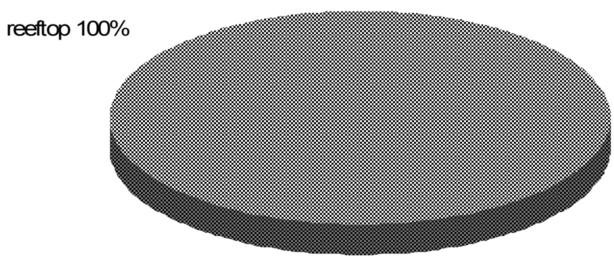

Figure 4.6: Proportion (%) of fishers targeting the primary invertebrate habitat found in Koulo. Data based on individual fisher surveys; data for combined fisheries are disaggregated.

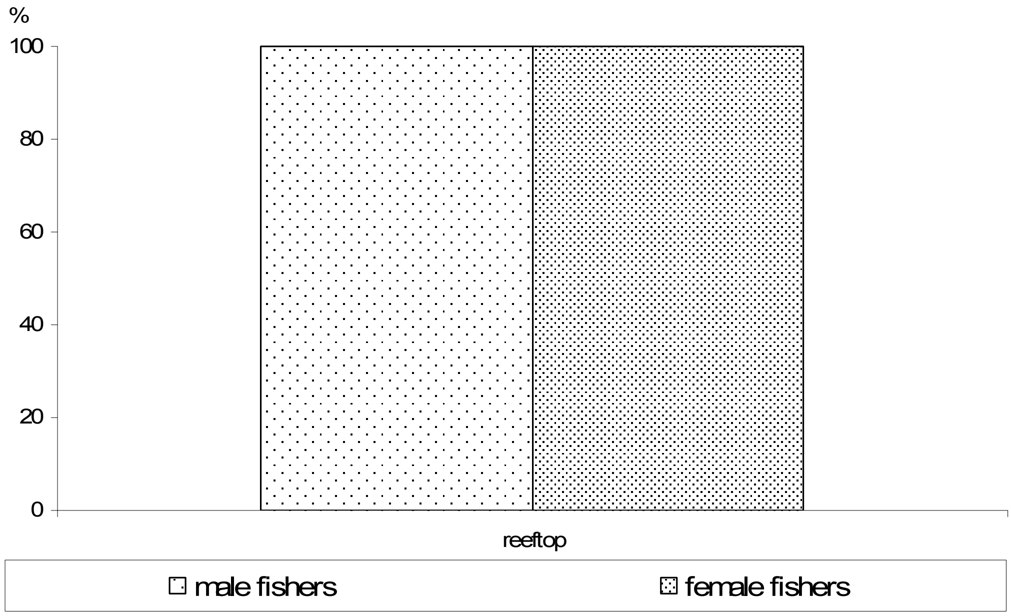

Figure 4.7: Proportion (%) of male and female fishers targeting the reeftop habitat in Koulo. Data based on individual fisher surveys; data for combined fisheries are disaggregated; figures refer to the proportion of all fishers who target each habitat: n = 3 for males, n = 9 for females.

Targeted stocks/habitat

Because Koulo is located at the seafront of the main island of Lifuka, fishing in the sheltered coastal reef does not require boat transport. However, male fishers venture out in motorised boats to the more distant, isolated reefs that are located in the deep-lagoon area. This fishing is perceived as 'lagoon' fishing; however, the reefs targeted are 'outer-reef' in nature, and the 'lagoon' is very deep and connected to the open ocean. In the following, it is therefore referred to as lagoon/outer-reef fishing in order to combine the male fishers' perception and geomorphological classification. For impact, reef surfaces are taken into account, while the deep-lagoon surface is only considered for determining the total fishing ground. Most of the fishing is done in the easily accessible sheltered coastal reef, and much less fishing (31% of all male fishers) is done in the area perceived as 'lagoon'. The fact that the major impact is on the sheltered coastal reef and less impact is on lagoon/outer-reef resources is shown in Table 4.2. Interviews showed that invertebrate collection only targets reef-associated species, and these are collected by walking along the reeftop surfaces and harvesting along the easily accessible sheltered coastal reef area (Figure 4.6). Reeftop gleaning is a female domain, and only 11% of male fishers glean or free-dive to collect giant clams, octopus, lobsters and other species (Figure 4.7).

Table 4.2: Proportion (%) of male and female fishers harvesting finfish and invertebrate stocks across a range of habitats (reported catch) in Koulo

Resource	Fishery / Habitat	% of male fishers interviewed	% of female fishers interviewed
Finfish	Sheltered coastal reef	75.0	0.0
	Lagoon / outer reef	31.3	0.0
Invertebrates	Reeftop	100.0	100.0

Finfish fisher interviews, males: n = 16; females: n = 0. Invertebrate fisher interviews, males: n = 3; females: n = 9.

Gear

Figure 4.8 shows that Koulo fishers use a variety of fishing gear, but mainly spear diving, handlining and some cast netting if targeting the sheltered coastal reef. For lagoon/outer-reef fishing, handlines are mostly used and gillnets are set at the exposed outer reefs that are located in the deep-lagoon system.

To collect invertebrates, most fishers use very simple techniques, such as digging, collecting by hand or poking with sticks, iron rods and knives in tidal pools and crevasses. Hand-woven baskets and plastic buckets are used to collect the catch and carry it back home for processing or cooking.

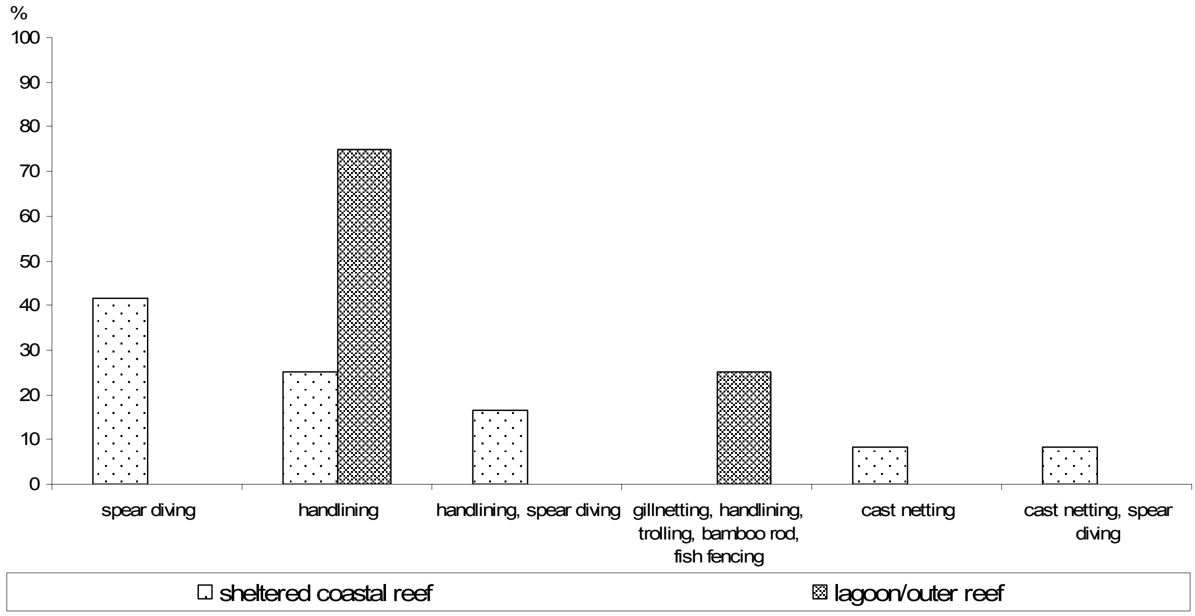

Figure 4.8: Fishing methods commonly used in different habitat types in Koulo.
Proportions are expressed in % of total number of trips to each habitat. One fisher may use more than one technique per habitat and target more than one habitat in one trip.

Frequency and duration of fishing trips

Male fishers go out to catch finfish about 1 to 2 times per week regardless of which habitat they choose. As shown in Table 4.3, an average fishing trip targeting the lagoon/outer reef takes longer (7 hours) because of the long travel distances to the isolated coral reefs within the deep-lagoon system. The average fishing trip along the coastline in front of the village takes four hours because fishers need to swim or walk to the appropriate fishing spots (No boat transport is used.).

Invertebrate fishers go fishing more often than finfish fishers, on average about three times per week. The average duration of a reeftop gleaning fishing trip is 2–3 hours (Table 4.3).

Finfish fishing and invertebrate collection are practised continuously throughout the year. Finfish fishing trips are strictly scheduled according to tidal conditions if targeting the sheltered coastal reef, and predominantly made at night if targeting the lagoon/outer reef. The latter is due to the frequent use of spear diving. Ice is often used on longer fishing trips, i.e. for lagoon/outer-reef fishing, but is rarely used for sheltered coastal reef fishing activities.

All invertebrate collection is done by walking, is performed exclusively at day time, and continues throughout the year.

Table 4.3: Average frequency and duration of fishing trips reported by male and female fishers in Koulo

Resource	Fishery / Habitat	Trip frequency (trips/week)		Trip duration (hours/trip)	
		Male fishers	Female fishers	Male fishers	Female fishers
Finfish	Sheltered coastal reef	2.14 (±0.29)		4.08 (±0.53)	
	Lagoon / outer reef	1.50 (±0.00)	0	7.00 (±1.00)	0
Invertebrates	Reeftop	3.00 (±1.00)	2.56 (±0.56)	3.00 (±0.58)	2.33 (±0.17)

Figures in brackets denote standard error.
Finfish fisher interviews, males: n = 16; females: n = 0. Invertebrate fisher interviews, males: n = 3; females: n = 9.

4.2.3 Catch composition and volume – finfish: Koulo

The reported catches from sheltered coastal reef and lagoon/outer-reef fishing in Koulo contain about 20 different vernacular names, representing different species and families. Because spearfishing and handlining are often practised it is not surprising that Scaridae, Serranidae, Acanthuridae and Lethrinidae dominate catches reported from the sheltered coastal reef, and Lutjanidae, Kyphosidae, Lethrinidae, Mugilidae, Mullidae and Carangidae are more important in catches from the lagoon/outer-reef habitats. Detailed information on catch composition by species, species groups and habitats is reported in Appendix 2.3.1.

Figure 4.9 confirms the findings from the socioeconomic survey reported earlier, that finfish fishing is done for both subsistence and income, but that fishing itself is not an important source of first income in Koulo. Although most of the catch is sold, the total annual catch reported and extrapolated for the entire community of Koulo is only ~26 t/year. Most of the catch is sourced from the easily accessible sheltered coastal reef, and only one-third is caught in the lagoon/outer-reef habitat. There was no information available on whether females in Koulo fish for finfish, at least occasionally and, if so, to what extent.

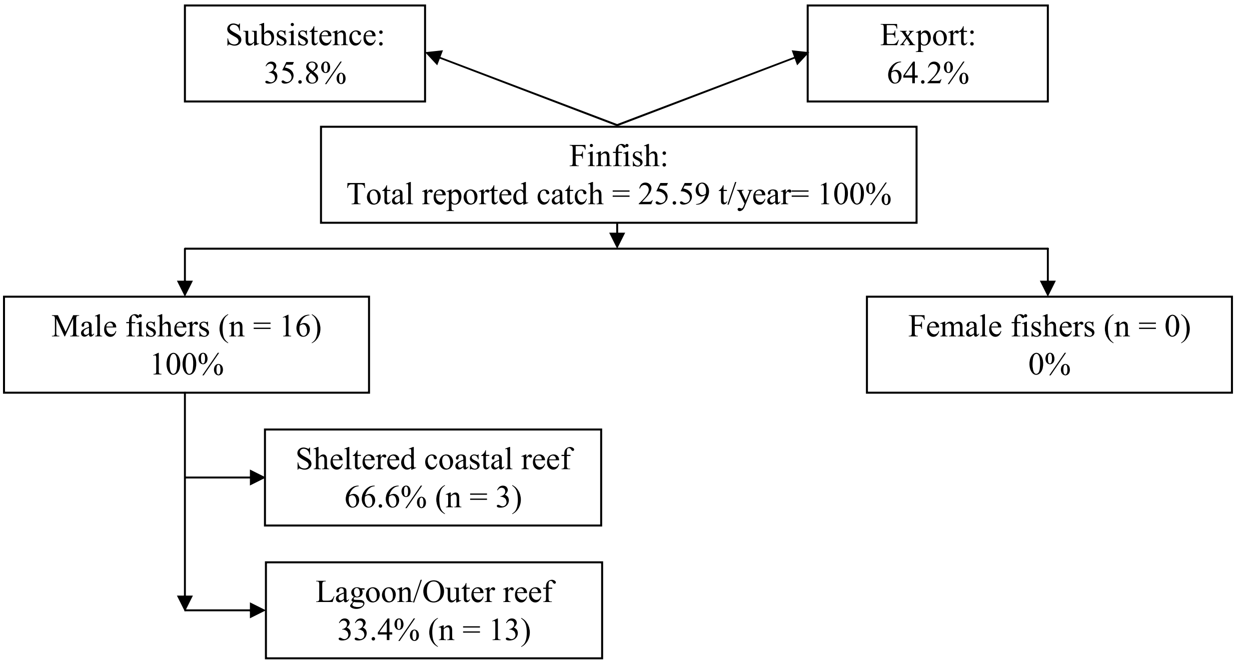

Figure 4.9: Total annual finfish catch (tonnes) and proportion (%) by fishery and gender (reported catch) in Koulo.
n is the total number of interviews conducted per each fishery; total number of interviews may exceed total number of fishers surveyed as one fisher may target more than one fishery and thus respond to more than one fishery survey.

The distribution of annual catch weight between the more accessible sheltered coastal reef, and the much more distant lagoon/outer-reef areas is a consequence of the number of fishers rather than the catch per unit effort or total annual productivity. As shown in Figure 4.10, the average annual catch per fisher is less if the sheltered coastal reef is targeted as compared to the lagoon/outer-reef habitat.

Comparing productivity rates between habitats (Figure 4.11), there is also some difference, with an average of 1.8 kg fish caught per hour of fishing trip at the sheltered coastal reef and 2.2 kg/hour at the lagoon/outer-reef. These differences may be attributable to the status of the resource, which is expected to increase with distance from shore, as well as to differences in the fishing strategies used.

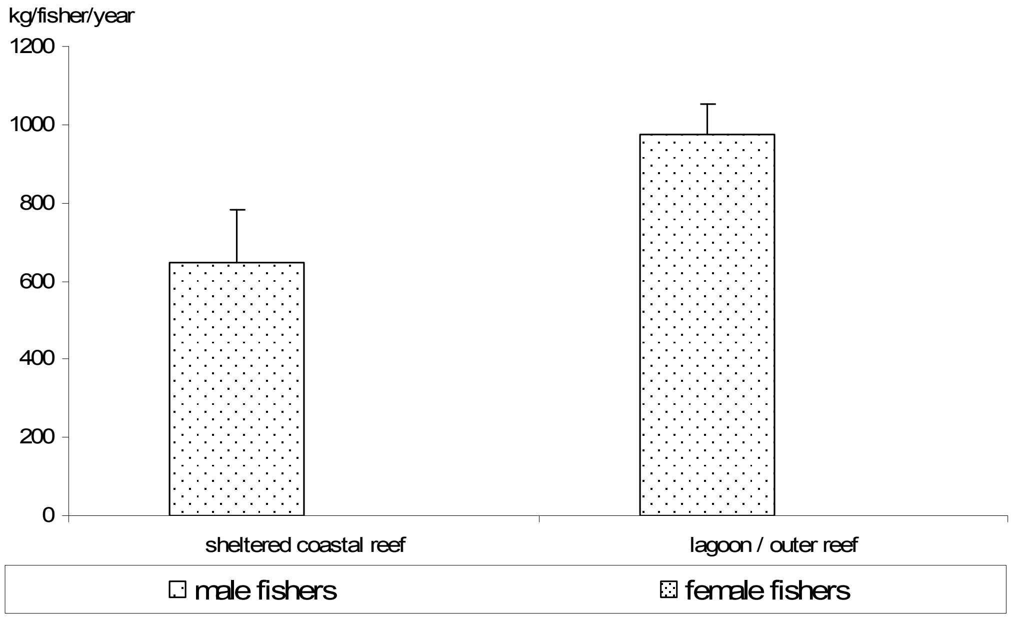

Figure 4.10: Average annual catch (kg/year, +SE) per fisher by gender and habitat in Koulo (based on reported catch only).

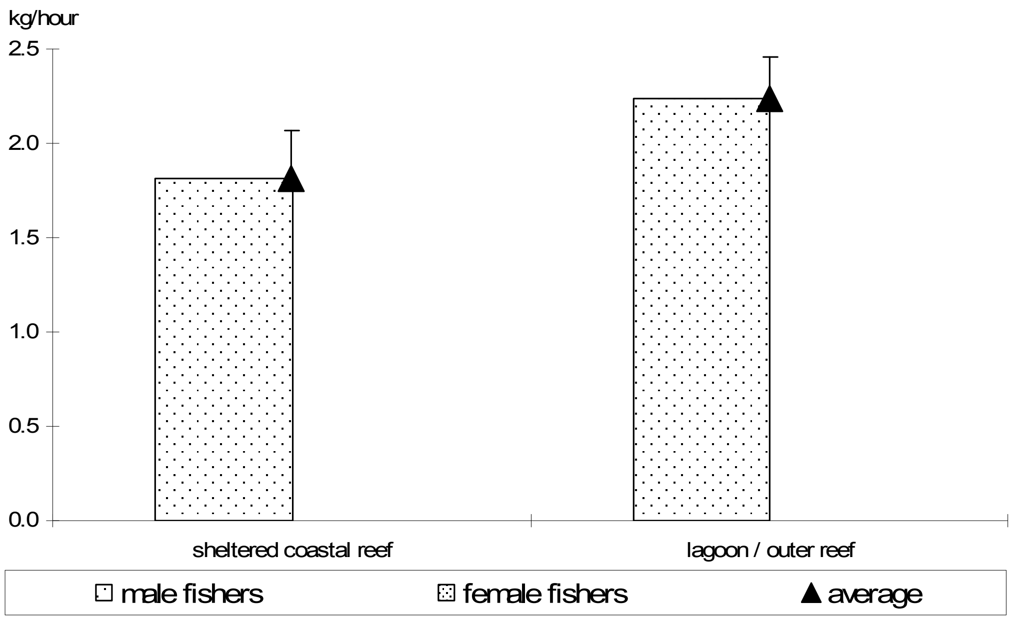

Figure 4.11: Catch per unit effort (kg/hour of total fishing trip) for male and female fishers by habitat in Koulo.
Effort includes time spent in transporting, fishing and landing catch. Bars represent standard error (+SE).

The fact that commercial fishing is more important than subsistence fishing for Koulo people shows in Figure 4.12. Data suggest that male fishers targeting the lagoon/outer reef mainly fish for income-generating purposes. Fishing of the sheltered coastal reef, an activity pursued by most fishers in Koulo, is mainly done to provide food for the family and the community.

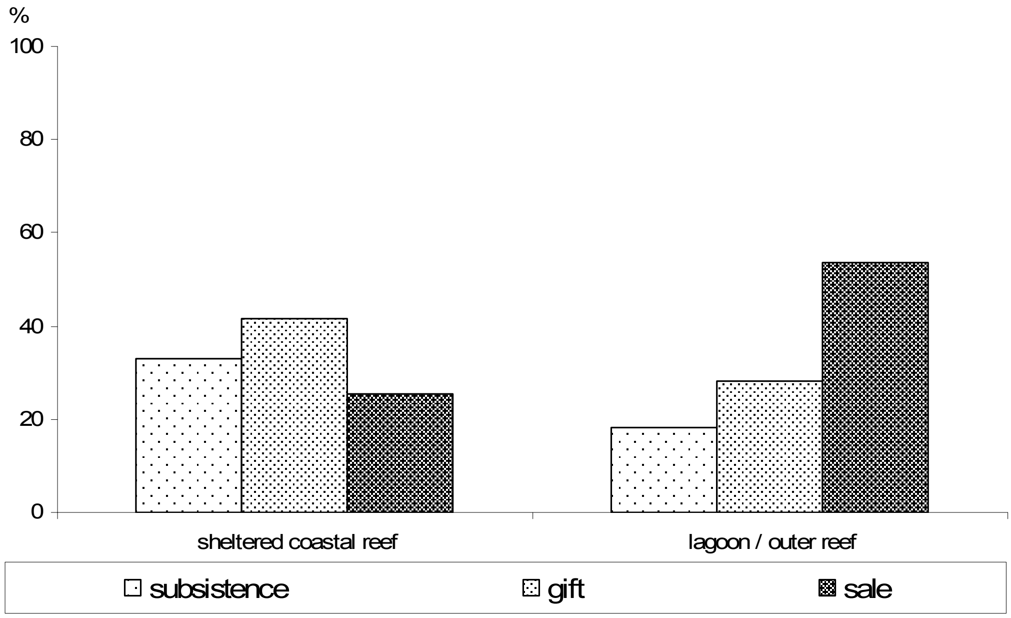

Figure 4.12: The use of finfish catches for subsistence, gift and sale, by habitat in Koulo. Proportions are expressed in % of the total number of trips per habitat.

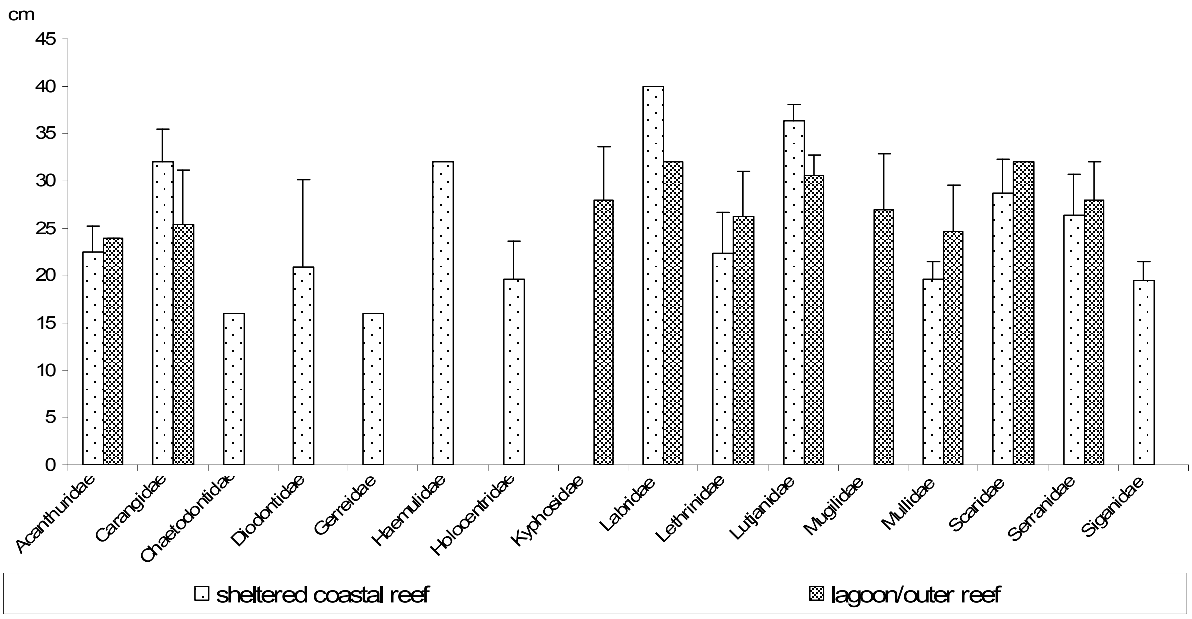

Figure 4.13: Average sizes (cm fork length) of fish caught by family and habitat in Koulo. Bars represent standard error (+SE).

Analysis of the overall finfish fishing productivity per habitat suggests that efficiency (CPUE) in the more distant lagoon/outer-reef locations is higher than in the sheltered coastal reef (Figure 4.11). This observation should be supported by much larger individual specimens being reported for catches from the lagoon/outer reef, following the general assumption that resource status increases with distance from shore. However, as shown in Figure 4.13, this is not the case for most fish families reported in catches from both habitats. Lutjanidae, Carangidae and Labridae were reportedly of larger size (forklength) closer to shore as compared to in the lagoon/outer reef. Only in the case of Serranidae, Scaridae, Lethrinidae and, perhaps, Acanthuridae, is there a general trend of increased fish sizes with distance from shore. Overall, the reported average fish sizes range between 25 and 35 cm.

The parameters selected to assess current fishing pressure on Koulo reef and lagoon resources are shown in Table 4.4. Due to the fact that the fishers' perception of a 'lagoon' is, in fact, geomorphologically an outer-reef habitat, the deep-lagoon surface area was not taken into consideration except for the total fishing ground. Overall, all parameters calculated for fishing pressure are low. This applies to finfish fisher density in both habitats, population density for total reef and fishing ground areas, and the impact due to subsistence fish catch. Even if we consider the total annual catch, which is 65% determined by catch for sale rather than subsistence, catch rates remain under 1 t/km² reef or fishing ground area per year. Thus, overall, there is no indication that the Koulo fishing community currently catches finfish at a rate which is detrimental to resource levels. However, the parameters contradict the findings from the underwater finfish resource survey, which found that, although the finfish resources are better than in Tongatapu, they are still far from good. This implies that previous and ongoing fishing pressure imposed not only by fishers from Koulo but also from elsewhere in Ha'apai has caused a detrimental and visible impact.

Table 4.4: Parameters used in assessing fishing pressure on finfish resources in Koulo

Parameters	Habitat			
	Sheltered coastal reef	Lagoon / outer reef	Total reef area	Total fishing ground
Fishing ground area (km^2)	40.3	9.2	49.5	339.3
Density of fishers (number of fishers/km^2 fishing ground) (1)	0.7	1.3	0.8	0.1
Population density (people/km^2) (2)			4.0	0.6
Average annual finfish catch (kg/fisher/year) (3)	648.8 (±131.7)	976.2 (±76.8)		
Total fishing pressure of subsistence catches (t/km^2)			0.2	0.0
Number of fishers	28	12	37	37

Figures in brackets denote standard error; (1) total number of fishers is extrapolated from household surveys; (2) total population = 200; total subsistence demand = 9.2 t/year; (3) catch figures are based on recorded data from survey respondents only. Finfish fishers perceived fishing at outer reef as lagoon fishing as locations are individual and isolated coral reefs within deep-lagoon / open sea conditions, hence fishing pressure refers to outer-reef habitats rather than lagoon; total deep-lagoon surface area is 289.8 km^2.

4.2.4 Catch composition and volume – invertebrates: Koulo

Analysis of catches reported from invertebrate fishers by wet weight shows that only a few species account for the major annual impact (Figure 4.14). *Holothuria* spp. catches are the most important, followed at a much lower level by octopus, giant clams and the sea urchin *Tripneustes gratilla*. Any other species, such as *Bohadschia argus*, *Actinogypa lecanora* or *Turbo crassus*, are by comparison insignificant.

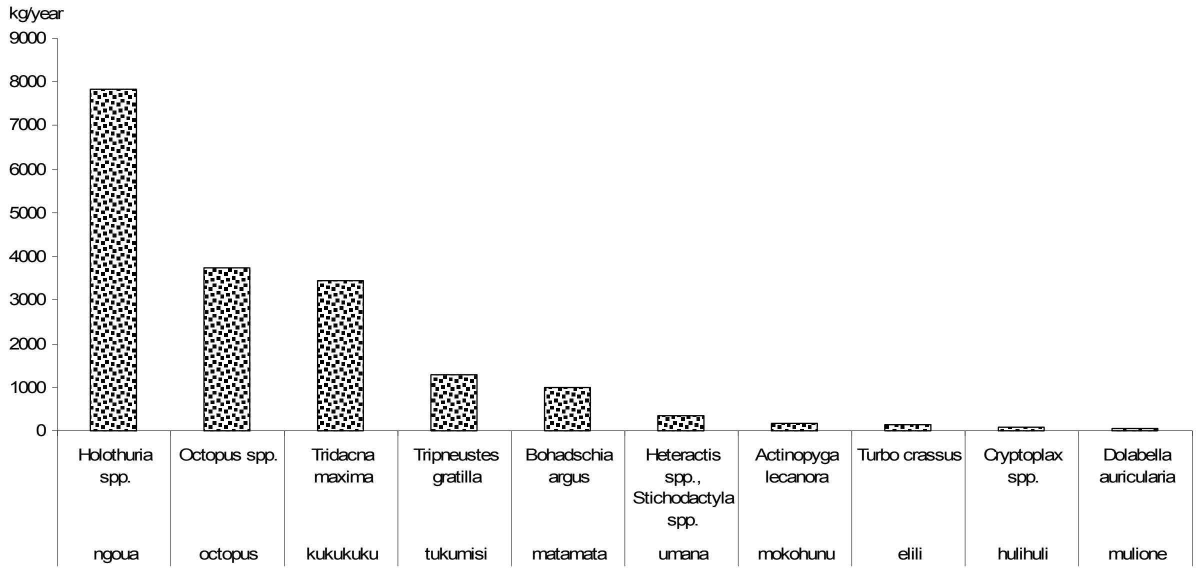

Figure 4.14: Total annual invertebrate catch (kg wet weight/year) by species (reported catch) in Koulo.

The fact that most impact is on a few species only also shows in the number of vernacular names that have been registered from respondents. Reeftop gleaning, the only invertebrate fishery performed by people from Koulo, is represented by only 10 vernacular names (Figure 4.15).

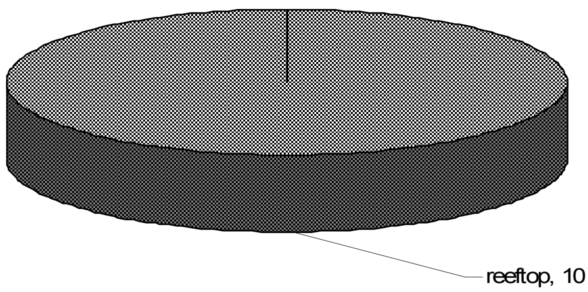

Figure 4.15: Number of vernacular names recorded for each invertebrate fishery in Koulo.

The average annual catch per fisher by gender and fishery (Figure 4.16) reveals substantial differences between male and female fishers. While female fishers on average collect about 1 t wet weight per year, male fishers collect about 1.5 times as much. As highlighted by Figure 4.16, most of the invertebrate catch, regardless of whether collected by males or females, is used for home consumption rather than sale. The potential share of total annual catch that may be sold is below 5%. No fisher reported collecting invertebrates for commercial purposes only.

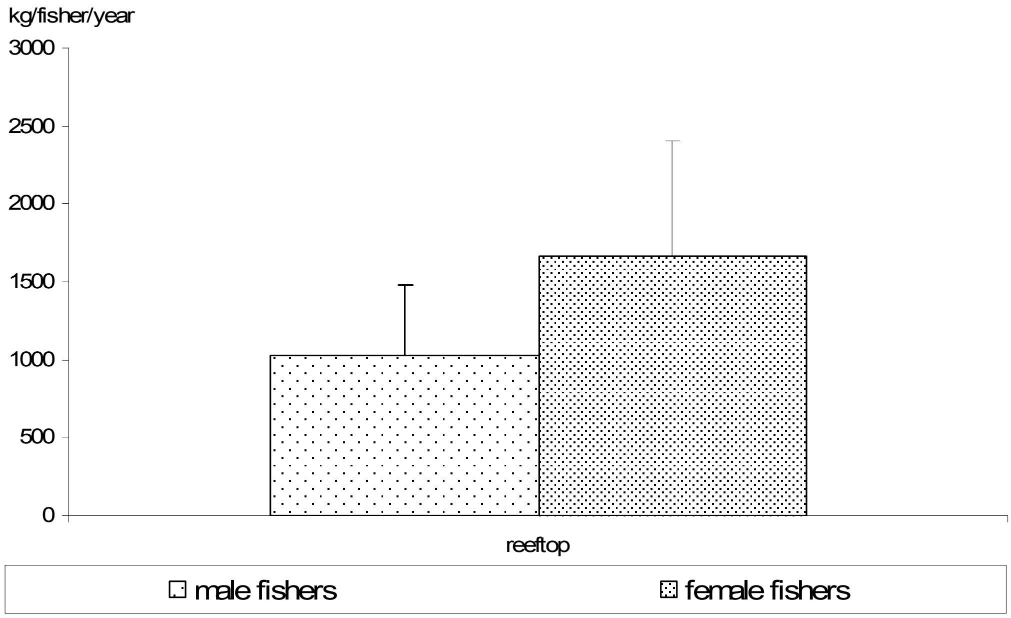

Figure 4.16: Average annual invertebrate catch (kg wet weight/year) by fisher, gender and fishery in Koulo.
Data based on individual fisher surveys. Figures refer to the proportion of all fishers who target each habitat (n = 3 for males, n = 9 for females).

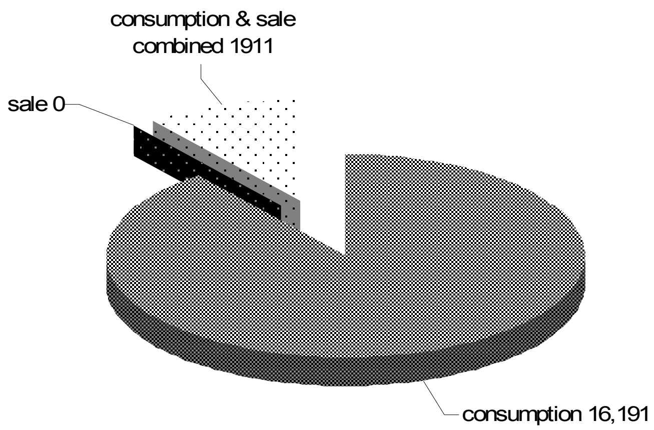

Figure 4.17: Total annual invertebrate biomass (kg wet weight/year) used for consumption, sale, and consumption and sale combined (reported catch) in Koulo.

Although fisheries are of little importance for income generation in Koulo, Figure 4.17 also suggests that invertebrate fisheries are far less important than finfish fisheries for income generation.

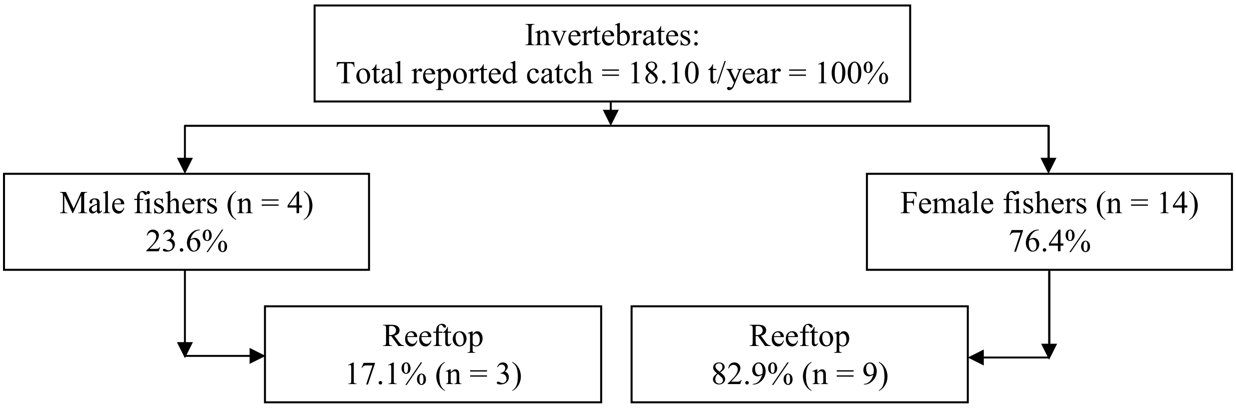

Figure 4.18: Total annual invertebrate catch (tonnes) and proportion (%) by fishery and gender (reported catch) in Koulo.
n is the total number of interviews conducted per each fishery; total number of interviews may exceed total number of fishers surveyed as one fisher may target more than one fishery and thus respond to more than one fishery survey.

As mentioned earlier, male and female fishers from Koulo are both engaged in invertebrate collection; however, females account for 76% of the total annual catch (wet weight) as shown in Figure 4.18. All impact is on reeftops that are located along the coastline close to the village.

Table 4.5: Parameters used in assessing fishing pressure on invertebrate resources in Koulo

Parameters	Fishery / Habitat
	Reeftop
Fishing ground area (km^2)	40.31
Number of fishers (per fishery) [(1)]	19
Density of fishers (number of fishers/km^2 fishing ground)	0.5
Average annual invertebrate catch (kg/fisher/year) [(2)]	1508.51 (±558.00)

Figures in brackets denote standard error; [(1)] number of fishers extrapolated from household surveys; [(2)] catch figures are based on recorded data from survey respondents only.

Taking into account the figure available for the total reeftop surface, reeftop fisheries, as expected, have a low fisher density, i.e. about 0.5 fishers/km^2 of reeftop surface. Even though invertebrates are relatively important as seafood for Koulo people, and the focus is on a few target species only, the average annual catch rates, fisher numbers and available reef area all suggest low fishing pressure and thus no detrimental effect from current fishing levels (Table 4.5).

4.2.5 Management issues: Koulo

Koulo is one of the main urban areas on Lifuka, the mainland of the Ha'apai island group. The village is divided by the airport on the island and has easy road access to the island's major market places. It is not as isolated as Lofanga or any village at the southern end of Lifuka. The Koulo population earns income from salaries and handicrafts (mat weaving) and has access to more modern food items, electricity and public water supplies. However, life in the village is still rather traditional, and traditional social institutions seem to be operational. As elsewhere in Tonga, fishing is governed by the open-access system, which does not restrict people from fishing wherever they wish. However, *de facto* and traditional fishing grounds and their ownership are recognised by communities. Conflicts may occur where population density and thus resource use increases. This is definitely true for some areas in the Tongatapu lagoon system; however, in Ha'apai, traditional fishing ground user systems are still widely accepted and operational. As described by Kronen and Bender (2006), user conflicts are rare and usually are not a subject of major concern among island communities. However, in the case of Koulo, sharing of marine resources is much more common due to the increasing population density and increasing fuel prices, which may restrict fishers in other neighbouring communities from fishing in far distant grounds and may result in higher fisher densities in the closer-to-shore reef areas.

The community fisheries management programme undertaken by Tonga Fisheries in cooperation with a former AusAID project has covered three communities in the Ha'apai group, but not Koulo.

4.2.6 Discussion and conclusions: socioeconomics in Koulo

Koulo is an urbanised coastal community, with access to modern infrastructure and cash income but which also adheres to traditional and, to some extent, religious institutions. People have good access to agricultural land and also to coastal and more distant marine resources. However, people in Koulo do not depend greatly on marine resources for income and may also be less dependent on seafood than other communities.

Due to the low population and fisher density, and the large size of appropriated fishing grounds and reef surfaces, fishing pressure is relatively low. However, this result is in contrast to the findings of the underwater finfish resource survey, which suggest that the finfish resources are not in very good condition.

In summary, survey results suggest:

- The Koulo population is not significantly dependent on its marine resources for income and only somewhat dependent on marine resources for home consumption. Salaries and mat weaving are the main sources of income generation.

- Per capita seafood consumption is considerable, but fresh fish and invertebrates are consumed less than elsewhere, while more canned fish is consumed than in all the other sites studied in Tonga.

- Tradition demands different gender roles in fisheries and these are still apparent in Koulo. Male fishers are the only official and commercial finfish fishers, while females take the lead in invertebrate collection. Although females also do catch fish at times, it is difficult to obtain any information on female finfish fishing activities. Males are also involved in invertebrate harvesting, but their annual production is far less than that of females. Holothurians are the major invertebrate species targeted when reeftop gleaning.

- Finfish is mainly sourced from the easily accessible, sheltered coastal reef, where no boat transport is needed. Much less catch is reported from lagoon/outer-reef habitats.

- Overall, CPUEs are moderate, with higher values for lagoon/outer-reef fishing.

- Handlining and spear diving are the main fishing techniques used, while gillnetting and cast netting are less often used. Invertebrates are collected using very low-cost equipment and little sophisticated support. The average reported fish sizes are moderate and range from 25 to 35 cm. The largest average fish sizes were reported for several families caught in the lagoon/outer reef; however, the average reported sizes (forklength) of Lutjanidae, Carangidae and Labridae from sheltered coastal reef catches exceeded those from the same families caught at the lagoon/outer reef.

- Results from the invertebrate fisher survey show that catches of sea cucumbers, octopus and giant clams are the most important, while all other species caught are of minor importance only.

- Differences were found between the average annual catches taken by male fishers and those taken by female fishers collecting invertebrates. Although male fishers are much fewer in number as compared to female fishers, they catch about 1.5 times more per year than female fishers.

- Fishing pressure parameters calculated for finfish fisheries suggest that finfish fishing pressure is low, due to the large available reef and overall fishing ground area, and low fisher and population densities and catch rates. The same conclusion is suggested for invertebrate catch, reef area and fisher density data. In summary, the current exploitation levels imposed by finfish and invertebrate fishing for subsistence and commercial purposes do not give any reason to assume any detrimental effects on resources. However, this estimation is based on current catch data and does not take into account previous exploitation history, or current impacts that may be caused by other communities targeting the same fishing grounds. As shown by the underwater finfish resource surveys, the current finfish resource status is poor and suggests that previous and ongoing finfish fishing pressure imposed by fishers, including fishers from outside the Koulo community, has caused a detrimental and visible impact on finfish resources.

- Given the increasing population density and thus resource sharing on Lifuka, it is strongly advised that Koulo and other communities on the main island of the Ha'apai group take part in the ongoing fisheries community management programme to ensure a more sustainable use of near-shore resources, and that protected areas be included to help stocks to recover.

4.3 Finfish resource surveys: Koulo

Finfish resources and associated habitats were assessed between 4 and 10 October 2008, for a total of 13 transects (6 back-reef and 7 outer reefs; Figure 4.19 and Appendix 3.3.1). Due to the geomorphology of the coralline islands and the absence of terrigenous (land) influence on the reefs, typical coastal reefs were not present. Intermediate reefs were absent as well, since the lagoon is, in fact, a deep-water lagoon system open to the outer ocean, with atolls and islands. Therefore, only the two back-reef and outer-reef systems were sampled. The outer reefs at the eastern coast of the islands were not accessible due to their exposure to the dominant wind. Male fishers do not normally have access to these areas either.

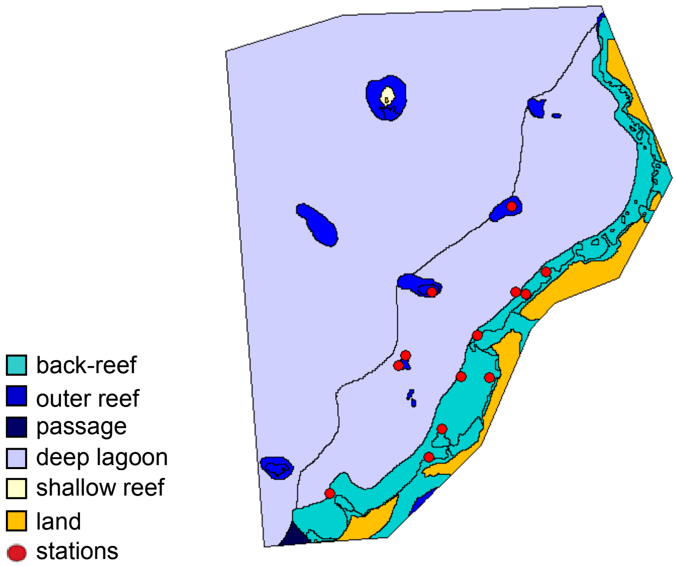

Figure 4.19: Habitat types and transect locations for finfish assessment in Koulo.

4.3.1 Finfish assessment results: Koulo

A total of 21 families, 49 genera, 136 species and 4881 fish were recorded in the 13 transects (See Appendix 3.3.2 for list of species.). Only data on the 15 most dominant families (See Appendix 1.2 for species selection.) are presented below, representing 42 genera, 126 species and 4528 individuals.

Finfish resources differed slightly between the two reef environments found in Ha'apai (Table 4.6). Density was similar at the two reefs (0.3 fish/m^2); however, biodiversity (40 individuals/transect), average size (17 cm FL), size ratio (64%) and biomass (43 g/m^2) were much higher at the outer reefs.

Table 4.6: Primary finfish habitat and resource parameters recorded in Koulo (average values ±SE)

Parameters	Habitat		
	Back-reef [(1)]	Outer reef [(1)]	All reefs [(2)]
Number of transects	6	7	13
Total habitat area (km^2)	40.3	9.3	49.6
Depth (m)	5 (2–12) [(3)]	4 (1–8) [(3)]	5 (1–12) [(3)]
Soft bottom (% cover)	18 ±6	4 ±2	15
Rubble & boulders (% cover)	13 ±5	5 ±2	11
Hard bottom (% cover)	31 ±6	45 ±8	33
Live coral (% cover)	32 ±8	33 ±7	32
Soft coral (% cover)	5 ±3	11 ±5	6
Biodiversity (species/transect)	35 ±2	40 ±4	38 ±2
Density (fish/m^2)	0.3 ±0.1	0.3 ±0.1	0.3
Size (cm FL) [(4)]	15 ±1	17 ±1	16
Size ratio (%)	58 ±3	64 ±3	59
Biomass (g/m^2)	32.7 ±9.5	42.8 ±8.1	34.6

[(1)] Unweighted average; [(2)] weighted average that takes into account relative proportion of habitat in the study area; [(3)] depth range; [(4)] FL = fork length.

Back-reef environment: Koulo

The back-reef environment of Koulo was dominated by three families in terms of density and biomass: Acanthuridae, Scaridae and Chaetodontidae (Figure 4.20, Table 4.7) but only by Acanthuridae and Scaridae in terms of biomass. These two families were represented by 19 species; particularly high biomass and abundance were recorded for *Ctenochaetus striatus*, *Chlorurus sordidus*, *Acanthurus nigrofuscus*, *Scarus psittacus* and *Zebrasoma scopas* (Table 4.7). This reef environment was composed of a high cover of live coral (32%) and hard bottom (31%), relatively high cover of soft bottom (18%) and a small amount of rubble and boulders (13%, Figure 4.20).

Table 4.7: Finfish species contributing most to main families in terms of densities and biomass in the back-reef environment of Koulo

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.08 ±0.02	13.6 ±4.8
	Acanthurus nigrofuscus	Brown surgeonfish	0.03 ±0.01	1.6 ±0.6
	Zebrasoma scopas	Two-tone tang	0.01 ±0.01	0.9 ±0.6
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.04 ±0.02	4.6 ±1.4
	Scarus psittacus	Common parrotfish	0.02 ±0.01	3.1 ±1.6

All the biological values except for density were lower in the back-reefs compared to the outer reefs. Density, however, was similar to the outer-reef value. The trophic structure of fish in Koulo was highly dominated by herbivorous fish, mostly Acanthuridae, in terms of density and biomass, followed by Scaridae. Carnivores were represented in very low numbers by Mullidae and Labridae. Size ratio was below the 50% value for several families, i.e. Mullidae, Lethrinidae, Labridae and Scaridae. These reefs displayed a high cover of hard substrate but still a relatively good cover of soft substrate; however, carnivores preferring mobile bottom were practically lacking, suggesting a strong impact from fishing.

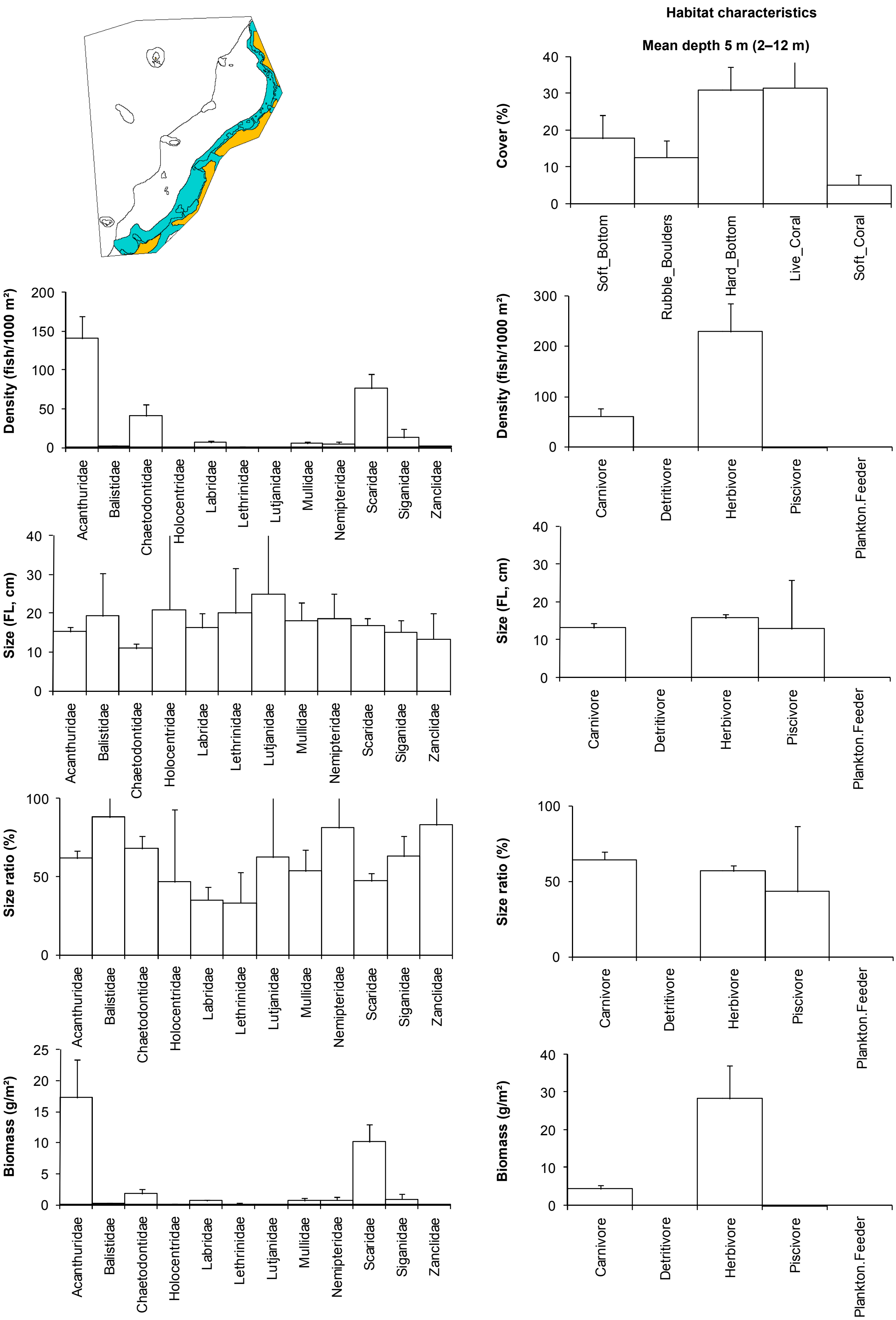

Figure 4.20: Profile of finfish resources in the back-reef environment of Koulo.
Bars represent standard error (+SE); FL = fork length.

Outer-reef environment: Koulo

The outer-reef environment of Koulo was dominated by two families of herbivores: Acanthuridae and, to a much smaller extent, Scaridae; other important families (but with much lower values) were the carnivores Mullidae and Holocentridae (Figure 4.21, Table 4.8). These four families were represented by 33 species; particularly high biomass and abundance were recorded for *Ctenochaetus striatus*, *Acanthurus nigrofuscus*, *Zebrasoma scopas*, *Mulloidichthys flavolineatus*, *A. lineatus*, *Chlorurus sordidus* and *Myripristis kuntee* (Table 4.8). This reef environment was highly dominated by hard bottom (45%) and live coral (33%), with very little soft bottom and rubble (9%, Table 4.6, Figure 4.21).

Table 4.8: Finfish species contributing most to main families in terms of densities and biomass in the outer-reef environment of Koulo

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.07 ±0.02	14.6 ±2.8
	Acanthurus nigrofuscus	Brown surgeonfish	0.03 ±0.01	1.6 ±0.6
	Zebrasoma scopas	Two-tone tang	0.02 ±0.01	1.4 ±0.4
	Acanthurus lineatus	Lined surgeonfish	0.02 ±0.01	4.9 ±1.8
Mullidae	*Mulloidichthys flavolineatus*	Yellow-striped goatfish	0.02 ±0.02	2.3 ±2.3
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.04 ±0.0	3.1 ±1.0
Holocentridae	*Myripristis kuntee*	Shoulderbar soldierfish	0.1 ±01	1.1 ±1.1

The biomass, size, size ratio and biodiversity of finfish in the outer reefs of Koulo were higher than at the back-reefs. Density, however, was comparable. The trophic structure of the fish community was highly dominated by herbivorous fish in terms of both density and biomass. Acanthuridae dominated in numbers and biomass but were mostly represented by small-sized species. Mullidae and Holocentridae were as important as Scaridae in terms of both density and biomass; however, other carnivorous families were practically absent. Size ratio was below the 50% value for Labridae and Lethrinidae. The outer reefs of Koulo displayed a substrate almost entirely composed of hard bottom and live corals, with also a good cover of soft coral (11%). The almost total lack of sandy substrate probably explains the lack of certain carnivores, e.g. Lethrinidae.

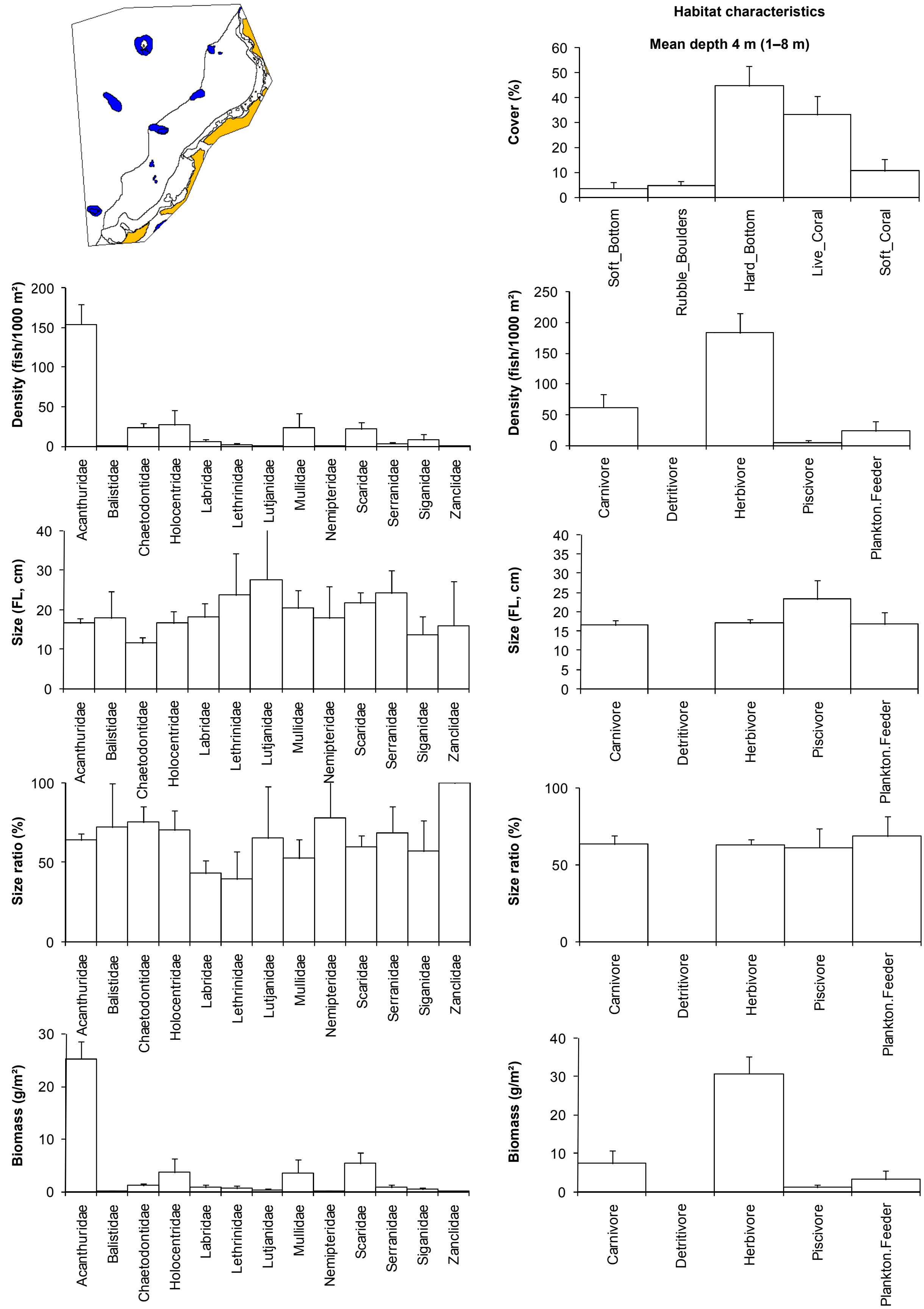

Figure 4.21: Profile of finfish resources in the outer-reef environment of Koulo.
Bars represent standard error (+SE); FL = fork length.

Overall reef environment: Koulo

Overall, the reefs of Koulo were heavily dominated by two families in terms of density, Acanthuridae and Scaridae (Figure 4.22). These major families were represented by a total of 28 species, dominated by *Ctenochaetus striatus*, *Acanthurus nigrofuscus*, *Chlorurus sordidus*, *Zebrasoma scopas* and *Scarus psittacus* (Table 4.9). Overall, hard-bottom and live-coral cover dominated the habitat (65%), while soft bottom was present in only a small amount (15%, Table 4.6 and Figure 4.22). The overall fish assemblage in Koulo shared characteristics of primarily back-reefs (81% of total habitat surface), followed by outer reefs (19% of total habitat).

Table 4.9: Finfish species contributing most to main families in terms of densities and biomass across all reefs of Koulo (weighted average)

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.08	13.8
	Acanthurus nigrofuscus	Brown surgeonfish	0.03	1.6
	Zebrasoma scopas	Two-tone tang	0.02	1.0
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.04	4.3
	Scarus psittacus	Common parrotfish	0.02	1.0

Overall, Koulo appeared to support an average finfish resource, similar to those at the other three study sites, with density, size, biomass and biodiversity being intermediate values between those at Ha'atafu and Lofanga. However, values were still low compared to the regional average. Detailed assessment of the fish community composition revealed lower density and biomass of carnivores and piscivores compared to herbivores, which strongly dominated the fish community. Few families dominated the community and a general lack or serious poverty of carnivores was the dominant profile. Mullidae were the most significant carnivores but were present in extremely low numbers and biomass. Holocentridae were relatively important in the outer reefs. The dominance of herbivores can be partially explained by the composition of the habitat, mostly hard rock and live coral (65%), with little percentage of soft substrate, which normally favours most invertebrate-feeding carnivores. However, the general conditions were impacted and the values of biological parameters were lower than the average for the region.

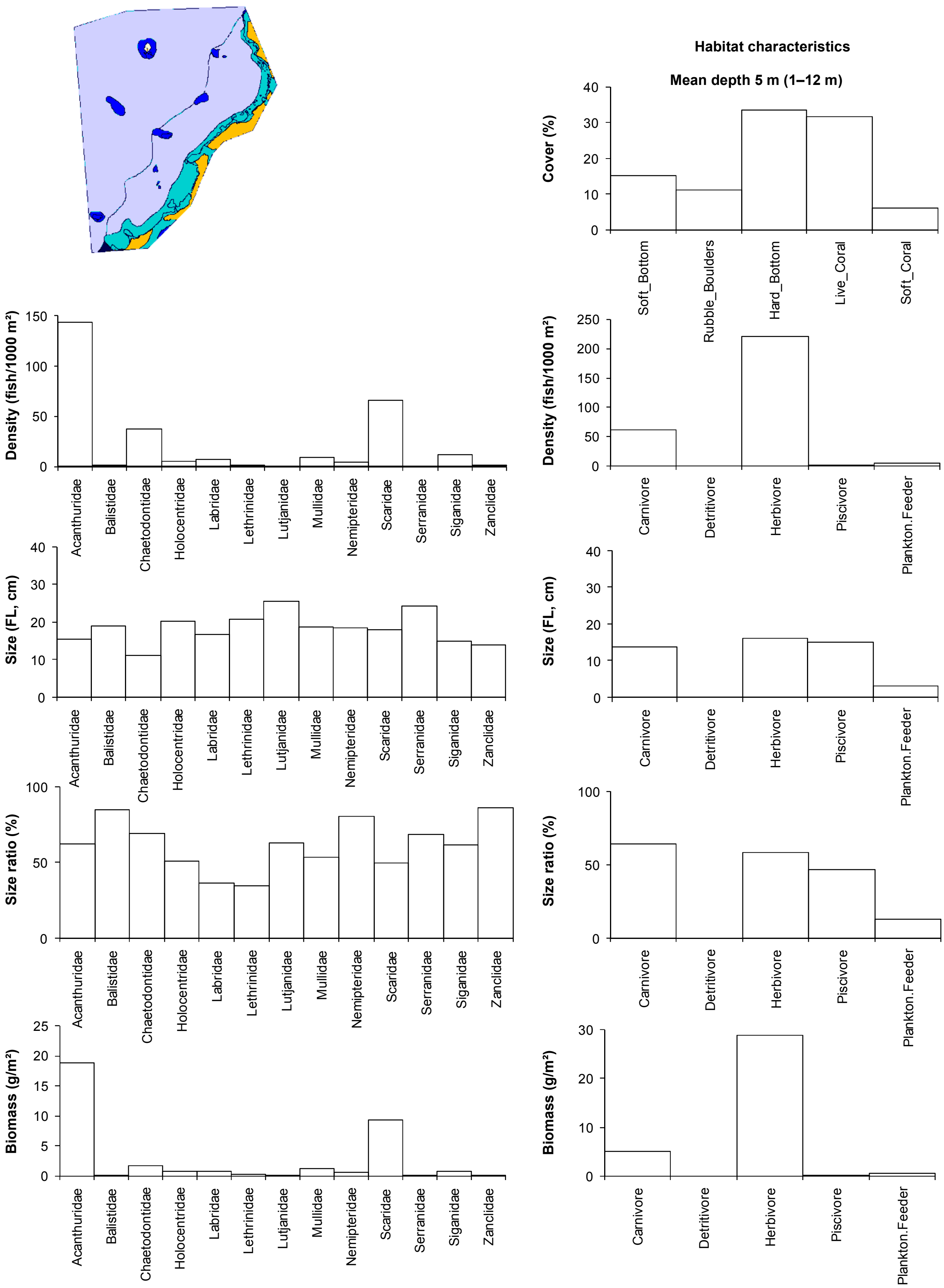

Figure 4.22: Profile of finfish resources in the combined reef habitats of Koulo (weighted average).
FL = fork length.

Comparisons with 2002 surveys

Fish biodiversity was lower in 2002 than in 2008, while density and size did not show important changes. Biomass was lower in 2008 (Table 4.10). The biomass decrease was mainly due to a decrease in number of fish, especially Scaridae (Figure 4.23). The trophic composition did not change between the two surveys (Figure 4.24). The most important species composition did not change much either, except that *Ctenochaetus striatus*, the dominant species in both years, decreased in abundance and biomass between the two surveys (Table 4.11).

Table 4.10: Primary finfish habitat and resource parameters recorded in Koulo in 2002 and 2008

Parameters	Year of survey	
	2002	2008
Number of transects	49	13
Total habitat area (km^2)	49.6	49.6
Depth (m)	6 (0–33) [1]	5 (1–12) [1]
Soft bottom (% cover)	20	15
Rubble & boulders (% cover)	13	11
Hard bottom (% cover)	51	33
Live coral (% cover)	16	32
Soft coral (% cover)	3	6
Biodiversity (species/transect)	26 ±1	38 ±2
Density ($fish/m^2$)	0.3	0.3
Size (cm FL) [2]	16	16
Size ratio (%)	47	59
Biomass (g/m^2)	40.2	34.6

[1] depth range; [2] FL = fork length.

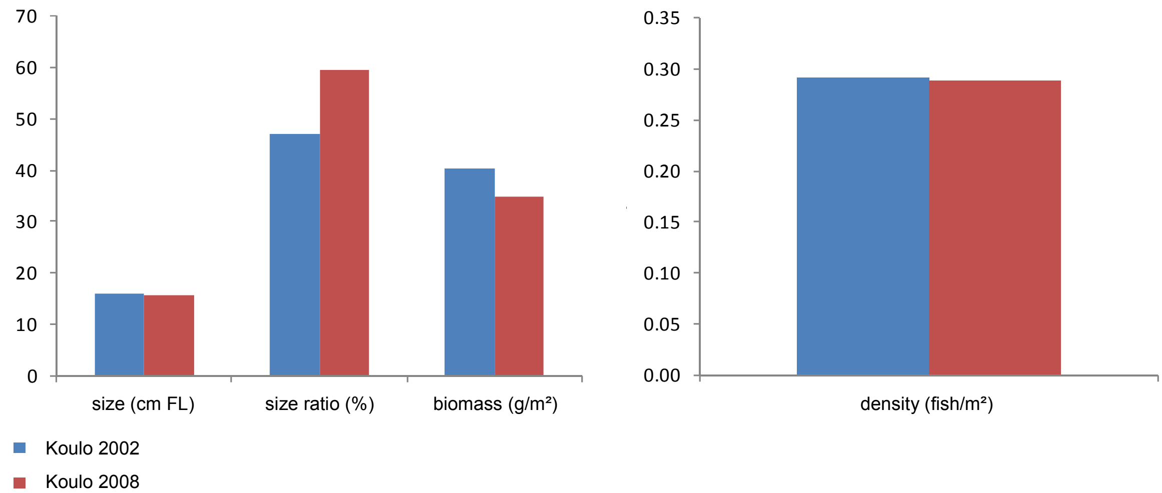

Figure 4.23: Variation in average size, size ratio, biomass and density of finfish in Koulo between 2002 and 2008.

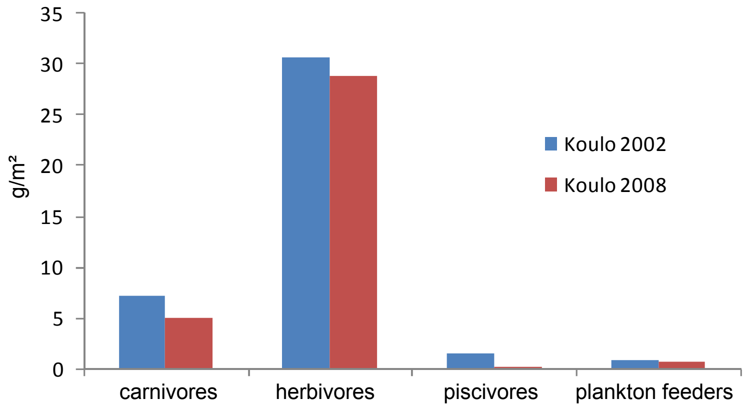

Figure 4.24: Trophic composition in terms of biomass in Koulo in 2002 and 2008.

Table 4.11: Finfish species contributing most to main families in terms of densities and biomass across all reefs of Koulo in 2002 (weighted average)

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.06	7.3
	Zebrasoma scopas	Two-tone tang	0.02	0.9
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.03	3.5

4.3.2 Discussion and conclusions: finfish resources in Koulo

The assessment indicated that the status of finfish resources in this site at the time of surveys was an average between the very poor condition at Tongatapu and the relatively healthier conditions at Lofanga. However, on a regional basis, biomass and sizes were low. Fish density at Koulo was comparable to the Lofanga and Ha'atafu values but size and biomass were more similar to those at Lofanga. Detailed analysis at family level showed that Acanthuridae consistently displayed the highest abundance and biomass, while Scaridae were rather poor. Carnivores were particularly poor, with the slight exception of Mullidae, which were only relatively important in terms of biomass in the outer reefs. Conditions did not show much change between the two survey seasons, except for a slight decrease in average biomass and a decrease in the most important species, *Ctenochaetus striatus*.

- Resources were, overall, in average-to-poor condition. The back-reefs were poorer than the outer reefs, with low density, sizes, biomass and biodiversity.

- The fish community composition was heavily dominated by small-sized Acanthuridae species.

- Sizes of Scaridae, Lethrinidae and Holocentridae were much lower than the maximum size recorded for the relative species, indicating an impact from fishing on such preferred targets.

- The use of gillnet fishing and the mesh size of nets should be regulated and their size limited.

- The establishment of community-driven reserves should be followed by patrolling to enforce compliance if the finfish resources are expected to recover.

- A monitoring system should be set in place to follow any further changes in finfish resources.

4.4 Invertebrate resources: Koulo

The diversity and abundance of invertebrate species at Koulo were independently determined using a range of survey techniques (Table 4.12), broad-scale assessment (using the 'manta-tow' technique; locations shown in Figure 4.25) and finer-scale assessment of specific reef and benthic habitats (Figures 4.26 and 4.27).

The main objective of the broad-scale assessment is to describe the distribution pattern of invertebrates (rareness/commonness, patchiness) at large scale and, importantly, to identify target areas for further, fine-scale assessment. Then, fine-scale assessment is conducted in target areas to specifically describe the status of resources in those areas of naturally higher abundance and/or most suitable habitat.

In-water work completed at Ha'apai was not all conducted according to the standard PROCFish survey method, as we used the opportunity of this scheduled work to respond to a specific request from the Government of Tonga to assess the sea cucumber resources of Ha'apai.

Table 4.12. Number of stations and replicates completed at Koulo

Survey method	Stations	Replicate measures
Broad-scale transects (B-S)	13	78 transects
Slope 'manta' transects (10–20 m)		240 transects (2)
Deep 'manta' transects (20–30 m)		240 transects (2)
Reef-benthos transects (RBt)	14	88 transects
Soft-benthos transects (SBt)	0	0 transect
Soft-benthos infaunal quadrats (SBq)	0	0 quadrat group
Mother-of-pearl transects (MOPt)	0	0 transect
Mother-of-pearl searches (MOPs)	0	0 search period
Reef-front searches (RFs)	3	18 search periods
Reef-front search by walking (RFs_w)	13	65 search periods (1)
Sea cucumber day searches (Ds)	See slope and deep 'manta' transects	480 transects (2)
Sea cucumber night searches (Ns)	0	0 search period

(1) Reef-front search by walking stations were completed with five officers walking close to the reef crest simultaneously, thereby giving five replicates per station. This is non-standard as usually two officers complete three sets of two replicates; (2) search periods for deep-water work were 100 m in length and 4 m swathe.

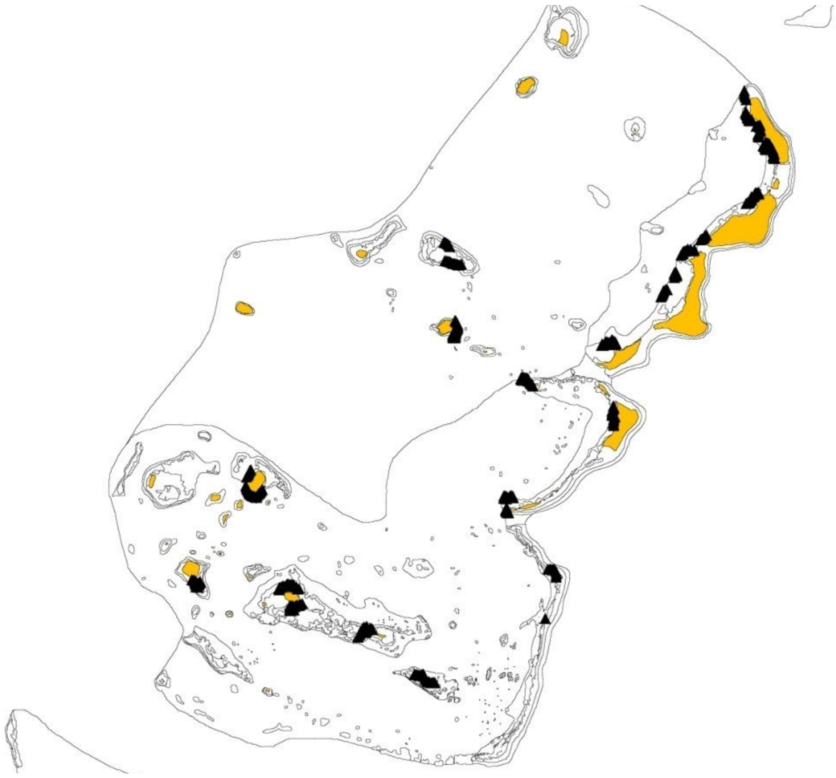

Figure 4.25: Broad-scale survey stations for invertebrates in Koulo and Lofanga.
Data from broad-scale surveys conducted using 'manta-tow' board;
black triangles: transect start waypoints.

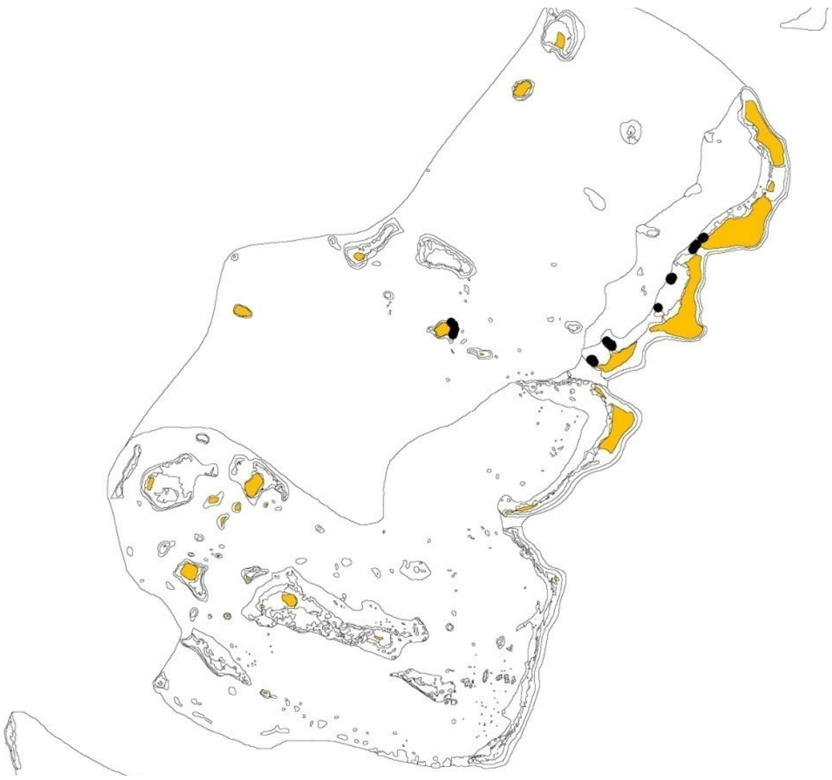

Figure 4.26: Fine-scale reef-benthos transect survey stations for invertebrates in Koulo.
Black circles: reef-benthos transect stations (RBt).

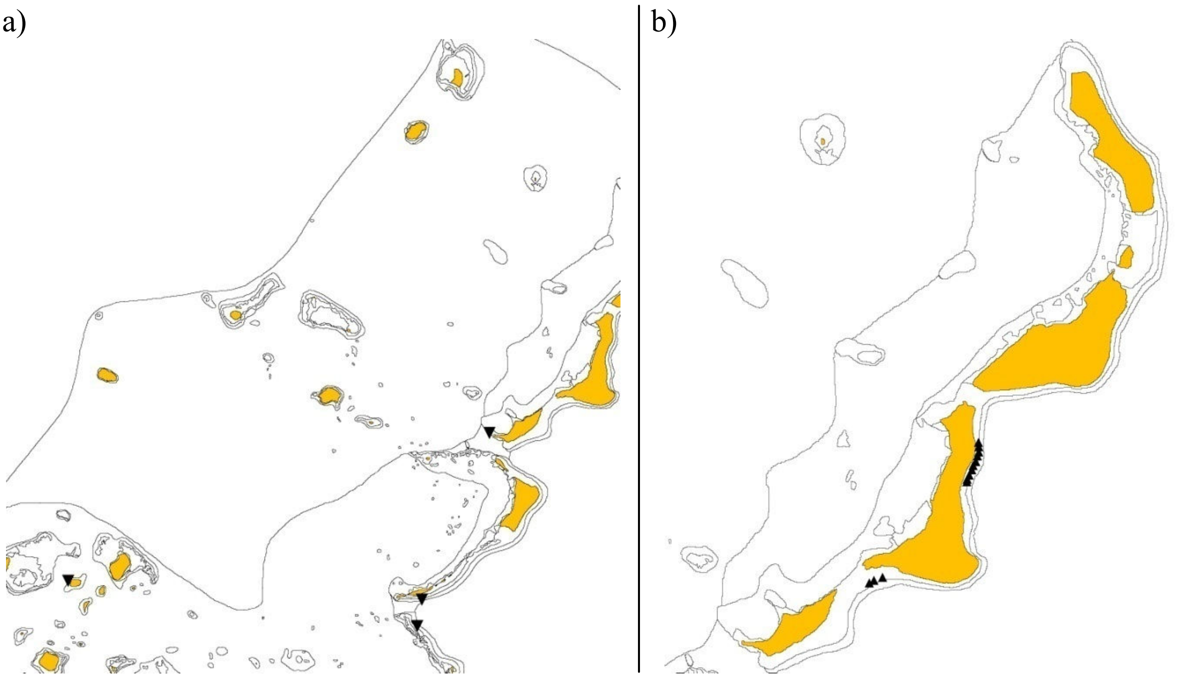

Figure 4.27: Fine-scale survey stations for invertebrates in Koulo.
a) Inverted black triangles: reef-front search stations (RFs);
b) black triangles: reef-front search by walking stations (RFs_w), on the easterly side of Lifuka Island.

Sixty-two species or species groupings (groups of species within a genus) were recorded in the invertebrate surveys at Ha'apai. These included, among others, 9 bivalves, 19 gastropods, 21 sea cucumbers, 5 urchins, 5 sea stars, 1 lobster and 1 cnidarian (Appendix 4.3.1). Information on key families and species is detailed below.

4.4.1 Giant clams: Koulo

Shallow-reef habitat that is suitable for giant clams on the fringing and offshore reefs associated with Koulo was extensive; however, fishing is generally open-access in Tonga and no set fishing area is noted in this report.

Reef benthos was commonly recorded on the fringes of the string of islands that make up the Ha'apai group. The nature of the Ha'apai group of islands is oceanic and the exposed shoreline, without rich lagoon environments, was subject to oceanic swell and high levels of flushing. The proportion of land mass to fishing area was small and the land was generally low-lying, with few natural embayments to slow the water flow and facilitate sedimentation of suspended solids. Some pseudo-lagoons existed, where the fringing reefs were large and enclosed pools, forming semi-barrier reefs.

As suggested by the island profile, nutrient inputs from the land were limited and in general the system looked to be nutrient-poor, with little epiphytic growth or silt and a generally 'clean' reef.

Reefs at this site held four species of giant clams: the elongate clam *Tridacna maxima*, the fluted clam *T. squamosa*, the smooth clam *T. derasa*, and the devil's clam *T. tevoroa.* Shallow-water broad-scale sampling provided an overview of giant clam distribution and yielded information on three of the species; *T. maxima* had the widest distribution (found in all 11 stations and 44 of 66 transects), followed by *T. squamosa* (6 stations and 6 transects) and *T. derasa* (1 station and 1 transect). *T. tevoroa* was rare and only noted in surveys of water deeper than 10 m. The average station density of *T. maxima* in broad-scale shallow-water surveys was 42.8 /ha ±9.3 (See Figure 4.28.).

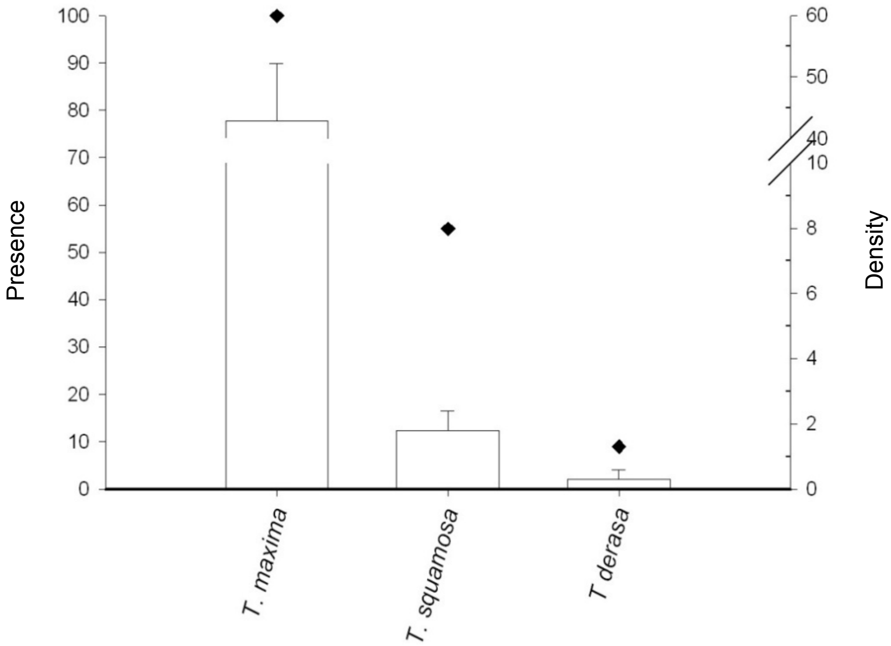

Figure 4.28: Presence and mean density of giant clam species in Koulo based on broad-scale survey.
Presence is measured as % of stations surveyed where clams were present and denoted by black diamonds; density is measured in numbers per hectare and is represented by bars (+SE).

Based on the findings of the broad-scale survey, finer-scale surveys targeted specific areas of clam habitat (Figure 4.29). In these reef-benthos assessments (RBt), *T. maxima* was present in 86% of stations at a mean density of 132.7 /ha ± 34.2.

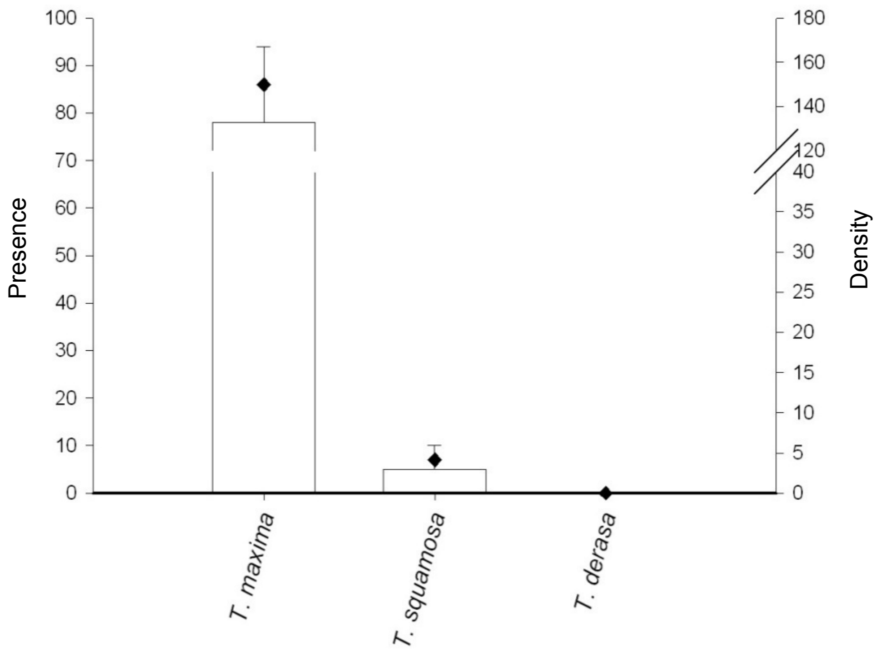

Figure 4.29: Presence and mean density of giant clam species in Koulo based on fine-scale survey.
Presence is measured as % of stations surveyed where clams were present and denoted by black diamonds; density is measured in numbers per hectare and is represented by bars (+SE).

In general clams were not uncommon, with only two RBt stations, not far distant from the main settlement of Koulo, holding no clam records (between Uiha and Lifuka). However, the density of clams was not high. Just four of the RBt stations returned densities greater than 200 /ha, with the highest average station density reaching 417 /ha.

A total of 205 clams were measured during all the surveys at Ha'apai. The average length of clams taken in reef-benthos transect assessments in Koulo was 10.9 cm ±0.6 (n = 45) for *T. maxima*. Only a single *T. squamosa* of 18 cm was recorded in RBt surveys in Koulo, but a further seven were noted in shallow-water broad-scale surveys (mean length 19.1 cm ±1.6). No *T. derasa* was noted in RBt stations; however, in shallow-water broad-scale surveys a single clam of 19 cm was recorded (Most *T. derasa* records originated from greater than 10 m depth.). A similar result was recorded for the devil's clam, *T. tevoroa*. No records originated from shallow water, with only two recorded during surveys made in deeper water (mean length of 44 cm ±6; see Figure 4.30).

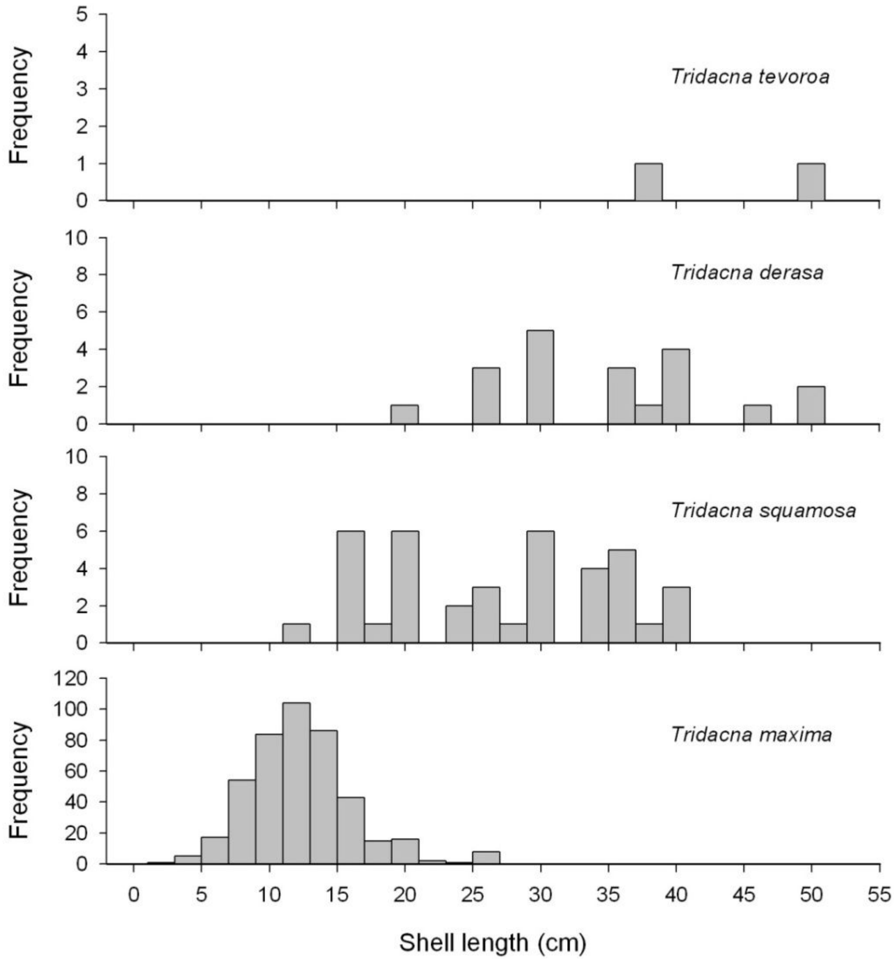

Figure 4.30: Size frequency histograms of giant clam shell length (cm) for Koulo.

4.4.2 Mother-of-pearl species (MOP) – trochus and pearl oysters: Koulo

Ha'apai lies at 19°S and 174°E, which is outside the east–west range of the commercial topshell, *Trochus niloticus* (found naturally on islands as far east as Wallis). As in other eastern Pacific islands, commercial mother-of-pearl shells have been introduced to Ha'apai.

The 1995 transplantation of trochus from the Lau Group in Fiji to Ha'apai is described by Gillett (1995). In this case, the 587 trochus placed in Ha'apai spent from 3 to 4.5 days out of reef habitat during the move. They were held dry in transit on the first occasion for 32.5 hours, followed by 14 hours in tanks of circulating, aerated seawater, and finally held dry again for 5.5 hours. Three trochus died after collection in Lakeba but there was no mortality during transportation. The trochus were all placed on the north side of Ava Auhanga Mea between Uoleva and Tataga islands. The location as determined by GPS equipment was 19°51'S, 174°25'W.

At the same time as the introductions of adult shells, maricultured juvenile trochus were established with assistance from Japanese aid, and the reseeding of reefs with hatchery-produced trochus juveniles (mainly released in Tongatapu) was a major part of this programme (Table 4.13).

Table 4.13: Summary of hatchery-produced *Trochus* released in Ha'apai, Tonga

Year	Released site	Released (number)	Released size (mm)
1998	Ha'apai	350	>50
1999	Ha'apai	450	>50
2000	Ha'apai	500	>50

The reefs at Ha'apai constitute a very extensive benthos suitable for *T. niloticus*, and records show the introductions of adult shells have been sufficient to build up some level of broodstock to create the conditions suitable for more large-scale colonisation.

Table 4.14: Presence and mean density of *Trochus niloticus*, *Tectus pyramis*, *Turbo marmoratus* and *Pinctada margaritifera* in Koulo.
Based on various assessment techniques; mean density measured in numbers/ha (±SE).

	Density	SE	% of stations with species	% of transects or search periods with species
Trochus niloticus				
B-S	0.3	0.3	1/11 = 9	1/66 = 2
RBt	8.9	6.4	2/14 = 1	2/88 = 2
RFs	3.9	2.3	2/3 = 66	2/18 = 1
Tectus pyramis				
B-S	2.3	0.8	4/11 = 36	8/66 = 12
RBt	77.4	17.9	10/14 = 71	19/88 = 22
RFs	32.7	32.7	1/3 = 33	6/18 = 33
Turbo marmoratus				
B-S	0	0	0/11 = 0	0/66 = 0
RBt	0	0	1/14 = 7	1/88 = 1
RFs	1.3	1.3	1/3 = 33	1/18 = 6
Pinctada margaritifera				
B-S	1.5	0.6	3/11 = 27	6/66 = 9
RBt	2.8	2.8	1/14 = 7	1/88 = 1
RFs	0	0	0/3 = 0	0/18 = 0

B-S = broad-scale survey; RBt = reef-benthos transect; RFs = reef-front search.

PROCFish survey work located just nine live *Trochus niloticus* at Ha'apai (Table 4.14), although *Tectus pyramis*, a closely related gastropod, was more common (n = 60 individuals). This less valuable species of topshell (an algal-grazing gastropod with a similar life history to trochus) was moderately common and at moderate density at Koulo, which potentially highlights the suitability of reefs for the more valuable species.

At Ha'apai, the mean size (basal width) of *T. niloticus* was 7.5 cm ±0.9 (n = 8 individuals), while that of *T. pyramis* was 7.9 cm ±0.5 (n = 10 individuals). Interestingly, most shells measured less than 9 cm across the base, which indicates that these shells are likely to be young derived from the reproduction of trochus introduced as adults or juveniles. However, no large recruitment pulse was identified in the survey (Figure 4.31).

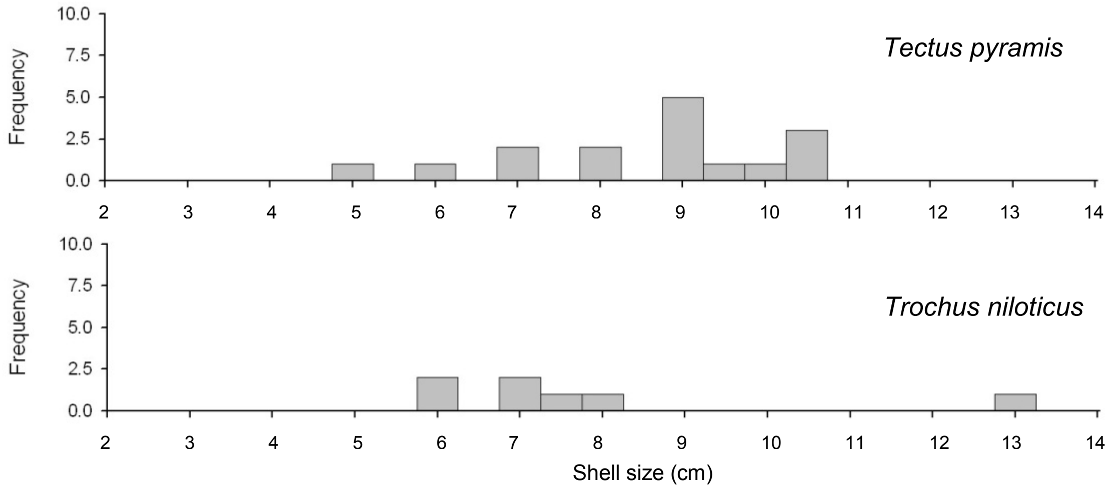

Figure 4.31: Size frequency histograms of *Tectus pyramis* and *Trochus niloticus* shell base diameters (cm) for Ha'apai.

Green snail (*Turbo marmoratus*) juveniles were also stocked on to the reefs in Ha'apai, close to Koulo and at a site further west. At the suggestion of local fisheries officers, we searched three reefs (RFs) that were stocked with maricultured juveniles. From these three stations, only a single *T. marmoratus* was recorded (average density for the three stations of 1.3 /ha ±1.3). However, on a separate search at Uolema point (location not logged), eight green snails were recovered. The size or height of a green snail can be difficult to measure, as the total shell height (See A in Figure 4.32) is not easy to measure because of the large whorls of the shell (Table 4.15). The best estimation of the average measure (total shell height) for the eight green snails measured was 17 cm ±0.3.

Table 4.15: Three measures for green snail shell morphometrics in Koulo
Please see Figure 4.32 for an image of the measures taken.

Shell height in cm (A)	Outer vertical height of opening in cm (B)	Inner vertical height of opening in cm (C)
17.5	-	10.0
17.5	-	9.3
18.0	13.0	10.0
17.0	13.5	10.0
16.7	12.5	9.5
17.5	15.5	10.0
15.5	13.0	9.4
16.5	13.5	9.0

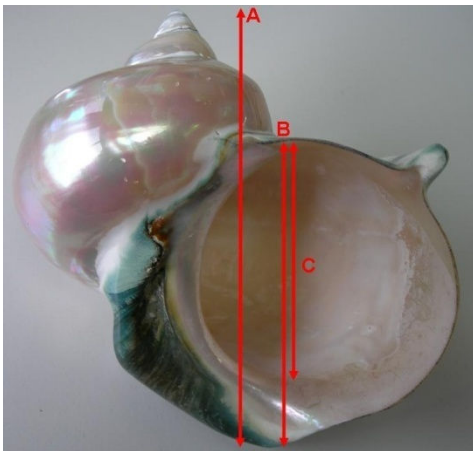

Figure 4.32: Three different size measures of green snail, *Turbo marmoratus*.
A is the shell height, B is the outer vertical height of the opening, and C is the inner vertical height of the opening. This specimen of green snail has been partially polished to reveal the nacre.

Blacklip pearl oysters, *Pinctada margaritifera*, are normally cryptic and sparsely distributed in open lagoon systems. This string of islands did not have any naturally enclosed structures, yet blacklip pearl oysters were not uncommon in survey (n = 7 individuals). The mean size of these shells was 13.0 cm ±0.4 (dorso–ventral measure).

4.4.3 Infaunal species and groups: Koulo

No fine-scale soft-benthos surveys or infaunal stations (quadrat surveys) were made at Koulo. Soft-benthos coastal margins were uncommon at Koulo and no extensive areas of seagrass or mud, or concentrations of in-ground resources (shell 'beds'), such as arc shells (*Anadara* spp.) or venus shells (*Gafrarium* spp.) were identified.

4.4.4 Other gastropods and bivalves: Koulo

The spider conch, *Lambis truncata* (the larger of the two common spider conchs) was recorded at low density (n = 4 individuals); however, larger numbers were noted in deeper-water surveys for sea cucumbers at Ha'apai (n = 30 individuals). In Koulo, 16 *L. lambis* individuals were recorded (Appendices 4.3.1 to 4.3.7).

In addition to *Turbo marmoratus*, a full range of small turban shells were recorded (e.g. *T. argyrostomus*, *T. chrysostomus* and *T. setosus*). Only a small number of *T. agyrostomus* were recorded (n = 7). It was not possible to closely inspect the surf zone on the eastern shores of Lifuka, Foa and Uiha islands but, overall, turban species were not very common. Other resource species targeted by fishers (e.g. *Astralium*, *Chicoreus*, *Conus*, *Cypraea*, *Latirolagena*, *Ovula*, *Pleuroploca*, *Thais* and *Tutufa*) were also recorded during independent surveys (Appendices 4.3.1 to 4.3.7). Data on other bivalves in broad-scale and fine-scale benthos surveys, such as *Atrina*, *Chama*, *Hyotissa* and *Spondylus*, are also in Appendices 4.3.1 to 4.3.7. No creel survey was conducted at Koulo.

4.4.5 Lobsters: Koulo

Koulo had extensive areas of exposed reef front (barrier reef). This exposed reef, with exposed reef platforms and submerged reef slopes, represents a large amount of suitable habitat for lobsters. Lobsters are an unusual invertebrate species, which can recruit from near and distant reefs, as their larvae drift in the ocean for 6–12 months (up to 22 months) before settling as transparent miniature versions of the adult (*pueruli*, 20–30 mm in length).

There was no dedicated night reef-front assessment of lobsters (See Methods.). Despite the lack of targeted surveys, the shallow- and deep-water survey work for sea cucumbers provided a potential source of lobster recordings. In these surveys, only one lobster (*Panulirus versicolor*) was noted, although a further three juvenile-sized lobsters were seen in RFs_w stations on the reef platform at Lifuka.

4.4.6 Sea cucumbers[8]: Koulo

Koulo did not have an extensive shallow-water lagoon system and low-lying *motu* were separated by channels of deep water. However, fringing reef margins, reef slopes and areas of shallow, mixed hard- and soft-benthos habitat in the lee of islands (suitable habitat for sea cucumbers) were present. There was little land influence, except close to shore and on extended reef platforms, which pooled water in pseudo-lagoons. Generally, surfaces were without heavy algal and epiphytic growth, although the reef platform to the east of Lifuka was sufficiently covered to support large numbers of surf redfish (*Actinopyga mauritiana*) and some patches of soft benthos to the east of Uiha Island held depositional environments. In general, the system can be considered to be largely oceanic-influenced, impacted by a large swell in the east and without extensive protected, enclosed shallow-water lagoons. As most commercial sea cucumbers are deposit feeders (which eat organic matter in the upper few mm of bottom substrates), they generally require richer depositional areas, where food is available.

Species presence and density were determined through broad-scale and fine-scale methods (Table 4.16, Appendices 4.3.2 to 4.3.6, also see Methods). In addition to the standard protocol for sampling, a special additional sampling protocol was initiated in Koulo to respond to a request from the Tongan government. To assist in this endeavour extra staff from Solomon Islands and Papua New Guinea took part in the surveys.

A short history shows that Tonga fisheries authority in 1997 recommended a zero quota (moratorium) on sea cucumber exports when it became clear that the fishery was in serious decline in the early 1990s. The Act provided for a 10-year moratorium, but also called for a five-year review of stocks to advise on their recovery and status. This work constitutes the review, provides a three-point time series of assessment in the sea cucumber fishery of Ha'apai and comprises much of the PROCFish assessment.

Although the survey results by the individual methods are separated for the two PROCFish sites in Ha'apai (Koulo and Lofanga), the joined species list returned 20 commercial species of sea cucumber from all in-water assessments (plus one indicator species, see Table 4.16). The range of sea cucumber species recorded reflected both the varied nature of the habitats present in Ha'apai and the level of management control that had been enforced over these largely exposed, oceanic-influenced islands.

[8] There has been a recent change to sea cucumber taxonomy that has changed the name of the black teatfish in the Pacific from *Holothuria* (*Microthele*) *nobilis* to *H. whitmaei*. It is possible that the scientific name for white teatfish may also change in the future. This should be noted when comparing texts, as in this report the 'original' taxonomic names are used.

Sea cucumber species associated with shallow-reef areas, such as the medium-value leopardfish (*Bohadschia argus*), were common (found in 61% of broad-scale transects and 36% of reef-benthos transect stations). The average density recorded (~20 /ha) was not very high, but consistent with the environment and the current low level of fishing.

Stocks of high-value sea cucumbers, e.g. black teatfish (*Holothuria nobilis*), which is also found in shallow reef and therefore easily targeted by fishers, were not commonly recorded at Koulo (in 8% of broad-scale transects) and were at low-average density (1.5 /ha). There is some evidence that this species is highly susceptible to fishing pressure and, once heavily depleted, can take years to recover to reasonable densities of >10 /ha. It is possible that previous heavy fishing around Ha'apai could still be impacting the viability of stocks at Koulo; as sea cucumbers are single-sexed, broadcast spawners (which release their eggs and sperm into the water column for fertilisation), stocks such as black teatfish, which are generally found at lower ranges of density, are susceptible to the negative effects that occur when overfishing decreases stock densities on the bottom. Fishing pressure affects reproduction success, as individuals become too widely dispersed to effectively maximise fertilisation rates (See Figure 2.35.).

Overall, the surveys conducted in Ha'apai show that black teatfish have recovered somewhat since the closure of the fishery, but not substantially and not to the levels recorded when the fishery was becoming active in 1990 (Figure 4.33).

The faster-growing and medium/high-value greenfish (*Stichopus chloronotus*) was more common, being recorded in most assessments but only at low-to-moderate density.

Surf redfish (*Actinopyga mauritiana*) were recorded across the site, especially on the easterly reef platform of islands, like Lifuka, that faced the prevailing swell and had many pools and gulleys, which were replenished with tidal water and spray from waves. This species can be recorded at commercial densities of 500–600 /ha in oceanic-influenced atoll islands in French Polynesia, Cook Islands and Solomon Islands; the densities in Tonga were also high. In RFs_w stations on the reef crest, 38% of stations recorded an average density of >750 /ha, and the overall average was 677.1 ±81.3 /ha. The reef platform was obviously suitable for this species but as one went further back towards the shoreline and away from the wave-influenced crest, *A. mauritiana* densities generally decreased, while densities of *Holothuria atra* and *Stichopus chloronotus* increased.

More protected areas of reef and soft benthos in lagoonal embayments were not common in Ha'apai. We did not record large numbers of small hairy blackfish (*Actinopyga miliaris*), stonefish (*A. lecanora*), elephant trunkfish (*Holothuria fuscopunctata*) or curryfish (*Stichopus herrmanni*) across Ha'apai, although they were noted at low density in locations that were partially suitable.

One higher-value species of great importance to Ha'apai is the golden sandfish, which is presently called *Holothuria scabra versicolor* (This scientific Latin name has changed recently to *Holothuria lessoni* but, for consistency, we have kept the previous name.). This species is concentrated at only a few locations in Ha'apai, predominantly on reef flats where pooled water creates a depositional environment and seagrass and soft benthos predominates. One important fishing area was in the westerly shallows of Oua island, where we went out with the village elders to look at the areas that were targeted by fishers. Anecdotal reports tell us that this area was targeted by fishers from other villages initially when the sea cucumber fishery was active and it was only later that fishers from Oua became aware of the value of this product and began fishing themselves. Supposedly, there were large stocks available, but in our visit we did not find any golden sandfish, despite 30 minutes of snorkelling in the seagrass areas targeted by fishers. Broad-scale surveys near Lekaleka, Luanamo and Teaupa islands (allocated to the Lofanga site) did return some records for this important species, so golden sandfish is not lost to the area. The low number of records (n = 8 individuals) means that continued controls are undoubtedly needed to allow golden sandfish densities to re-establish.

Some lower-value species, e.g. lollyfish (*Holothuria atra*), pinkfish (*H. edulis*) and brown sandfish (*Bohadschia vitiensis*), were also noted at low density at Koulo. Lollyfish is probably more common in very shallow water not targeted by the surveys, on the margin of island groups in Ha'apai.

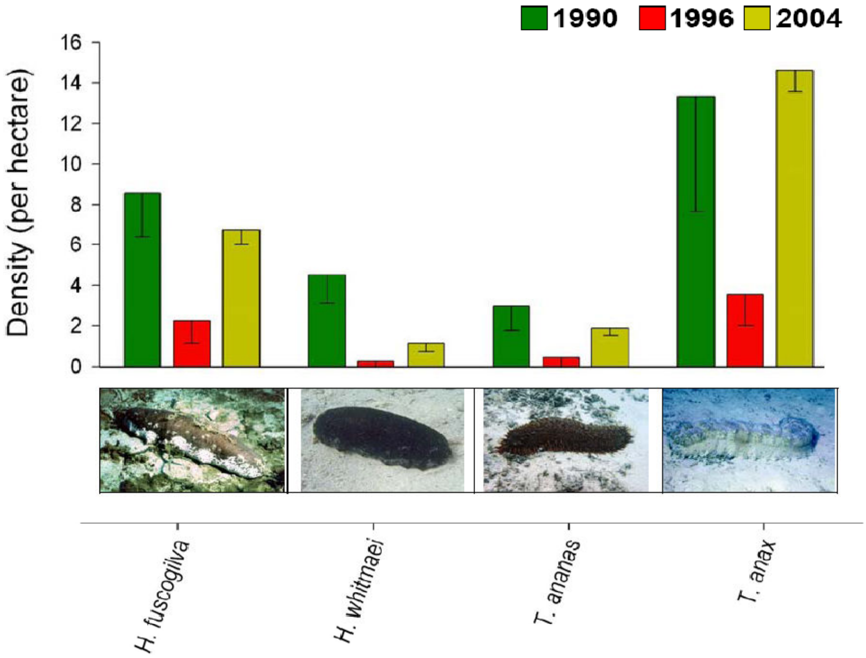

Figure 4.33: Temporal survey of sea cucumber stocks in Ha'apai, showing the density of four important fishery species before the moratorium, once the moratorium came into place, and during the current PROCFish work in 2004.

Mid-water and deep-water assessments were conducted using a broad-scale system on SCUBA (Friedman *et al.* 2004). In these surveys, 240 medium-depth water transects (100 m length, 4 m width, depth range 10–20 m, average depth 13.7 m) and 240 deep-water transects (100 m length, 4 m width, depth range 20–40 m, average depth 24.5 m) were completed to obtain a preliminary abundance estimate for white teatfish (*Holothuria fuscogilva*), prickly redfish (*Thelenota ananas*), amberfish (*T. anax*) and partially for elephant trunkfish (*H. fuscopunctata*). Oceanic-influenced benthos in the areas between islands, at the foot of reef slopes and in the passages had suitably dynamic water movement for these species and the density records showed that there had been recovery in the fishery following the introduction of the moratorium (Figure 4.33 and Appendix 4.3.3).

The high-value white teatfish (*H. fuscogilva*) was commonly recorded in these surveys. White teatfish were found in moderate numbers (6.7 ±1.2 /ha) in SCUBA zones, but were not noted in shallow water. This density is similar to the densities recorded in the 1990 survey

(8.6 /ha) and shows a recovery from the 2.2 ±1.1 /ha recorded in 1996, when the fishery was under the greatest pressure from commercialisation.

Deep-water assessments also detected large numbers of amberfish (*T. anax*), while prickly redfish (*T. ananas*) were only moderately common. Both these species were also noted in standard PROCFish shallow-water broad-scale records (Table 4.16), as well as during the deeper surveys (Figure 4.33).

4.4.7 Other echinoderms: Koulo

The edible collector urchin (*Tripneustes gratilla*) and slate urchin (*Heterocentrotus mammillatus*) were present and both were recorded in a small number of broad-scale replicates (5%). Slate urchins (*H. mammillatus*) were more common on RBt, being recorded in 43% of the stations, at a density of 63.7 ±29.3 /ha.

Other urchins that can be used as a food source or as potential indicators of habitat condition (*Echinometra mathaei*, *Diadema* spp. and *Echinothrix* spp.) were also recorded at low levels. The large, black *Echinothrix* species (*E. diadema* and *E. calamaris*) were the more common species (mean station density 65.5 ±41.6 /ha for RBt stations; see Appendices 4.3.1 to 4.3.7).

Starfish were well represented at Koulo. The common blue starfish (*Linckia laevigata*) was recorded in 29% of broad-scale transects, and pincushion stars (*Culcita novaeguineae*) had a similar coverage (26% of broad-scale transects), although neither species was at high density (<18 /ha in broad-scale survey). Another coralivore (coral eating) starfish, the crown-of-thorns starfish (*Acanthaster planci*) was noted but was not common and was at low density. Although rare (n = 3), records were concentrated in the Foa Island area near Koulo (See presence and density estimates in Appendices 4.3.1 to 4.3.7).

Table 4.16: Sea cucumber species records for Koulo

Species	Common name	Commercial value [5]	B-S transects n = 66			Reef-benthos stations n = 14			Other stations RFs = 3; RFs_w = 13		
			D [1]	DwP [2]	PP [3]	D	DwP	PP	D	DwP	PP
Actinopyga echinites	Deep-water redfish	M/H									
Actinopyga lecanora	Stonefish	M/H	0.3	16.7	2						
Actinopyga mauritiana	Surf redfish	M/H	1.8	23.3	8	50.6	88.5	57	22.2 677.1	22.2 677.1	100 RFs 100 RFs_w
Actinopyga miliaris	Blackfish	M/H	1.0	0.5	6				1.6	5.3	31 RFs_w
Actinopyga palauensis	Blackfish	M/H	0.3	16.7	2						
Bohadschia argus	Leopardfish	M	18.9	31.2	61	27.4	76.7	36			
Bohadschia similis	False sandfish	L									
Bohadschia vitiensis	Brown sandfish	L	7.1	51.9	14	11.9	83.3	14			
Holothuria atra	Lollyfish	L	12.4	58.3	21	190.5	296.3	64	6.5 513.7	9.8 513.7	66 RFs 100 RFs_w
Holothuria coluber	Snakefish	L									
Holothuria edulis	Pinkfish	L	1.5	25.0	6						
Holothuria fuscogilva [4]	White teatfish	H	Present – see mid-water and deep-water survey comments and Appendices tables								
Holothuria fuscopunctata	Elephant trunkfish	M	1.8	16.7	11						
Holothuria leucospilota	-	L							10.3	22.3	46 RFs_w
Holothuria nobilis [4]	Black teatfish	H	1.5	20.0	8				0.5	3.5	15 RFs_w
Holothuria scabra versicolor	Golden sandfish	H	Anecdotally present – see text								
Stichopus chloronotus	Greenfish	H/M	5.3	35.0	15	26.2	73.3	36	2.6 45.3	7.8 49.1	33 RFs 92 RFs_w
Stichopus hermanni	Curryfish	H/M	0.3	16.7	2						
Stichopus horrens	Peanutfish	M/L	Noted in walks on easterly reef platform at Lifuka								
Synapta spp.	-	-	0.3	16.7	2						
Thelenota ananas	Prickly redfish	H	7.3	28.3	26	3.0	41.7	7			
Thelenota anax	Amberfish	M	8.1	28.1	29						

[1] D = mean density (numbers/ha); [2] DwP = mean density (numbers/ha) for transects or stations where the species was present; [3] PP = percentage presence (units where the species was found); [4] the scientific name of the black teatfish has recently changed from *Holothuria* (*Microthele*) *nobilis* to *H. whitmaei* and the white teatfish (*H. fuscogilva*) may have also changed name before this report is published. [5] L = low value; M = medium value; H= high value; H/M is higher in value than M/H; B-S transects= broad-scale transects; RFs = reef-front search; RFs_w = reef-front search by walking.

4.4.8 Discussion and conclusions: invertebrate resources in Koulo

A summary of environmental, stock status and management factors for the main fisheries is given below. Please note that information on other, smaller fisheries and the status of less prominent species groups can be found within the body of the invertebrate chapter.

In summary, data on giant clam habitat, distribution, density and shell size suggest that:

- Reefs at Koulo had extensive areas of limestone and coral benthos that were suitable for a range of giant clam species. Water movement was dynamic, and shorelines of fringing reef were generally oceanic-influenced. Areas of embayment and shoaling reef in mid-water afforded giant clam populations a range of exposure grades, despite the generally exposed nature of the environment at Ha'apai.

- Four species of giant clam were recorded at Koulo: the elongate clam *Tridacna maxima*, the fluted clam *T. squamosa*, the smooth clam *T. derasa* and the devil's clam *T. tevoroa*. *T. tevoroa* is a rare species that has only been recorded in Tonga, Fiji Islands and New Caledonia.

- Giant clam coverage across the study area was not noticeably disrupted (There was no major decline around main settlement areas.), although larger species were not recorded in shallow-water locations. On the other hand, the total number of clams recorded was not high. The densities recorded at Koulo were at best moderate for an exposed, oceanic environment such as that found at Koulo (and Ha'apai as a whole) and such a density is indicative of an impacted clam fishery.

- In an 'open' reef location, such as found in Ha'apai, fishing is likely to have a greater impact on the sustainability of stocks than in lagoon systems, where natural 'trapping' of planktonic larvae is more likely due to the longer water residence time seen in more enclosed, or embayed environments.

- *Tridacna maxima* displayed a 'full' range of size classes, including young clams, which indicate successful spawning and recruitment, although the abundance of large clams was relatively low, supporting the assumption that clam stocks are moderately impacted by fishing.

- Giant clams are broadcast spawners that only mature as females at larger size classes (protandric hermaphrodites). This means that, for successful stock management, a percentage of large clams of each species needs to be maintained at high density, to ensure that sufficient successful spawning takes place to produce new generations of clams for the fishery. Noting the size profile of clams in Koulo (few *T. maxima* clams above 15 cm), and the generally moderate concentration of clams spatially, it is likely that some stocks are in decline.

In summary, data on MOP habitat, presence, distribution, density and shell size suggest that:

- The reefs at Koulo were extensive, mainly oceanic-influenced and with little lagoon habitat (not enclosed) or land influence. These characteristics are not always advantageous for grazing gastropods, as algal food supply can be low and recruitment can be variable due to the distances between reef systems found in this archipelago (lack of 'interconnectedness').

- The false trochus or green topshell (*Tectus pyramis*) was successful at colonising the oceanic-influenced reefs at Koulo and gave an indication that, in general, algal-grazing Trochidae might not be as limited as the oceanic nature of the reefs suggests.

- The reefs at Koulo are outside the natural range of the commercial topshell, *Trochus niloticus*, but now support this species after successful introductions. Introductions have included the movement of both adults (from Fiji Islands) and juveniles (from the hatchery on Tongatapu). A similar situation exists for green snail, *Turbo marmoratus*, which was also introduced as juveniles from hatchery rearing.

- Trochus (*Trochus niloticus*) and green snail (*Turbo marmoratus*) were recorded at Koulo, but only in small numbers and at low density. In Koulo, two of three reef-front searches and two of 14 reef-benthos transect stations held trochus.

- Size measures of both trochus and green snail suggest that growth and reproduction of these species is occurring, despite the lack of widespread colonisation of local reefs.

- There is no potential at this time to fish for MOP species in Koulo. The presence and density records suggest that MOP stocks are below the level at which commercial fishing is recommended and are in need of ongoing protection to allow time for stocks to build. Trochus need to be protected to ensure there is a future for this fishery, and stocks may need at least another five-to-ten years, or at least enough time for density at the major aggregations to reach at least 500 shells/ha.

- The blacklip pearl oyster (*Pinctada margaritifera*) was not uncommon at Koulo, and the high-energy environment is probably suited to the life habit of this species, which is a filter feeder characteristically found in low-nutrient reef environments.

In summary, data on the habitat for and distribution and density of sea cucumbers at Koulo and Ha'apai reveal that:

- The range of sea cucumber species present at Koulo was large, despite biogeographical influences (the easterly location of Ha'apai and its relatively isolated position in the Pacific), and the limited range of protected, shallow-water habitats available in this largely oceanic-influenced reef system.

- Sea cucumbers were relatively common around Koulo, despite the overall oceanic influence of the system. The densities of medium- and high-value species offered some potential for the development of commercial fishing, although other species had not recovered noticeably since the moratorium was implemented.

- The medium-value leopardfish or tigerfish (*Bohadschia argus*) and lower-value lollyfish (*Holothuria atra*) were recorded at reasonable coverage and density. The high-value black teatfish (*H. nobilis*), which is easily targeted by fishers, was one species that had not recovered markedly around Koulo since the ban on commercial fishing, although other species (such as the surf redfish *Actinopyga mauritiana*) were noted at high density on the eastern reef platform of Lifuka.

- Assessments targeting deeper-water white teatfish (*Holothuria fuscogilva*) stocks revealed that this high-value species was common and at moderate density. Other deep-water species, such as the lower-value amberfish (*Thelonata anax*), were at high density at Ha'apai.

- Ha'apai is one of the few areas in the Pacific that has had three sequential sea cucumber surveys that document the start, collapse and (partial) recovery of stocks in the fishery. This allows for a temporal understanding of both the decline of stocks as a result of fishing and rates of recovery after the fishery has been protected.

- Since the 1996 survey when stocks were shown to be over-fished, the majority of high-value sea cucumber species have again begun to show densities similar to those seen in 1990. However, the black teatfish (*Holothuria nobilis*) stocks are still at depleted levels, and some other species have not recovered as strongly as might have been hoped. The recovery in density of commercial species since 1996 needs to be tempered by the experience of more highly productive sea cucumber habitats in other parts of the Pacific, as the low-lying islands and oceanic environment found in Ha'apai present a less-than-optimal condition for these deposit-feeding resources. Because of these factors, the potential of Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

4.5 Overall recommendations for Koulo

- Koulo and neighbouring communities on Ha'apai be included in the ongoing community-based fisheries management programme.

- Protected zones or no-take marine parks be established to help the recovery and maintenance of finfish and invertebrate resources and habitat condition, with appropriate monitoring and enforcement to ensure compliance.

- Regulations be put in place to regulate and control the mesh size of nets and their use.

- A monitoring system be set in place to follow any further changes in finfish resources.

- For successful stock management, a percentage of large clams of each species be maintained at high density, to ensure there is sufficient successful spawning taking place to produce new generations of clams for the fishery.

- Ongoing protection be provided to the trochus stocks for at least another five-to-ten years to enable them to benefit from the increased spawning activity that the high-density base population will provide, thus allowing stocks to rebuild to a minimum of 500–600 shells/ha before commercial harvests are considered.

- The potential of Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

5. PROFILE AND RESULTS FOR LOFANGA

5.1. Site characteristics

The volcanic island of Lofanga (Figure 5.1), located at the coordinates 19°49' S and 174°33' W, is a slightly elevated island (maximum altitude 15 m), which has no lagoon and is inhabited by a community of about 300 people. The village is only accessible by sea from the west or southeast coast. It is about 1.9 km long by 0.9 km wide. The fishing area, excluding the island itself, includes, to the north and northwest, the lagoon reef complexes of Hakau Houa'ulu (5.6 km x 1.5 km, the *motu* of Niniva included) and Hakau Lahi (4.8 km x 1.9 km, the *motu* of Nukupule and Meama included). Southeast of Lofanga, fishers also use the reefs on the small islands of Makauata and Luangahu along with about a dozen other reef microstructures, each no more than 200 m in diameter. There are only two types of habitat at the site, outer reefs and back-reefs. In reality, this fishing area is not exclusive (open-access), although preferred by the Lofanga community as it is closer and has more fish.

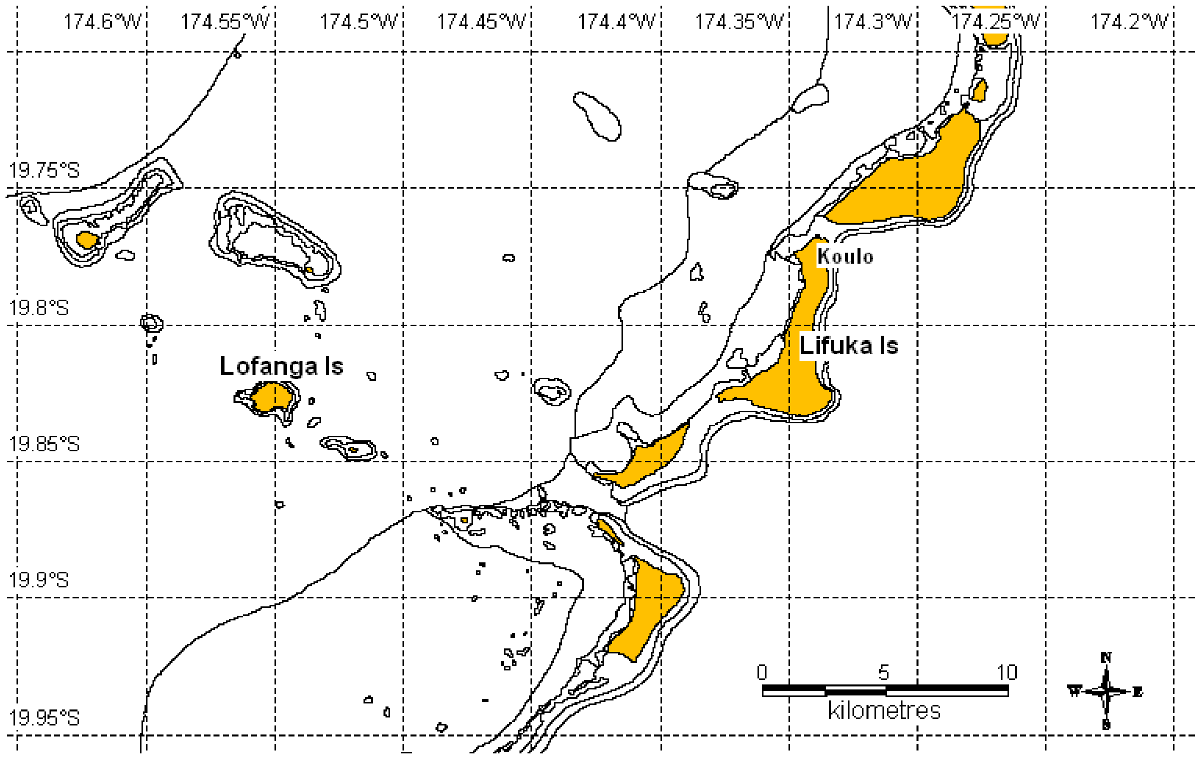

Figure 5.1: Map of Lofanga.

5.2. Socioeconomic survey: Lofanga

Socioeconomic fieldwork was carried out in Lofanga, the only community on Lofanga island, off the Lifuka mainland in the Ha'apai Island group in May 2008. The survey included households and fishers on Lofanga island and some people who resided at the time of the survey in the Lofanga squatter community at Hihifo on the Lifuka mainland.

The Lofanga community has a resident population of 187 people with a total of 39 households. A total of 20 households, i.e. 51% of total households in the community, were surveyed, with the majority (85%) of these households being engaged in some form of fishing activities. In addition, a total of 16 finfish fishers (males only) and 18 invertebrate fishers (4 males and 14 females) were interviewed. The average household size was four people per household. Household interviews focused on the collection of general demographic, socioeconomic and consumption data.

5.2.1 The role of fisheries in the Lofanga community: fishery demographics, income and seafood consumption patterns

Our results (Figure 5.2) suggest that fisheries provide by far the main source of household income. The Lofanga community has very limited access to agricultural land on its island, and salary-based income is limited to a few community-service positions. This situation is reflected in the low importance of agriculture (~10%), salaries (~5%) and 'others' (~15%), mostly handicraft activities, as first income sources. Complementary secondary income is mainly sourced from handicrafts, i.e. mat weaving done by females (>60%), and by agriculture (~30%). However, almost every household has a couple of pigs and chickens, mostly for home consumption and feasts.

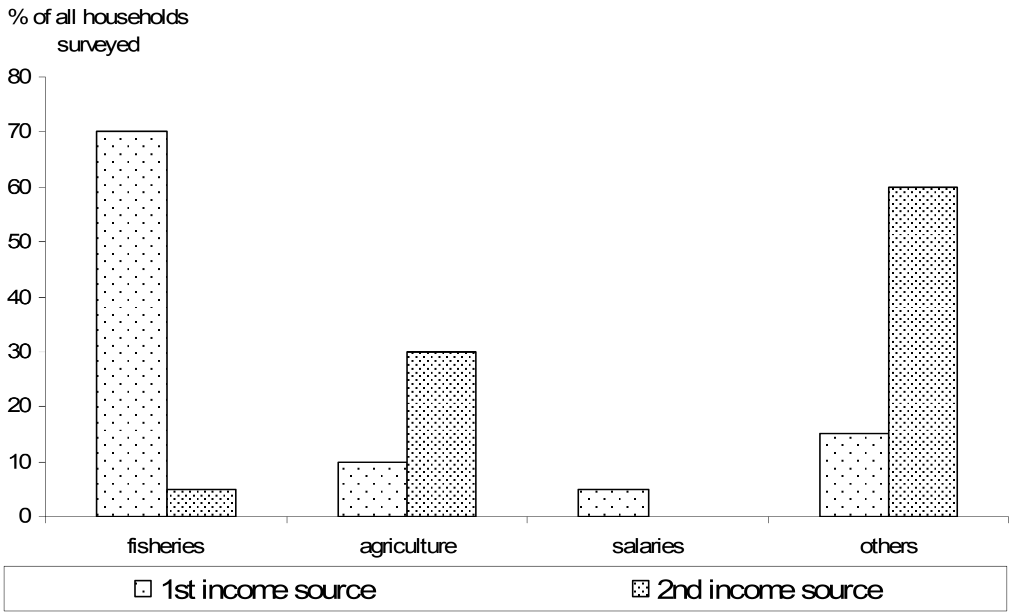

Figure 5.2: Ranked sources of income (%) in Lofanga.
Total number of households = 20 = 100%. Some households have more than one income source and those may be of equal importance; thus double quotations for 1st and 2nd incomes are possible. 'Others' are mostly home-based small businesses.

Our results (Table 5.1) show that annual household expenditures are relatively high, at an average of USD 2254. Remittances play an important role for Lofanga's household income; 75% of households receive remittances, and those that do get an average of USD ~767 /year, corresponding to almost one-third of the average basic household expenditure.

Table 5.1: Fishery demography, income and seafood consumption patterns in Lofanga

Survey coverage	Site (n = 20 HH)	Average across sites (n = 87 HH)
Demography		
HH involved in reef fisheries (%)	85.0	82.8
Number of fishers per HH	1.70 (±0.26)	1.47 (±0.16)
Male finfish fishers per HH (%)	23.5	43.0
Female finfish fishers per HH (%)	0.0	0.0
Male invertebrate fishers per HH (%)	0.0	2.3
Female invertebrate fishers per HH (%)	38.2	32.0
Male finfish and invertebrate fishers per HH (%)	38.2	22.7
Female finfish and invertebrate fishers per HH (%)	0.0	0.0
Income		
HH with fisheries as 1st income (%)	70.0	39.1
HH with fisheries as 2nd income (%)	5.0	4.6
HH with agriculture as 1st income (%)	10.0	10.3
HH with agriculture as 2nd income (%)	30.0	20.7
HH with salary as 1st income (%)	5.0	21.8
HH with salary as 2nd income (%)	0.0	10.3
HH with other sources as 1st income (%)	15.0	29.9
HH with other sources as 2nd income (%)	60.0	31.0
Expenditure (USD/year/HH)	2254.29 (±380.98)	3160.33 (±610.10)
Remittance (USD/year/HH) (1)	767.06 (±184.14)	1165.99 (±150.20)
Consumption		
Quantity fresh fish consumed (kg/capita/year)	65.25 (±12.95)	68.57 (±6.36)
Frequency fresh fish consumed (times/week)	2.90 (±0.24)	3.44 (±0.19)
Quantity fresh invertebrate consumed (kg/capita/year)	16.83 (±2.68)	10.71 (±6.36)
Frequency fresh invertebrate consumed (times/week)	1.76 (±0.24)	1.13 (±0.11)
Quantity canned fish consumed (kg/capita/year)	21.24 (±3.67)	16.99 (±1.57)
Frequency canned fish consumed (times/week)	2.11 (±0.30)	2.00 (±0.15)
HH eat fresh fish (%)	100.0	100.0
HH eat invertebrates (%)	95.0	77.0
HH eat canned fish (%)	90.0	89.7
HH eat fresh fish they catch (%)	85.0	76.2
HH eat fresh fish they buy (%)	20.0	42.9
HH eat fresh fish they are given (%)	80.0	81.0
HH eat fresh invertebrates they catch (%)	85.0	71.4
HH eat fresh invertebrates they buy (%)	0.0	14.3
HH eat fresh invertebrates they are given (%)	65.0	52.4

HH = household; (1) average sum for households that receive remittances; numbers in brackets are standard error.

Survey results indicate an average of two fishers per household and, when extrapolated, the total number of fishers in Lofanga is 66. Among these are 16 exclusive finfish fishers (males only), 25 exclusive invertebrate fishers (females only), and 25 fishers who fish for both finfish and invertebrates (males only). During this survey, females denied any active participation in finfish fishing, although they do at times catch fish for subsistence purposes and as a side product of gleaning activities. Only a quarter of all households own a boat and most (~80%) are motorised canoes; only 20% are paddling canoes.

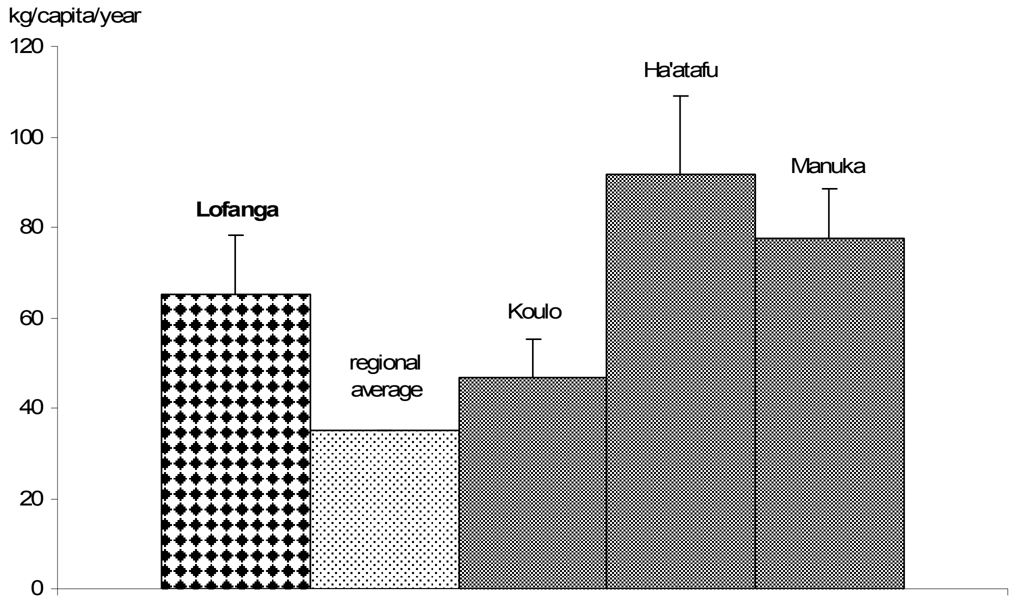

Figure 5.3: Per capita consumption (kg/year) of fresh fish in Lofanga (n = 20) compared to the regional average (FAO 2008) and the other three PROCFish sites in Tonga.
Figures are averages from all households interviewed, and take into account age, gender and non-edible parts of fish. Bars represent standard error (+SE).

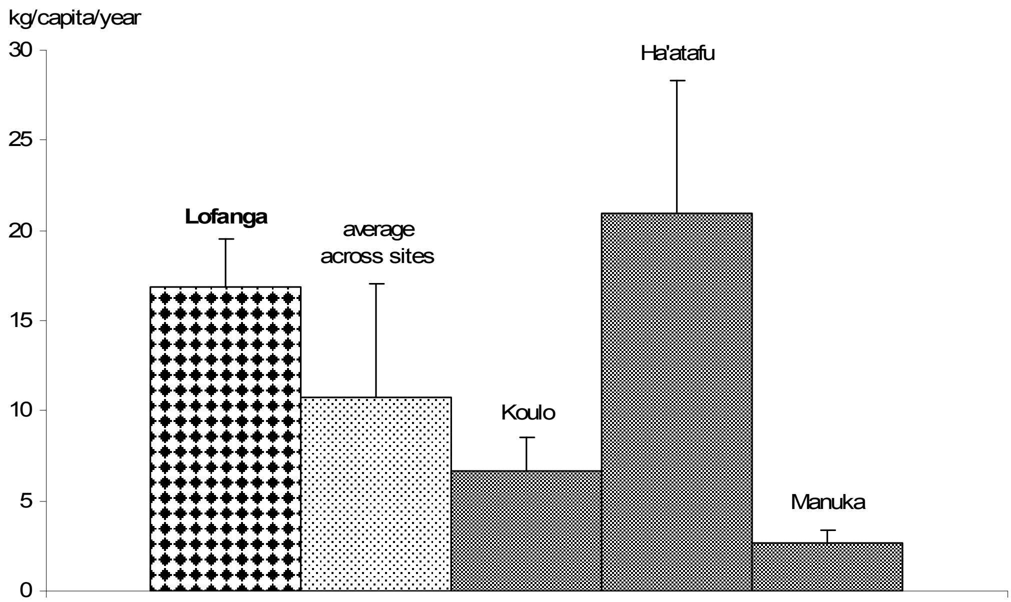

Figure 5.4: Per capita consumption (kg/year) of invertebrates (meat only) in Lofanga (n = 20) compared to the other three PROCFish sites in Tonga.
Figures are averages from all households interviewed, and take into account age, gender and non-edible parts of invertebrates. Bars represent standard error (+SE).

Consumption of fresh fish is high at ~65 kg/person/year, a consumption figure that is similar to the average across all four study sites in Tonga, but significantly higher than the estimated average given by Preston (2000) of 25.2 kg/year, or the regional average of ~35 kg/year (Figure 5.3). By comparison, consumption of invertebrates (edible meat weight only) (Figure 5.4) is lower, at 16.8 kg/person/year. Canned fish (Table 5.1) adds a considerable amount (21.2 kg/person/year) to the protein supply from seafood. Canned fish is an established nutritional substitute in Tonga and available even in remote locations. The consumption pattern of seafood found in Lofanga highlights the fact that the people have limited access to urban markets and that they live a rural and traditional lifestyle.

Comparing results obtained for Lofanga to the average figures across all four study sites surveyed in Tonga, people of the Lofanga community eat fresh fish, invertebrates and canned fish about as often as found on average. However, although they eat a similar amount of fresh fish, they eat more invertebrates and more canned fish than average. Lofanga people eat more fresh fish and invertebrates that a member of the household has caught, and less fresh seafood that is bought than observed across all study sites. Sharing seafood among community members on a non-monetary basis is very common, and as important as found elsewhere in Tonga. Income from fisheries as first income and from mat weaving as secondary income play a much greater role, and salaries a lesser role in generating first or second income than across all the Tongan study sites. The household expenditure level and remittances received in Lofanga are substantially lower than elsewhere. By comparison, boat ownership and the dominance of motorised boats is about average and does not vary much from most other sites surveyed in Tonga.

5.2.2 Fishing strategies and gear: Lofanga

Degree of specialisation in fishing

Tonga has an open-access system; however, communities may consider certain areas as their own fishing grounds. This observation is true for Lofanga and most of the communities in the Ha'apai group, as population density is relatively low and the available fishing grounds are large. User conflicts are still rare and not a subject of major concern. While, so far, no marine management interventions have been initiated for or with the Lofanga fishing community, a fisheries management plan has been developed and resource surveys have been undertaken in three communities in Ha'apai by an AusAID-funded project and Tonga Fisheries Division working in cooperation.

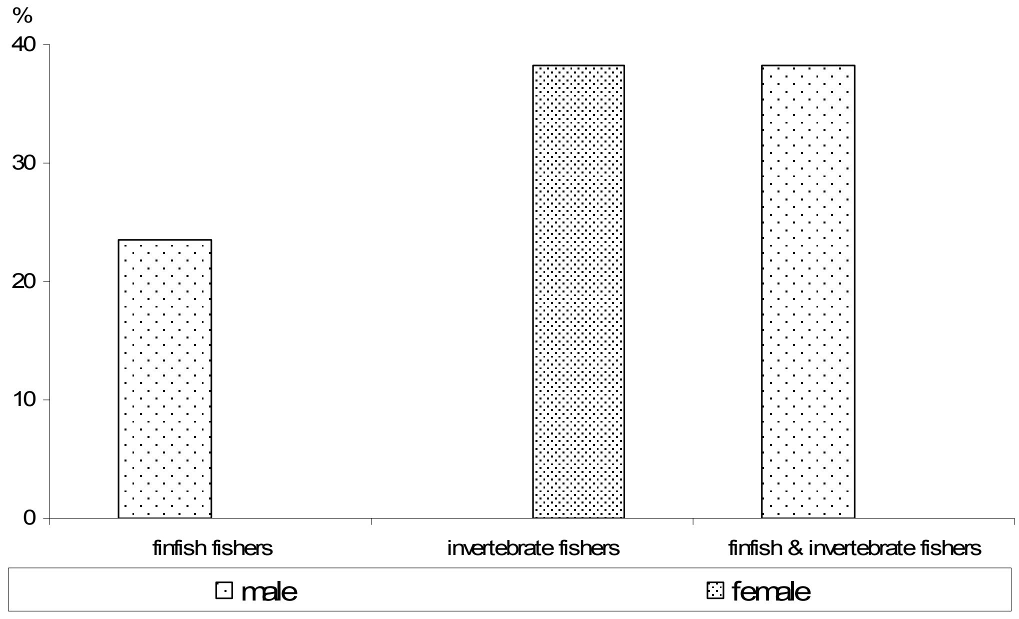

Figure 5.5: Proportion (%) of fishers who target finfish or invertebrates exclusively, and those who target both finfish and invertebrates in Lofanga.
All fishers = 100%.

As mentioned earlier, Lofanga fishers follow the traditional gender roles, with males being the major finfish fishers, and females in command of invertebrate collection. However, as shown in an earlier study (Kronen and Bender 2006), gender roles have changed over time and females do also catch finfish at times, while males actively participate in the collection of invertebrates, particularly if for sale or while spearfishing. Nevertheless, due to the traditional *tabu* and the traditional lifestyle of the Lofanga community, it is very difficult to obtain any data related to fishing by females.

Fishing patterns and strategies

The number of fishers, the frequency of fishing trips and the average catch per fishing trip are the basic factors used to estimate the fishing pressure imposed by people from Lofanga on their fishing grounds (Tables 5.2 and 5.3).

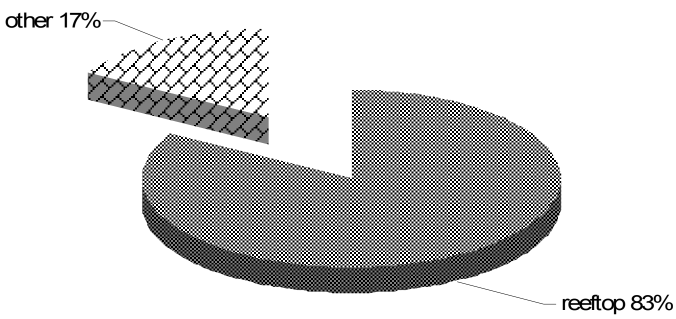

Figure 5.6: Proportion (%) of fishers targeting the two primary invertebrate habitats found in Lofanga.
Data based on individual fisher surveys; data for combined fisheries are disaggregated. 'Other' refers to giant clam and sea urchin fisheries.

Our survey sample suggests that fishers from Lofanga have a limited choice of types of fishing ground that they can target. Basically the choice is between fishing close to shore around Lofanga island, or venturing out on a much longer fishing trip, using motorised boat transport and targeting the isolated coral reefs located in the deep lagoon some distance from Lofanga island. The same observation is true for invertebrate fisheries as the island has reeftop habitats but little else. Free-diving may be done on the top of the exposed, isolated coral reefs within the deep-lagoon area, and in certain spots close to the island of Lofanga itself. There are no mangroves, seagrass or any important soft-benthos habitats available (Figures 5.6 and 5.7).

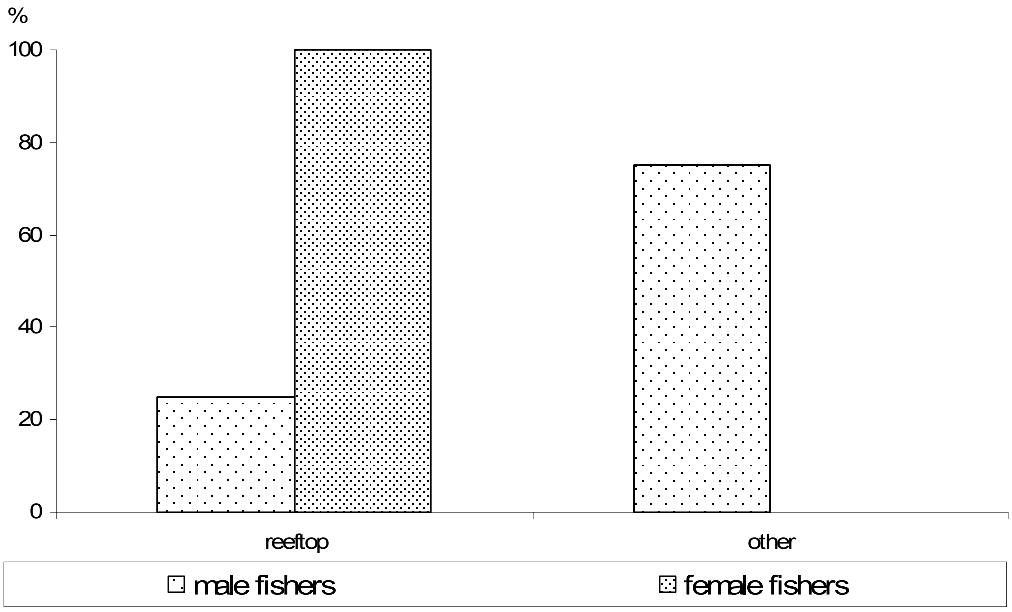

Figure 5.7: Proportion (%) of male and female fishers targeting various invertebrate habitats in Lofanga.
Data based on individual fisher surveys; data for combined fisheries are disaggregated; fishers commonly target more than one habitat; figures refer to the proportion of all fishers who target each habitat: n = 4 for males, n = 14 for females. 'Other' refers to lobster, giant clam and octopus fisheries.

Targeted stocks/habitat

Because Lofanga is located on an isolated, small island, the ocean provides the main transport route and motorised boats are important for both transport and fishing. Most of the fishing is done in the area perceived as 'lagoon' by the local male fishers. However, what is meant by 'lagoon' is, in fact, exposed coral reefs within the deep lagoon, which is of open-ocean character, and this type of habitat is elsewhere classified as 'outer reef'. Therefore, in order to compare data with other sites, the combined term 'lagoon/outer reef' is used in the case of Lofanga's finfish fisheries. In terms of surface areas, the geomorphological classification and hence habitat surface of 'outer reef' is applied. Table 5.2 shows that the least fishing impact is imposed on the sheltered coastal reef area that surrounds the island, as only 19% of all male fishers reported targeting this habitat on occasion. Most fishers (81%) go out using motorised boats to catch fish at the isolated coral reefs in the deep-lagoon area. Interviews showed that invertebrate collection mainly targets reef-associated species, most of which are collected by gleaning, and less (17%) may be harvested by free-diving. Reeftop gleaning is a female domain, and only 20% of all male fishers glean, while all other males free-dive to collect giant clams, octopus, lobsters and other species (Figure 5.7).

Table 5.2: Proportion (%) of male and female fishers harvesting finfish and invertebrate stocks across a range of habitats (reported catch) in Lofanga

Resource	Fishery / Habitat	% of male fishers interviewed	% of female fishers interviewed
Finfish	Sheltered coastal reef	18.8	0.0
	Lagoon/outer reef	81.2	0.0
Invertebrates	Reeftop	25.0	100.0
	Other	75.0	0.0

'Other' refers to giant clam and sea urchin fisheries.
Finfish fisher interviews, males: n = 16; females: n = 0. Invertebrate fisher interviews, males: n = 4; females: n = 14.

Gear

Figure 5.8 shows that Lofanga fishers use a variety of different gear and that they may combine different fishing techniques in one fishing trip. However, the use of low-cost handlining dominates, often combined with spear diving. Trolling and cast netting, particularly to catch bait and to quickly satisfy the subsistence needs of the family, are less frequently used.

Most invertebrate fishers use very simple techniques, such as digging, collecting by hand or poking with sticks, iron rods and knives in tidal pools and crevasses. Hand-woven baskets and plastic buckets are used to collect the catch and carry it back home for processing or cooking.

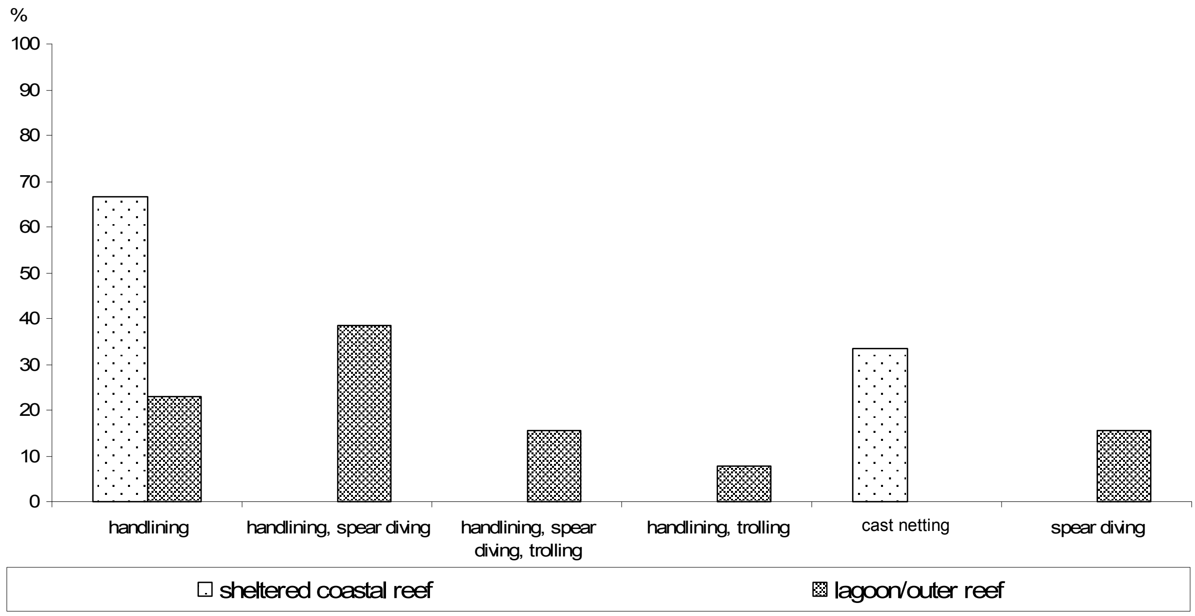

Figure 5.8: Fishing methods commonly used in different habitat types in Lofanga.
Proportions are expressed in % of total number of trips to each habitat. One fisher may use more than one technique per habitat and target more than one habitat in one trip.

Frequency and duration of fishing trips

Male fishers go out to catch finfish about two to three times per week regardless of which habitat they target. As shown in Table 5.3, an average fishing trip targeting the lagoon/outer reef takes longer (6–7 hours) because of the long travel distances to the isolated coral reefs within the deep-lagoon system. The average duration of four hours for a fishing trip around the island of Lofanga is explained by the time-consuming practice of swimming to appropriate fishing spots (not using any boat transport) at times performed by young male spear fishers, or the time spent paddling a canoe to good fishing spots closer to the island.

Invertebrate fishers go fishing less often than finfish fishers. Both male and female fishers harvest invertebrates about twice a week. The average reeftop gleaning trip by female fishers takes about two hours; male fishers free-diving for giant clams, octopus, lobsters and 'others' usually go out for 2–3 hours (Table 5.3).

Finfish fishing and invertebrate collection are practised throughout the year. Finfish fishing trips are strictly scheduled according to tidal conditions and hence are conducted either at day or night time. Boat transport is mandatory for any finfish fishing; however, motorised boat transport is only required for reaching the outer-reef/lagoon habitats. The use of ice during fishing trips is almost a standard requirement due to the extended duration of the fishing trip and the need to transport it to the Ha'apai mainland for sale. However, ice is only occasionally used if fishing in the vicinity of Lofanga island, as this is mainly done for subsistence purposes.

Most invertebrates are collected while walking; however, when male fishers combine spear fishing and free-diving, they need motorised boats to reach the isolated coral reefs within the deep lagoon. Usually, invertebrates are collected all year round with no particular season. Octopus is a special fishery for Lofanga people, and harvests are seasonal. All activities are performed exclusively during the day, with very few exceptions, apart from diving for lobsters, which is done at night.

Table 5.3: Average frequency and duration of fishing trips reported by male and female fishers in Lofanga

Resource	Fishery / Habitat	Trip frequency (trips/week)		Trip duration (hours/trip)	
		Male fishers	Female fishers	Male fishers	Female fishers
Finfish	Sheltered coastal reef	2.67 (±0.67)	0	4.00 (±0.00)	0
	Lagoon/outer reef	2.35 (±0.31)	0	6.85 (±0.84)	0
Invertebrates	Reeftop	3.00 (n/a)	2.21 (±0.28)	2.00 (n/a)	2.21 (±0.11)
	Other	1.67 (±0.33)	0	2.67 (±0.33)	0

Figures in brackets denote standard error; n/a = standard error not calculated. 'Other' refers to giant clam and sea urchin fisheries.
Finfish fisher interviews, males: n = 16; females: n = 0. Invertebrate fisher interviews, males: n = 4; females: n = 14.

5.2.3 Catch composition and volume – finfish: Lofanga

The catches reported from the sheltered coastal reef and lagoon/outer-reef fishing in Lofanga contain numerous species and species groups. Acanthuridae, Lethrinidae, Lutjanidae and Serranidae are the main families reported. While Acanthuridae play a more important role in the composition of catches reported for sheltered coastal reef fishing, Serranidae and Lethrinidae are the most prominent families in catches from the lagoon/outer-reef habitats. Overall, the reported variety of catches from the lagoon/outer reef as expressed by vernacular names is much greater than that of catches from the sheltered coastal reef. Detailed information on catch composition by species, species groups and habitats is reported in Appendix 2.4.1.

Figure 5.9 confirms the findings from the socioeconomic survey reported earlier, that finfish fishing serves mainly income and much less subsistence purposes. The total annual catch is estimated to amount to ~79 t, of which ~85% is used for sale, while only ~15% is consumed by the Lofanga people and their relatives. As also mentioned earlier, most of the impact (90%) is due to lagoon/outer-reef fishing rather than fishing close to Lofanga island, i.e. in the sheltered coastal reef, which provides only about 10% of the total annual catch.

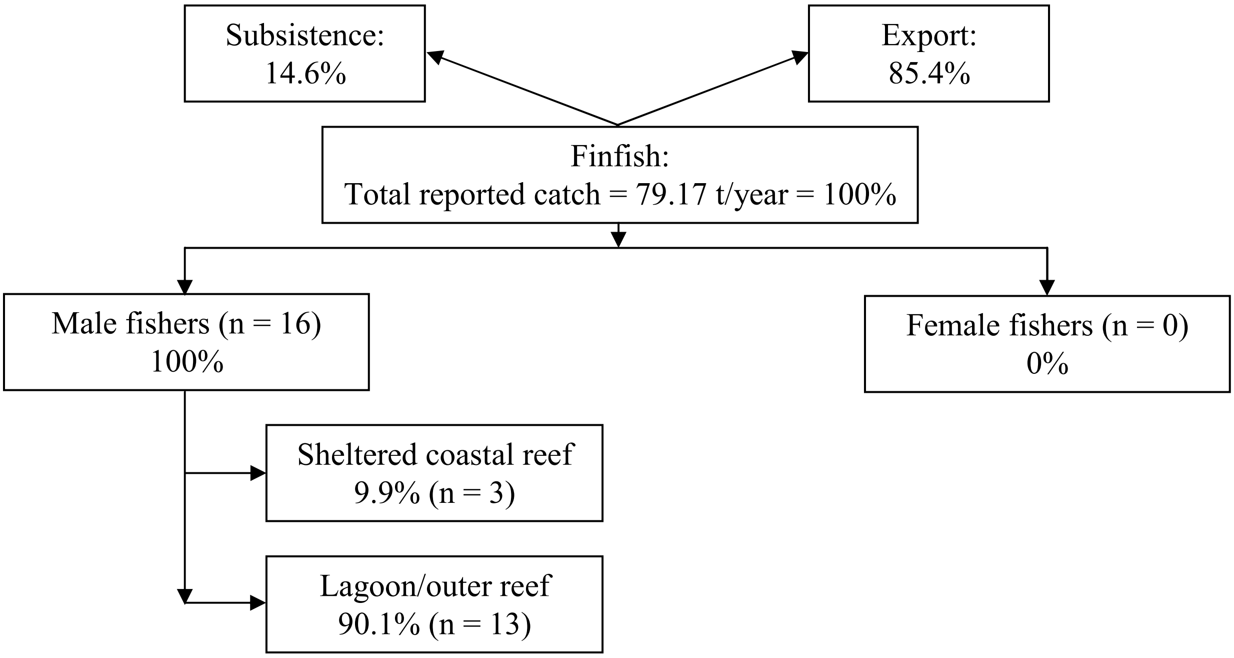

Figure 5.9: Total annual finfish catch (tonnes) and proportion (%) by fishery and gender (reported catch) in Lofanga.
n is the total number of interviews conducted per each fishery; total number of interviews may exceed total number of fishers surveyed as one fisher may target more than one fishery and thus respond to more than one fishery survey.

The distribution of annual catch weight between the more accessible sheltered coastal reef and the much more distant lagoon/outer-reef areas is a consequence of the number of fishers, catch per unit effort and total annual productivity. As shown in Figure 5.10, the average annual catch per fisher is less than half if the sheltered coastal reef is targeted compared to the lagoon/outer-reef habitat.

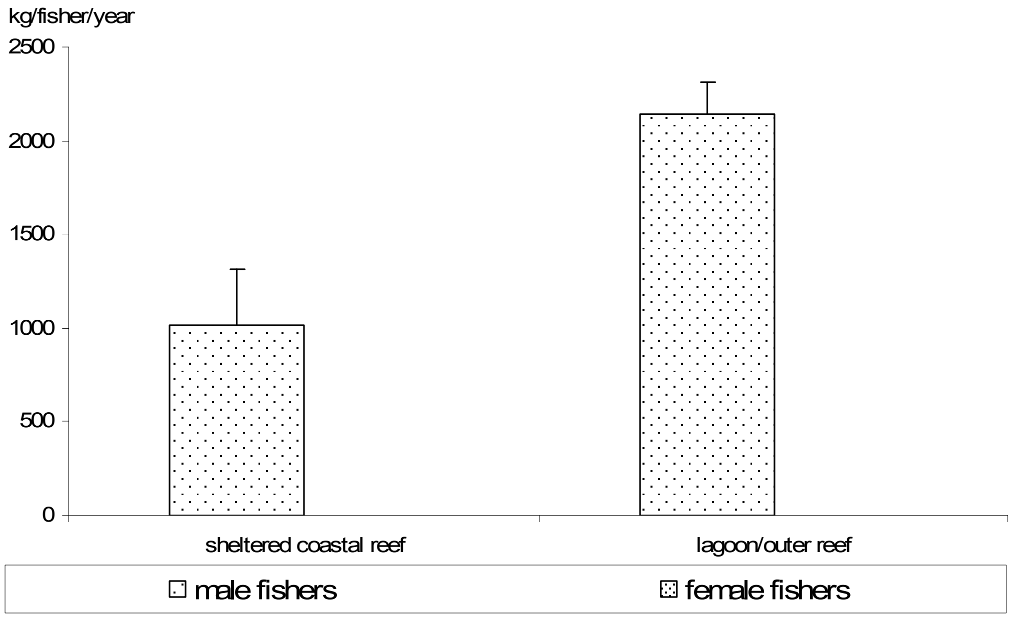

Figure 5.10: Average annual catch (kg/year, +SE) per fisher by gender and habitat in Lofanga (based on reported catch only).

Comparing productivity rates between genders and habitats (Figure 5.11), there are also substantial differences. An average of 2.5 kg fish are caught per hour of fishing trip at the sheltered coastal reef; this amount doubles (>4 kg/hour of fishing trip) at the lagoon/outer-reef sites. It cannot be ruled out that differences in the resource status may explain this important variation in CPUE. However, it should also be borne in mind that fishing trips targeting the sheltered coastal reef are mainly undertaken for subsistence needs rather than commercial purposes, while fishing at the lagoon/outer-reef sites serves commercial interests. Thus, this variation in CPUE may also be attributed to differences in fishing strategies.

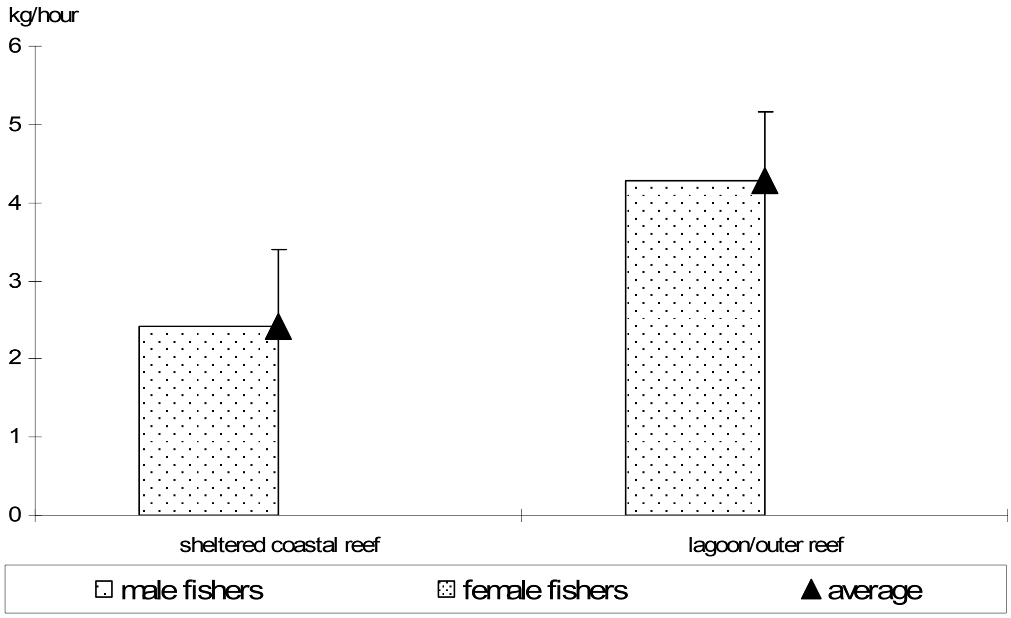

Figure 5.11: Catch per unit effort (kg/hour of total fishing trip) for male and female fishers by habitat type in Lofanga.
Effort includes time spent transporting, fishing and landing catch. Bars represent standard error (+SE).

The fact that commercial fishing is more important than subsistence fishing for Lofanga people clearly shows in Figure 5.12. As observed earlier, male fishers targeting the lagoon/outer reef mainly fish to generate income. The fishing of the sheltered coastal reef, an activity pursued by far fewer fishers in Lofanga, is mainly done to provide food for the family and the community.

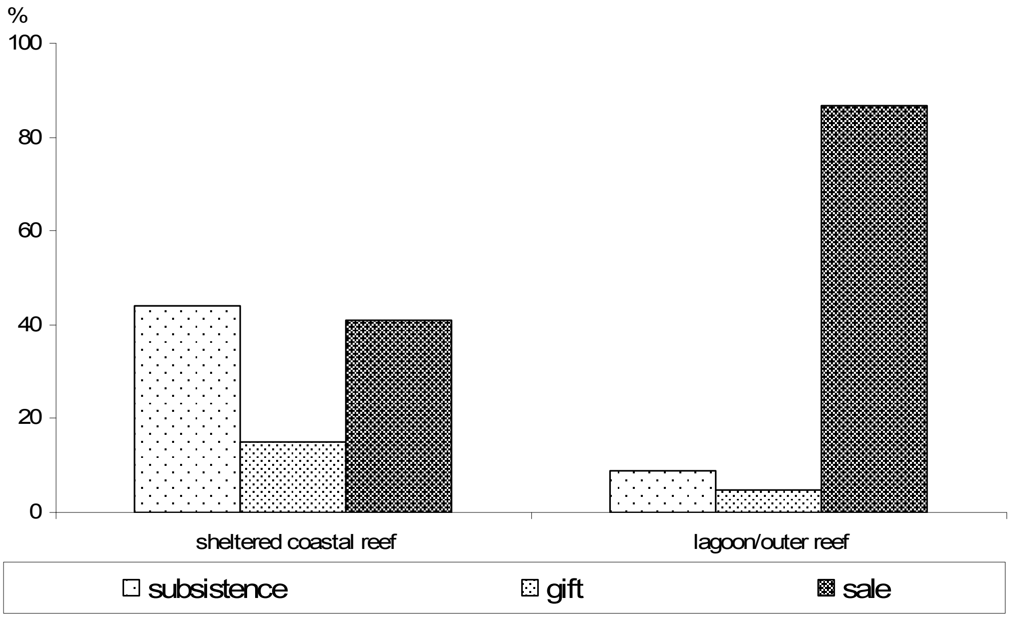

Figure 5.12: The use of finfish catches for subsistence, gifts and sale, by habitat in Lofanga.
Proportions are expressed in % of the total number of trips per habitat.

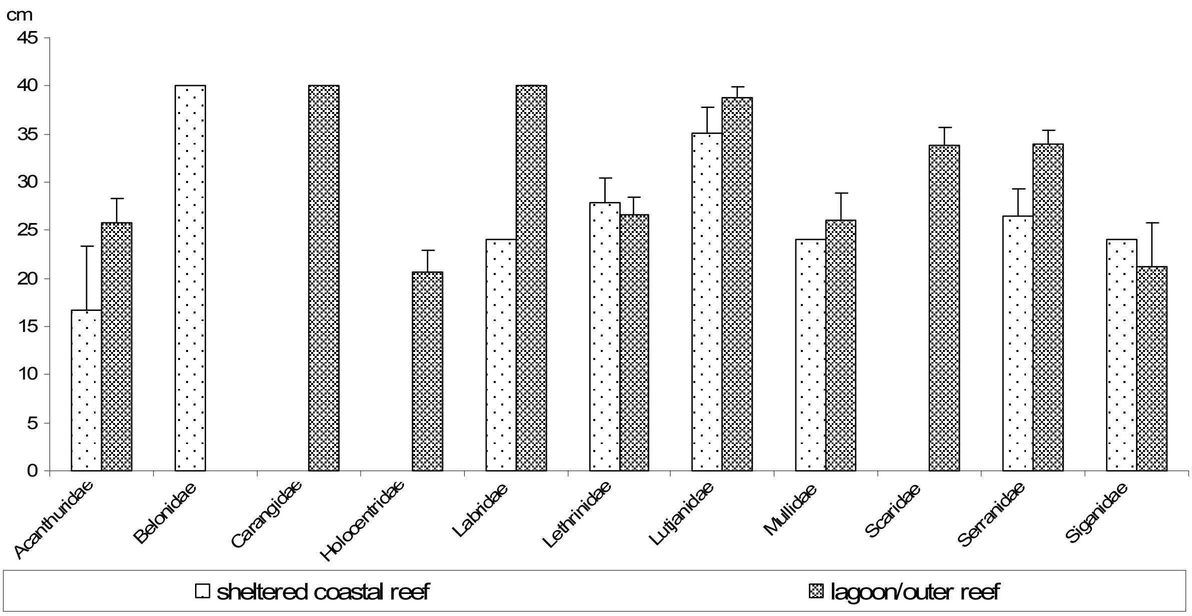

Figure 5.13: Average sizes (cm fork length) of fish caught by family and habitat in Lofanga.
Bars represent standard error (+SE).

Comparing the overall finfish fishing productivity between habitats suggests that the efficiency in the lagoon/outer-reef locations is far greater than in the sheltered coastal reef areas (Figure 5.11). This observation is supported by the much larger individual fish reported in catches from the lagoon/outer reef. Generally, average sizes (forklength) are significantly larger, particularly for Acanthuridae, Labridae, Lutjanidae, Mullidae and Serranidae. Interestingly, the opposite is true for Siganidae and Lethrinidae. The first may be due to the small and therefore perhaps unrepresentative sample size. For Lethrinidae, however, there is no logical explanation (Figure 5.13). Overall, reported average fish sizes are considerable (30–40 cm forklength) for the catches from the lagoon/outer-reef habitats.

The parameters selected to assess the current fishing pressure on Lofanga's reef and lagoon resources are shown in Table 5.4. Due to the fact that the habitat perceived by fishers as 'lagoon' is, in fact, a geomorphological outer-reef habitat, the deep-lagoon surface area was not taken into consideration except in the calculation of the total fishing ground. Overall, all parameters calculated for fishing pressure are low. This applies to finfish fisher density in any of the habitats considered, population density for total reef and fishing ground areas, and the impact due to subsistence fish catch. Even if we consider total annual catch, which is 85% determined by catch for sale rather than subsistence, catch rates only reach 0.4–3 mt/km² total fishing ground or reef area per year. Thus, overall, there is no indication that Lofanga's fishing community currently catches finfish at a rate that is detrimental to resource levels.

However, the results from the underwater resource survey revealed that, although the fish resource status in Lofanga's reef and lagoon areas is the best of all the sites studied in Tonga, it is still far from good. Taking into account the fact that Lofanga people do not have much access to income and food sources other than fisheries, finfish fishing will continue to play an important role for households that remain on the island. Based on the survey results, it is concluded that the current resource status is a result of previous and current fishing pressure imposed by fishers not only from Lofanga but also from elsewhere in the Ha'apai group.

Table 5.4: Parameters used in assessing fishing pressure on finfish resources in Lofanga

Parameters	Habitat			
	Sheltered coastal reef	Lagoon/outer reef (4)	Total reef area	Total fishing ground
Fishing ground area (km^2)	1.6	23.0	24.6	191.9
Density of fishers (number of fishers/km^2 fishing ground) (1)	5.1	1.4	1.7	0.2
Population density (people/km^2) (2)			1.7	0.2
Average annual finfish catch (kg/fisher/year) (3)			0.5	0.1
Total fishing pressure of subsistence catches (t/km^2)	1018.2 (±299.4)	2144.5 (±170.7)		
Total number of fishers	8	33	41	41

Figures in brackets denote standard error; (1) total number of fishers is extrapolated from household surveys; (2) total population = 187; total subsistence demand =11.6 t/year; (3) catch figures are based on recorded data from survey respondents only; (4) Finfish fishers perceived fishing at the outer reef as 'lagoon fishing' as locations are individual and isolated coral reefs within deep-lagoon/open sea conditions; hence, fishing pressure refers to 'outer-reef' rather than lagoon habitats; total deep-lagoon surface area is 167.3 km^2.

5.2.4 Catch composition and volume – invertebrates: Lofanga

Analysis of catches reported by invertebrate fishers by wet weight shows that only a few species account for the major annual impact (Figure 5.14). The combined catches of giant clams, namely *Tridacna maxima*, and others, including *T. derasa*, octopus and the sea urchin *Tripneustes gratilla*, account for most of the reported annual catch of 11.3 t (wet weight). Other species, by comparison far less important, are *Turbo crassus*, *Crytoplax* spp. and *Holothuria atra*.

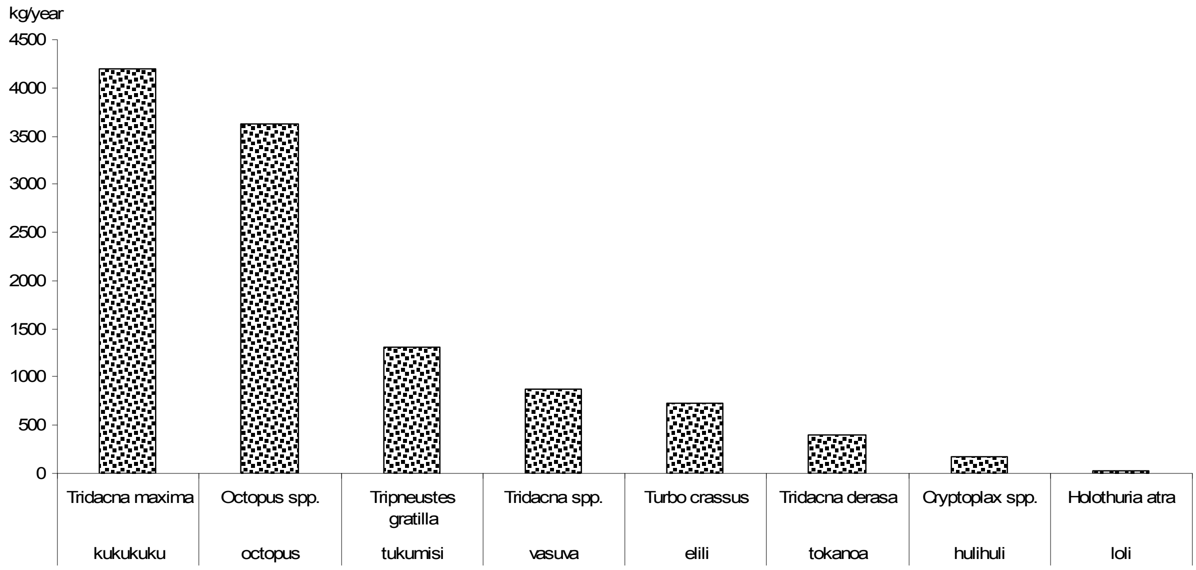

Figure 5.14: Total annual invertebrate catch (kg wet weight/year) by species (reported catch) in Lofanga.

The fact that most impact is on a few species only also shows in the number of vernacular names that have been registered from respondents. Reeftop gleaning and diving for most reef-associated species are represented by a maximum of 10 vernacular names (Figure 5.15).

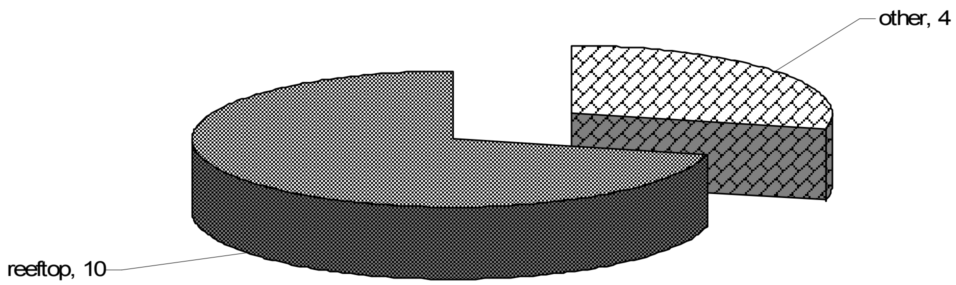

Figure 5.15: Number of vernacular names recorded for each invertebrate fishery in Lofanga.

Analysis of the average annual catch per fisher by gender and fishery (Figure 5.16) reveals substantial differences between fisheries. Male fishers harvest on average about 200 kg more per year (wet weight) by diving for reef-associated invertebrates as compared to female fishers, who mainly glean reeftops. The sample size of male fishers pursuing reeftop gleaning is too small to allow any gender comparison. The results also suggest that male invertebrate fishers in Lofanga fish more commercially than female gleaners. Females do occasionally, or some even regularly, sell their catch, but they are also responsible for supplying most of the family's home consumption needs. As already shown, invertebrate consumption among people in Lofanga is relatively high.

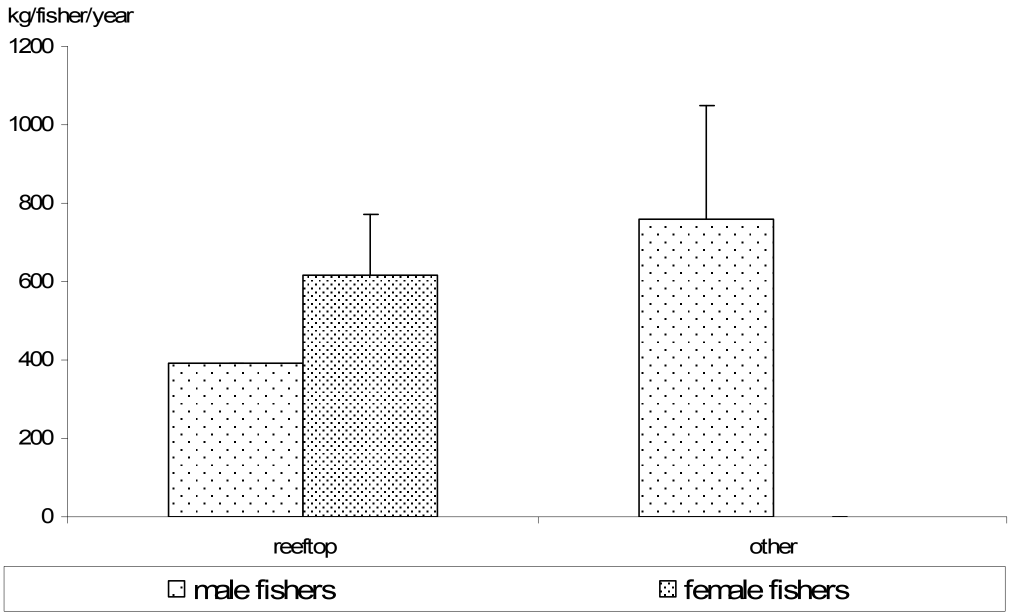

Figure 5.16: Average annual invertebrate catch (kg wet weight/year) by fisher and gender in Lofanga.
Data based on individual fisher surveys. Figures refer to the proportion of all fishers who target each habitat (n = 4 for males, n = 14 for females).

However, Figure 5.17 also suggests that invertebrate fisheries in general are far less important than finfish fisheries for income generation. This conclusion is mainly based on the fact that no respondent reported exclusively harvesting any invertebrate for commercial purposes only. This is further confirmed if we assume that half of the reported catch that may or may not be sold, is actually sold, i.e. the commercial share of invertebrate catch does not exceed 21% of the total annual catch by wet weight.

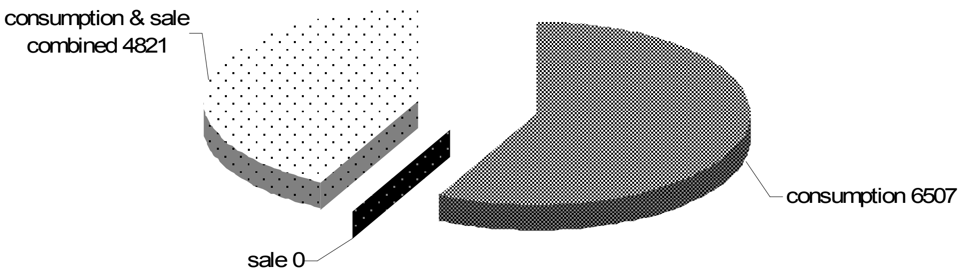

Figure 5.17: Total annual invertebrate biomass (kg wet weight/year) used for consumption, sale, and consumption and sale combined (reported catch) in Lofanga.

As mentioned earlier, male and female fishers from Lofanga both engage in invertebrate collection; however, females take a much higher proportion of the total annual catch (wet weight) as shown in Figure 5.18. Female invertebrate fishers take ~76% of the total annual catch, while male fishers take ~24% only. The major impact is on reeftops, and less is on the coral reef resources targeted by male fishers as a by-product of spearfishing, which may occur further away from Lofanga island itself.

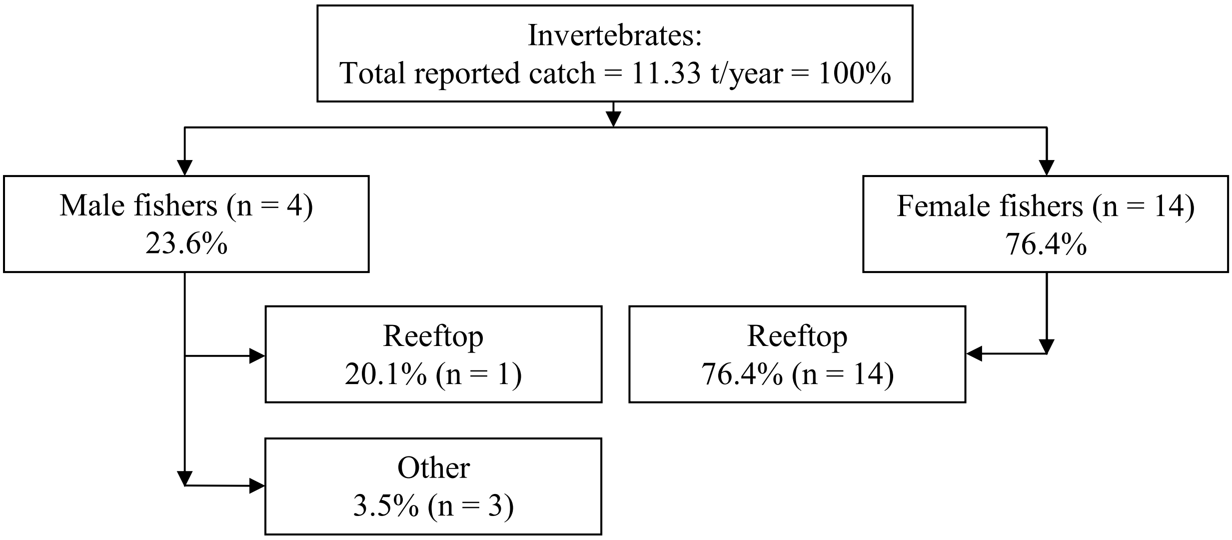

Figure 5.18: Total annual invertebrate catch (tonnes) and proportion (%) by fishery and gender (reported catch) in Lofanga.
n is the total number of interviews conducted per each fishery; total number of interviews may exceed total number of fishers surveyed as one fisher may target more than one fishery and thus respond to more than one fishery survey.

Taking into account figures on the available reeftop surface, reeftop fisheries have, as expected, a low fisher density, i.e. about 20 fishers/km² of reeftop surface. Although the surface area of other reefs further away from Lofanga island is not known, the total number of fishers targeting these, i.e. 19, is low and suggests that there is little fishing pressure resulting. Even though invertebrate fisheries are important for Lofanga people and the focus is on a few target species only, the low average annual catch rates and low fisher numbers and the large available reef area, all suggest that fishing pressure is low and thus no detrimental effect is caused by the current fishing levels (Table 5.5).

Table 5.5: Parameters used in assessing fishing pressure on invertebrate resources in Lofanga

Parameters	Fishery / Habitat	
	Other	Reeftop
Fishing ground area (km^2)	n/a	1.58
Number of fishers (per fishery) [(1)]	19	32
Density of fishers (number of fishers/km^2 fishing ground)	n/a	20
Average annual invertebrate catch (kg/fisher/year) [(2)]	760.00 (±287.25)	603.15 (±143.79)

Figures in brackets denote standard error; n/a = no information available; [(1)] total number of fishers is extrapolated from household surveys; [(2)] catch figures are based on recorded data from survey respondents only.

5.2.5 Management issues: Lofanga

Lofanga is the most isolated and rural coastal community of all the sites studied in Tonga. The Lofanga population still pursues a rather traditional lifestyle and social institutions appear to be operational. The island is one of the few non-electrified communities in the Ha'apai group; however, modern technology, including mobile phones, has arrived on the island, too. As elsewhere in Tonga, fishing is governed by the open-access system, which does not restrict people from fishing wherever they whish. However, *de facto*, traditional fishing grounds and their ownership are recognised by communities. Conflicts may occur where population density and thus resource use increases. This is definitely true for some areas in the Tongatapu lagoon system; however, in Ha'apai, traditional fishing ground user systems are still widely accepted and operational. As described by Kronen and Bender (2006), user conflicts are rare and usually are not a subject of major concern among island communities. However, price mechanisms and, in particular, the dependency on fuel for boat transport to the Ha'apai mainland, cause concern for the Lofanga community, particularly as selling prices for fishery produce have hardly changed over the past decade. The fact that fishing is not a very lucrative activity and is sensitive to fuel and other cost factors may show in the fact that several attempts to organise a middlemen's business located at Lofanga to improve the efficiency of marketing the catch to Ha'apai mainland have repeatedly failed. Boat trips to the mainland, where Lofanga people have a camp near the main centre at Hihifo, often serve several purposes, not only marketing fish; thus transport costs can be offset by the income earnt from selling the fish. The mainland camp is made possible through the provision of land by the former Crown Prince, now King of Tonga, the owner of Lofanga island.

The ongoing Tonga Fisheries Services programme to start community fisheries management in the country has to date covered three communities in the Ha'apai group, but not Lofanga.

5.2.6 Discussion and conclusions: socioeconomics in Lofanga

The Lofanga community is an isolated, rural coastal area determined by traditional and, to some extent, religious institutions. People have limited access to agricultural land and thus depend primarily on marine resources. Due to the distance from mainland Ha'apai, the lack of electrification and thus proper cooling facilities and production of ice, and the dependency on boat transport as the only means of connection, fisheries marketing is limited, and the risks and costs involved are relatively high.

Due to the low population and fisher density, and the large size of appropriated fishing grounds and reef surfaces, current fishing pressure is relatively low. However, results from the underwater resource surveys suggest that the finfish resources are not in as good a condition as the fishing pressure parameters suggest.

In summary, survey results suggest:

- The Lofanga population is heavily dependent on its marine resources for home consumption, and finfish fisheries provide the main source of income generation. Revenues obtainable from marketing fisheries produce, however, are limited due to the distance to the Ha'apai mainland, the lack of electricity (for ice and cooling), the dependency on fuel, and the cost of boat transport.

- Per capita seafood consumption is high, with fresh fish being the most important, followed by invertebrates. The community also consumes rather high amounts of canned fish.

- Traditional gender roles in fisheries are still apparent in Lofanga. Male fishers are the only official and commercial finfish fishers, while females are in charge of invertebrate collection. Although it is known that females also do catch fish at times, it is difficult to obtain any information on females' finfish fishing activities. Males are increasingly involved in invertebrate harvesting but mainly as a by-product of spearfishing, or when free-diving for giant clams, octopus and lobsters. Female fishers mainly glean the reeftops around the island. However, Lofanga females play an important role in the island's octopus fishery (Kronen and Malimali 2009).

- Finfish is mainly sourced from the lagoon/outer-reef habitats and much less from the sheltered coastal reef areas that surround Lofanga island.

- Overall, CPUEs for finfish fishing are high, and much higher for lagoon/outer-reef fishing than for sheltered coastal reef fishing.

- Handlining and spear diving are the dominant fishing techniques used, while trolling and cast netting are less often used. Invertebrates are collected using very low-cost equipment and little sophisticated support. The average reported fish sizes are large (30–40 cm). The largest average fish sizes were reported for catches from the lagoon/outer reef, while the sizes of fish caught at the sheltered coastal reef are much smaller. Most families show the expected increase in average size with distance from the island; however, Lethrinidae are the exception.

- Results from the invertebrate fisher survey show that catches of giant clams, octopus and sea urchins account for most of the annual harvest (wet weight). By comparison, *Turbo crassus*, *Cryptoplax* spp. and *Holothuria atra* catches are low.

- In contrast to finfish fishing, significant differences were found in the average annual catches by invertebrate fishery. Annual average catches reported for the gleaning of reeftops are less than those obtained by free-diving for selected, reef-associated species.

- The fishing pressure parameters calculated for finfish fisheries suggest that finfish fishing pressure is low due to the large available reef and overall fishing ground area, and the low fisher and population densities and catch rates. The same conclusion is suggested by the data on invertebrate catch, reef area and fisher density. In summary, the current exploitation level of finfish and invertebrate fishing for subsistence and commercial purposes does not give any reason to assume it is detrimental to resources. However, this estimation is based on current catch data and does not take into account earlier exploitation history, or impacts that may be caused by other communities targeting the same fishing grounds. In fact, the results from the underwater finfish resource survey suggest that the condition found is far from favourable. Hence, we conclude that the previous and ongoing finfish fishing pressure imposed by fishers from the Lofanga community and elsewhere, has had detrimental and visible impacts on the finfish resource.

- Given the high dependency of the Lofanga community on marine resources for livelihood and income it is recommended that marketing facilities be provided, electricity be provided for cooling and ice production, transport of produce to Ha'apai and Tongatapu be improved, and selling prices be raised to reflect the real production costs, notably operational costs (fuel, boat maintenance, cold chain), investment costs (motorised boats for fishing and transport), and labour costs.

- It is recommended that the Lofanga community be included in the ongoing fisheries community management programme, and areas be designated for protection by controlling or excluding finfish fishing in order to help the recovery and maintenance of finfish resources and habitats in the area.

5.3 Finfish resource surveys: Lofanga

The volcanic island of Lofanga, located at the coordinates 19°49.2' S and 174°33.3' W (Figure 5.19), is a slightly elevated island (maximum altitude 15 m), which has no lagoon and is inhabited by a community of about 300 people. The village is only accessible by sea from the west or southeast coast. It is about 1853 m long by 926 m wide. The fishing area, excluding the island itself, includes, to the north and northwest, the lagoon reef complexes of Hakau Houa'ulu (5560 x 1483 m, the *motu* of Niniva included) and Hakau Lahi (4818 x 1853 m, the *motu* of Nukupule and Meama included). Southeast of Lofanga, fishers also use the reefs on the small islands of Makauata and Luangahu along with about a dozen other reef microstructures, no more than 200 m in diameter each.

There are only two types of habitat at the site, i.e. outer reefs and back-reefs. In reality, this fishing area is not exclusive, although it is preferred by the Ha'apai fisher community as it is closer and has more fish. There are no reserves; however, there is an overall strong willingness to create a protected area. The fishing techniques used at the site are similar to those used in Tongatapu except for fish traps.

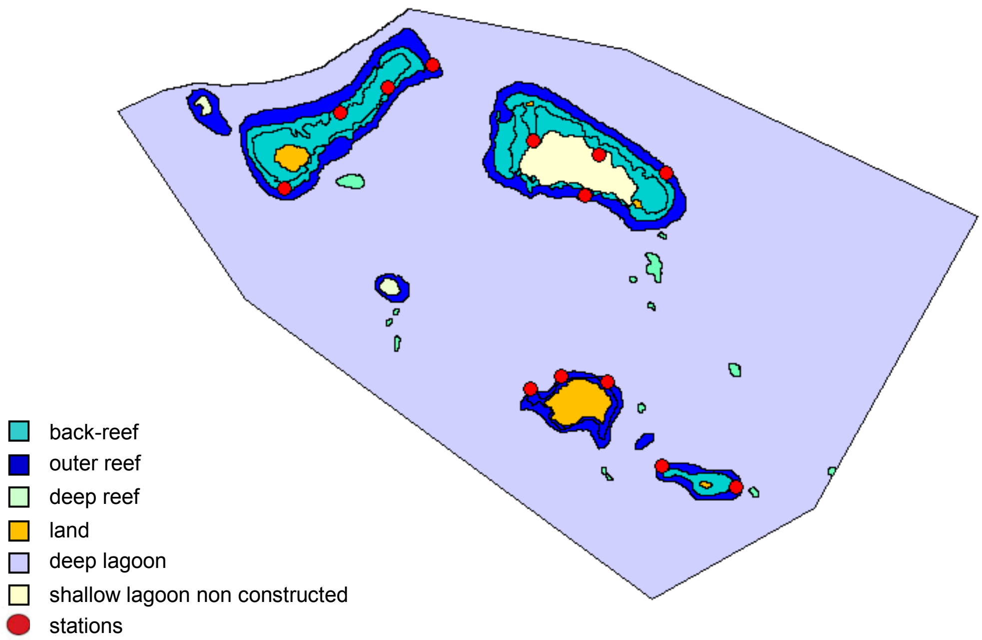

Figure 5.19: Habitat types and transect locations for finfish assessment in Lofanga.

5.3.1 Finfish assessment results: Lofanga

Finfish resources and associated habitats were assessed between 30 September and 11 October 2008, for a total of 13 transects (4 back-reefs, 9 outer reefs).

A total of 20 families, 52 genera, 138 species and 5866 fish were recorded in the 13 transects (See Appendix 3.4.2 for list of species.). Only data on the 15 most dominant families (See Appendix 1.2 for species selection.) are presented below, representing 45 genera, 131 species and 5474 individuals.

Finfish resources differed slightly between the two reef environments found in Lofanga (Table 5.6). Biomass was higher at the outer reefs (52 versus 44 g/m²) but density and average size displayed the same value among the reefs (0.3 fish/m², 17 cm FL). Size ratio was slightly higher at the outer reefs (62% versus 60% at back-reefs). Biodiversity (47 species/transect) was also noticeably higher at the outer reefs.

Table 5.6: Primary finfish habitat and resource parameters recorded in Lofanga (average values ±SE)

Parameters	Habitat		
	Back-reef (1)	**Outer reef** (1)	**All reefs** (2)
Number of transects	4	9	13
Total habitat area (km^2)	10.6	10.6	21.2
Depth (m)	3 (1–5) (3)	6 (2–15) (3)	4 (1–15) (3)
Soft bottom (% cover)	27 ±14	7 ±3	17
Rubble & boulders (% cover)	10 ±4	5 ±1	7
Hard bottom (% cover)	39 ±9	45 ±2	42
Live coral (% cover)	21 ±7	28 ±3	25
Soft coral (% cover)	1 ±1	13 ±2	7
Biodiversity (species/transect)	35 ±4	47 ±4	43 ±3
Density (fish/m^2)	0.3 ±0	0.3 ±0.1	0.3
Size (cm FL) (4)	17 ±1	17 ±1	17
Size ratio (%)	60 ±3	62 ±2	61
Biomass (g/m^2)	43.5 ±2.1	52.0 ±11.4	47.7

(1) Unweighted average; (2) weighted average that takes into account relative proportion of habitat in the study area; (3) depth range; (4) FL = fork length.

Back-reef environment: Lofanga

The back-reef environment of Lofanga was dominated by one herbivorous family, the Acanthuridae, and to a much lower extent by the herbivores Scaridae and carnivores Mullidae, Lethrinidae and Holocentridae (Figure 5.20, Table 5.7). These five families were represented by 27 species; particularly high biomass and abundance were recorded for *Ctenochaetus striatus*, *Acanthurus nigrofuscus*, *Mulloidichthys vanicolensis*, *A. lineatus*, *Neoniphon sammara*, *Gnathodentex aureolineatus* and *Chlorurus sordidus* (Table 5.7). This reef environment was composed of a high cover of hard bottom (39%), a relatively high cover of live coral (21%), and a high cover of mobile bottom (37% with sand and rubble together, Figure 5.20, Table 5.6).

Table 5.7: Finfish species contributing most to main families in terms of densities and biomass in the back-reef environment of Lofanga

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.08 ±0.02	15.1 ±1.9
	Acanthurus nigrofuscus	Brown surgeonfish	0.03 ±0.01	1.4 ±0.5
	Acanthurus lineatus	Lined surgeonfish	0.01 ±0.01	3.0 ±1.8
Holocentridae	*Neoniphon sammara*	Blood-spot squirrelfish	0.01 ±0.01	1.0 ±0.8
Lethrinidae	*Gnathodentex aureolineatus*	Goldlined seabream	0.01 ±0.01	1.0 ±0.9
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.01 ±0.00	2.0 ±0.3
Mullidae	*Mulloidichthys vanicolensis*	Yellowfin goatfish	0.01 ±0.01	1.3 ±1.3

The average biomass and size ratio of finfish in the back-reefs of Lofanga were slightly lower than the outer-reef values. Biodiversity was much lower than at the outer reefs. Density and average sizes were comparable. The trophic structure of fish in Lofanga back-reefs was dominated by herbivorous fish, here mainly represented by Acanthuridae, and much less by Scaridae. Carnivores were represented mainly by Mullidae, Lethrinidae and Holocentridae, which displayed density and biomass comparable to Scaridae. Size ratios were below the 50% values for Kyphosidae, Lethrinidae, Lutjanidae and Siganidae, suggesting a negative response from fishing. These reefs displayed a substrate composed of a higher percentage of hard bottom than live coral but, however, with a high presence of soft bottom and rubble, normally favouring carnivores such as Lethrinidae, which were found but, in a small amount, suggesting an impact from fishing.

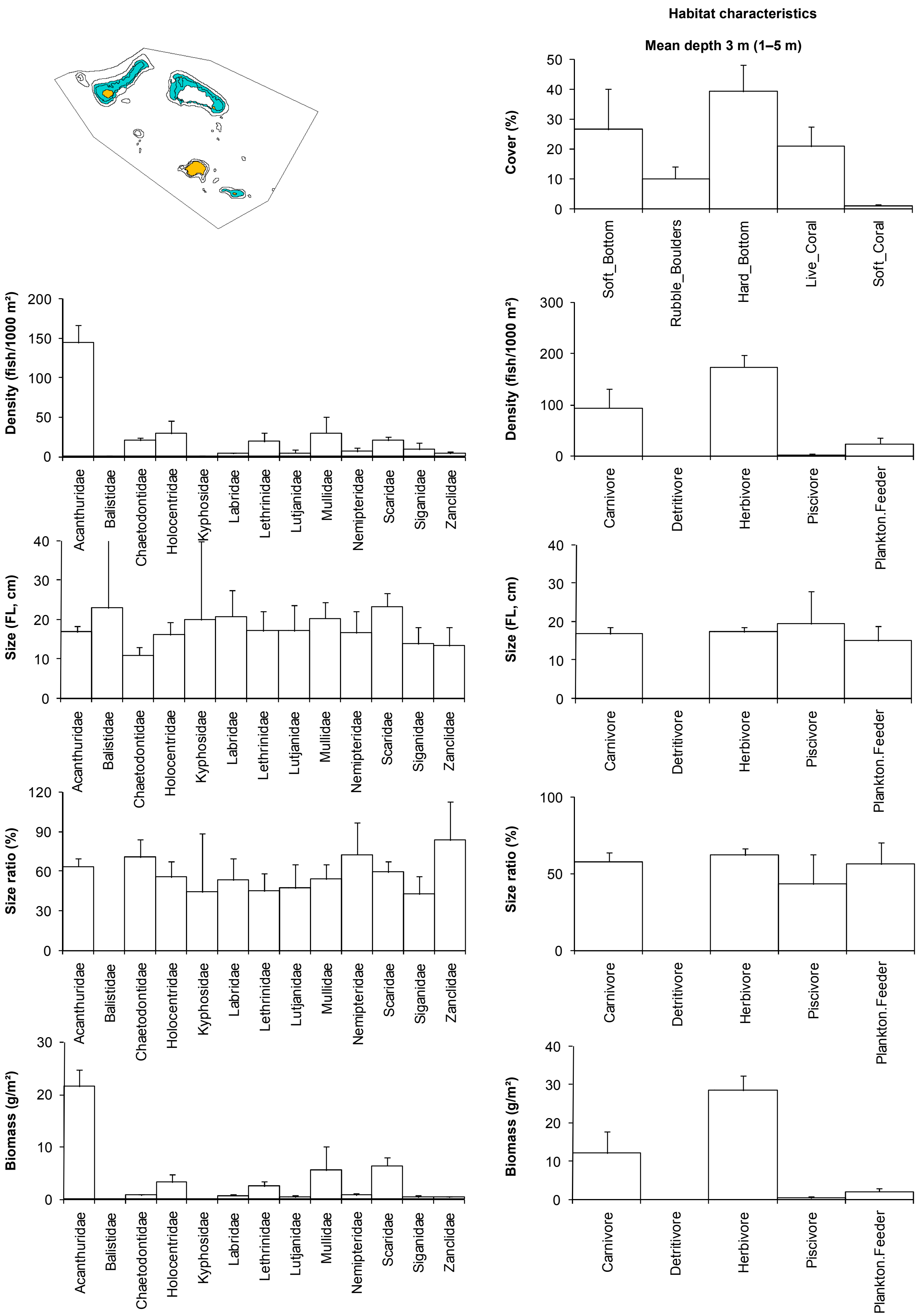

Figure 5.20: Profile of finfish resources in the back-reef environment of Lofanga.
Bars represent standard error (+SE); FL = fork length.

Outer-reef environment: Lofanga

The outer-reef environment of Lofanga was dominated by two major families of herbivores: Acanthuridae and Scaridae and, to a much lower extent, by the carnivores Mullidae and Holocentridae (Figure 5.21, Table 5.8). These four families were represented by 34 species; particularly high biomass and abundance were recorded for *Ctenochaetus striatus*, *Acanthurus nigrofuscus*, *A. lineatus*, *Zebrasoma scopas*, *Scarus altipinnis* and *Chlorurus sordidus* (Table 5.8). This reef environment was dominated by hard bottom (45%), with a relatively high cover of live coral (28%) and a small amount of rubble and soft bottom (12%, Table 5.6, Figure 5.21).

Table 5.8: Finfish species contributing most to main families in terms of densities and biomass in the outer-reef environment of Lofanga

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.10 ±0.03	17.9 ±3.0
	Acanthurus nigrofuscus	Brown surgeonfish	0.04 ±0.02	1.5 ±0.5
	Acanthurus lineatus	Lined surgeonfish	0.02 ±0.01	4.0 ±2.6
	Zebrasoma scopas	Two-tone tang	0.02 ±0.01	1.2 ±0.7
Scaridae	*Scarus altipinnis*	Filament finned parrotfish	0.02 ±0.01	7.3 ±4.8
	Chlorurus sordidus	Daisy parrotfish	0.01 ±0.00	2.7 ±0.6

The size, size ratio and biomass of finfish in the outer reefs of Lofanga were higher than in the back-reefs. Biodiversity was much higher. The trophic structure of the fish community was dominated by herbivorous fish in terms of both density and biomass, but to a lesser extent than in the back-reefs. Acanthuridae highly dominated in terms of numbers and biomass, and were represented by small-sized species. Carnivores were mostly composed of Mullidae and Holocentridae; other families were practically absent. Size ratio was below 50% only for Labridae, suggesting a better condition than in the back-reef habitat and at the other sites. These outer reefs had a substrate dominated by hard bottom and live coral, with very little soft bottom, which may explain the lack of Lethrinidae.

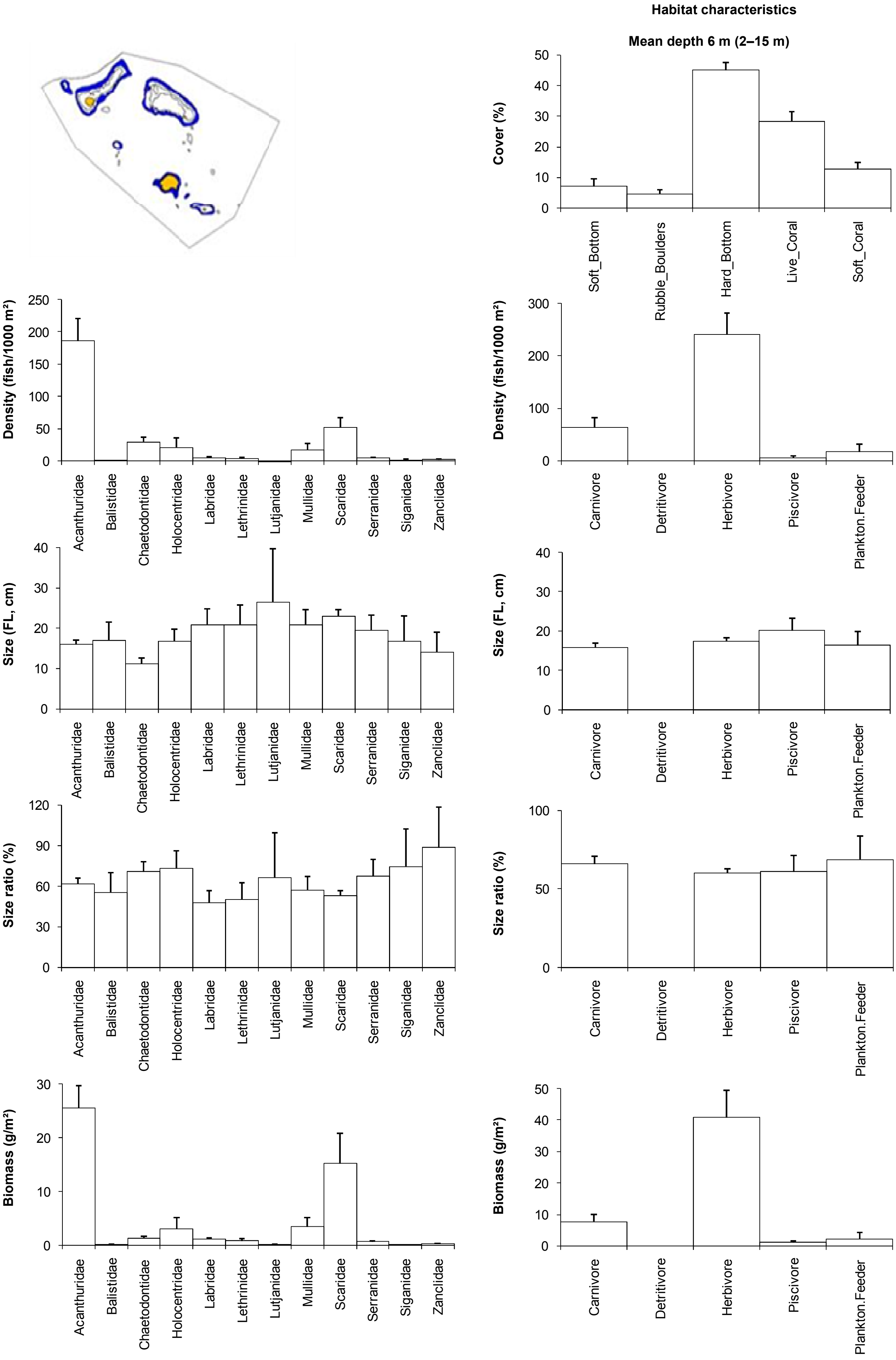

Figure 5.21: Profile of finfish resources in the outer-reef environment of Lofanga.
Bars represent standard error (+SE); FL = fork length.

Overall reef environment: Lofanga

Overall, the reefs of Lofanga were heavily dominated by one family in terms of density as well as biomass: Acanthuridae. Scaridae, Mullidae and Holocentridae were the other important families, although to a much lower degree (Figure 5.22). These four major families were represented by a total of 41 species, dominated by *Ctenochaetus striatus*, *Acanthurus nigrofuscus*, *A. lineatus*, *Mulloidichthys vanicolensis*, *Zebrasoma scopas* and *Chlorurus sordidus* (Table 5.9). Overall, hard-bottom cover dominated the habitat (42%) and cover of live coral was relatively good (25%, Table 5.9 and Figure 5.22). The overall fish assemblage in Lofanga shared characteristics of back- and outer reefs in similar extent (50% each of total habitat).

Table 5.9: Finfish species contributing most to main families in terms of densities and biomass across all reefs of Lofanga (weighted average)

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.09	16.5
	Acanthurus nigrofuscus	Brown surgeonfish	0.03	1.4
	Acanthurus lineatus	Lined surgeonfish	0.02	3.5
	Zebrasoma scopas	Two-tone tang	0.01	0.9
Mullidae	*Mulloidichthys vanicolensis*	Yellowfin goatfish	0.01	3.0
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.01	2.3

Overall, Lofanga appeared to support a slightly better finfish resource than the two sites in Tongatapu and in Koulo. All values of density, size, size ratio, biomass and biodiversity were higher than at all the other sites. However, comparisons among sites are meaningful only when values are compared between Lofanga and Koulo, as they both share the same type of reef habitats: back- and outer reefs. These results suggest that the finfish resource in Lofanga was in slightly better condition than the resource in Koulo, although values of density, biomass and diversity were rather low when compared to other countries. The detailed assessment at fish community composition level revealed poorer density and biomass of carnivores and piscivores compared to herbivores, one family of which, the Acanthuridae family, strongly dominated the fish community.

Overall, few families dominated the community and a general lack or serious poverty of carnivores was the dominant profile. Mullidae and Holocentridae were the most significant carnivores but were present only in extremely low numbers and biomass. Kyphosidae, Balistidae and Lethrinidae had average sizes lower than 50% of the maximum values. The dominance of herbivores can be partially explained by the composition of the habitat, mostly hard rock and live coral, with little soft substrate, which normally favours most invertebrate-feeding carnivores. However, the study of the fish community and of size and size ratio trends disclosed the dominance of small-sized species of low average size, indicating an impact from fishing.

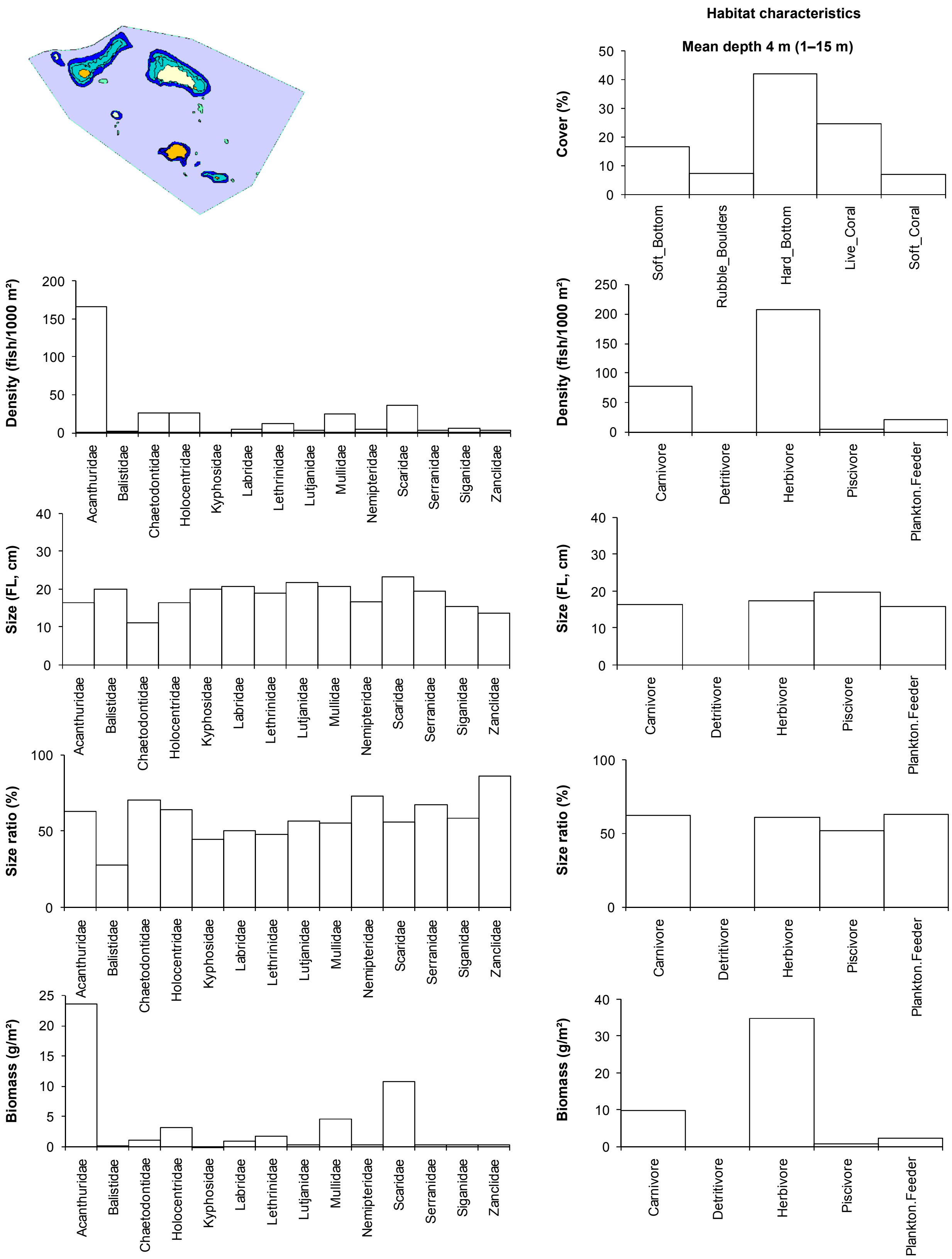

Figure 5.22: Profile of finfish resources in the combined reef habitats of Lofanga (weighted average).
FL = fork length.

Comparisons with 2002 surveys

Biodiversity and size ratio of fish were lower in 2002 than in 2008; however, average size and biomass were slightly lower in 2008 (Figure 5.23). Trophic composition did not change trend between the two surveys but piscivore biomass decreased strongly (Figure 5.24). The most important species composition, represented by small-sized Acanthuridae and Scaridae, did not show any change and the density and abundance of these families remained practically unvaried.

Table 5.10: Primary finfish habitat and resource parameters recorded in Lofanga in 2002 and 2008

Parameters	Year	
	2002	2008
Number of transects	17	13
Total habitat area (km^2)	27.44	21.2
Depth (m)	7 (1–16) [(1)]	4 (1–15) [(1)]
Soft bottom (% cover)	12	17
Rubble & boulders (% cover)	6	7
Hard bottom (% cover)	66	42
Live coral (% cover)	16	25
Soft coral (% cover)	4	7
Biodiversity (species/transect)	37±1	43±3
Density (fish/m^2)	0.3	0.3
Size (cm FL) [(2)]	19	17
Size ratio (%)	60	61
Biomass (g/m^2)	59.9	47.7

[(1)] Depth range; [(2)] FL = fork length.

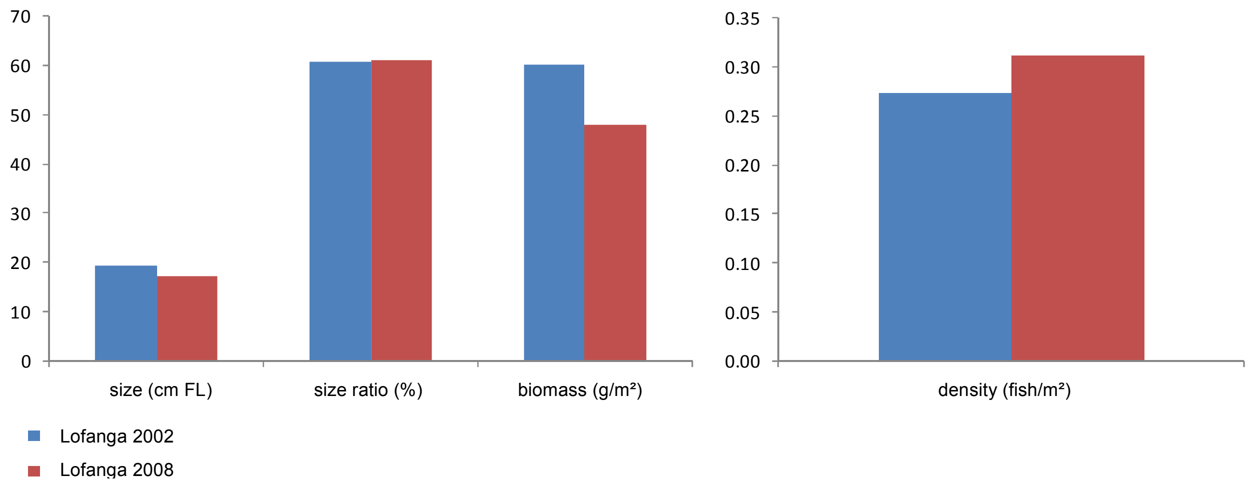

Figure 5.23: Variation in average size, size ratio, biomass and density of finfish in Lofanga between 2002 and 2008.

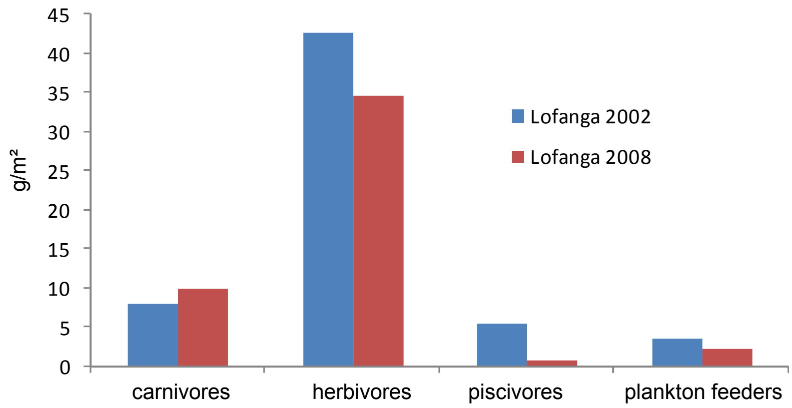

Figure 5.24: Trophic composition in terms of biomass in Lofanga in 2002 and 2008.

Table 5.11: Finfish species contributing most to main families in terms of densities and biomass across all reefs of Lofanga in 2002 (weighted average)

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.08	16.4
	Zebrasoma scopas	Two-tone tang	0.02	1.9
Scaridae	*Chlorurus sordidus*	Daisy parrotfish	0.02	3.7

5.3.2 Discussion and conclusions: finfish resources in Lofanga

- The status of the finfish resources in Lofanga was better than at the other three sites but only mediocre when related to the regional values. Density, size and biomass were the highest recorded at the four sites, however, still quite low compared to the regional values. At a detailed analysis at family level, Acanthuridae was the dominant family but was represented by small-sized species; Scaridae were much less abundant. This is already a sign of impact from heavy fishing, as was proved for the whole Pacific region. Carnivores were not very important and only in the outer reef did they represent one-third of the herbivore biomass, which is a higher value than found in the back-reefs and other reefs of the remaining sites. There were some good-sized fish but these were very rare. Piscivores belonging to the families Lutjanidae and Serranidae were also extremely rare. The existence of *Siganus niger*, endemic to Tonga, was confirmed. Big predators were rare, particularly sharks and Epinephelidae.

- Overall, resources were in average-to-poor condition.

- Density, biomass and diversity of fish were higher in the outer reefs but community composition was heavily dominated by Acanthuridae. Carnivores were rare and Lutjanidae and Serranidae practically absent.

- Finfish abundance, size, biomass and biodiversity were lower in the back-reefs, where most fishing takes place.

- Size ratios of Kyphosidae, Balistidae and Lethrinidae were lower than 50% of the maximum values.

- The use of gillnets and the mesh size of nets should be regulated. Existing restrictions should be complied with by all male fishers.

- A monitoring system should be set in place to follow further changes in finfish resources.
- The establishment of community-driven reserves, explicitly requested by the entire fisher community, should be made easier and more efficient.

5.4 Invertebrate resources: Lofanga

The diversity and abundance of invertebrate species at Lofanga were independently determined using a range of survey techniques (Table 5.12), broad-scale assessment (using the 'manta-tow' technique; locations shown in Figure 5.25) and finer-scale assessment of specific reef and benthic habitats (Figure 5.26).

The main objective of the broad-scale assessment is to describe the distribution pattern of invertebrates (rareness/commonness, patchiness) at large scale and, importantly, to identify target areas for further, fine-scale assessment. Then, fine-scale assessment is conducted in target areas to specifically describe the status of resources in those areas of naturally higher abundance and/or most suitable habitat.

In-water work completed at Ha'apai was not all conducted according to the standard PROCFish survey method, as we used the opportunity of this scheduled work to respond to a specific request from the Government of Tonga to assess the sea cucumber resources of Ha'apai.

Table 5.12: Number of stations and replicate measures completed at Lofanga

Survey method	Stations	Replicate measures
Broad-scale transects (B-S)	10	61 transects
Slope 'manta' transects (10–20 m)		240 transects [2]
Deep 'manta' transects (20–30 m)		240 transects [2]
Reef-benthos transects (RBt)	8	48 transects
Soft-benthos transects (SBt)	0	0 transect
Soft-benthos infaunal quadrats (SBq)	0	0 quadrat group
Mother-of-pearl transects (MOPt)	0	0 transect
Mother-of-pearl searches (MOPs)	0	0 search period
Reef-front searches (RFs)	1	6 search periods
Reef-front search by walking (RFs_w) [1]	0	0 search period
Sea cucumber day searches (Ds)	See slope and deep 'manta' transects	480 transects
Sea cucumber night searches (Ns)	0	0 search period

[1] Reef-front search by walking stations were completed with five officers walking close to the reef crest simultaneously, thereby giving five replicates per station. This is non-standard as usually two officers complete three sets of two replicates; [2] search areas for deep-water work were 100 m in length and 4 m swathe.

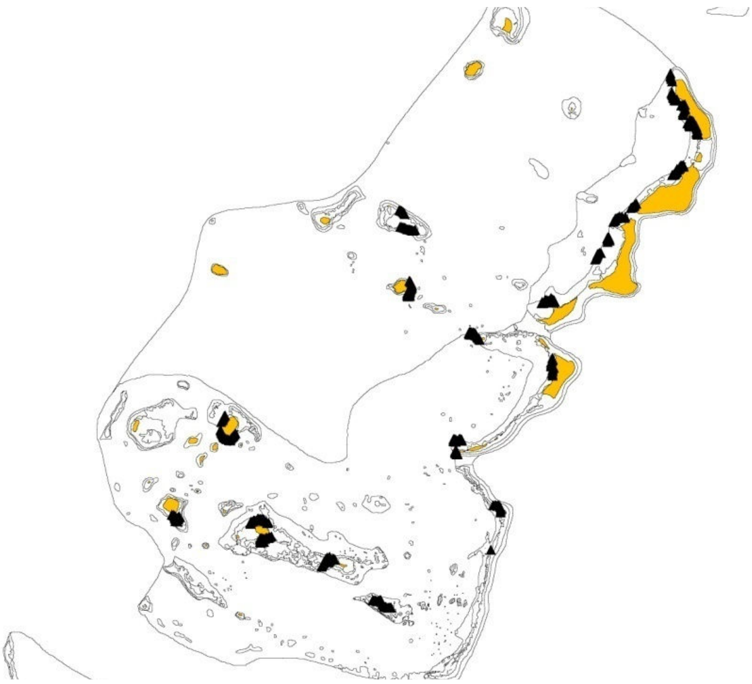

Figure 5.25: Broad-scale survey stations for invertebrates in Lofanga.
Data from broad-scale surveys conducted using 'manta-tow' board;
black triangles: transect start waypoints.

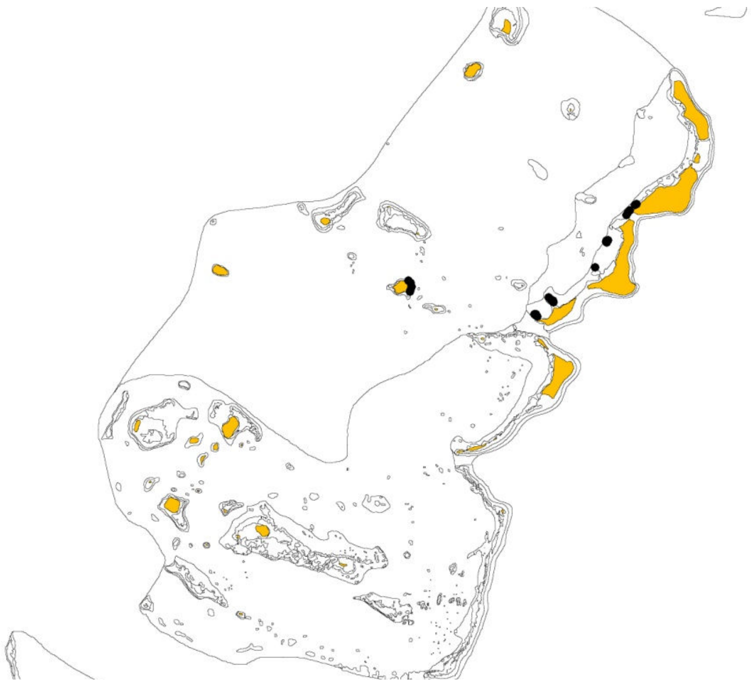

Figure 5.26: Fine-scale reef-benthos transect survey stations for invertebrates in Lofanga.
Black circles: reef-benthos transect stations (RBt). The single reef-front search station was conducted at the northeast of Lofanga island.

Sixty-two species or species groupings (groups of species within a genus) were recorded during the invertebrate surveys at Ha'apai. These included 9 bivalves, 19 gastropods, 21 sea cucumbers, 5 urchins, 5 sea stars, 1 lobster and 1 cnidarian (Appendix 4.4.1). Information on key families and species is detailed below.

5.4.1 Giant clams: Lofanga

Shallow-reef habitat that is suitable for giant clams on the fringing and offshore reefs associated with Lofanga was extensive; however, fishing is generally open-access in Tonga and no set fishing areas are noted in this report. Kronen and Bender (2006) in their study of socioeconomic factors of fishing at Lofanga quote a traditional fishing ground area of 79.35 km^2 and a total reef area of 136.21 km^2.

Reef benthos was commonly recorded on the fringes of the string of islands that make up the Ha'apai archipelago. The nature of the Ha'apai group of islands is oceanic and the exposed shorelines, without rich lagoon environments, were subject to oceanic swell and high levels of flushing. This was especially true for Lofanga, which was a small, low-lying island (1.4 km^2). The proportion of fishing area to land mass was large, and the land generally had few natural embayments to slow water flow and facilitate the sedimentation of suspended solids. Some pseudo-lagoons existed on nearby islands, where the fringing reefs enclosed pools of shallow water. As suggested by the island profile, nutrient inputs from land were limited, and in general the system looked to be nutrient-poor, with little epiphytic growth and silt (generally 'clean' reef).

Shallow reefs at this site held two species of giant clams: the elongate clam *Tridacna maxima* and the fluted clam *T. squamosa*. Shallow-water broad-scale sampling provided an overview of the distribution and density of these clams. The devil's clam *T. tevoroa* and the smooth clam *T. derasa* were also noted, but only in the more extensive deep-water searches of Ha'apai, where both were rare and only noted in water greater than 10 m depth.

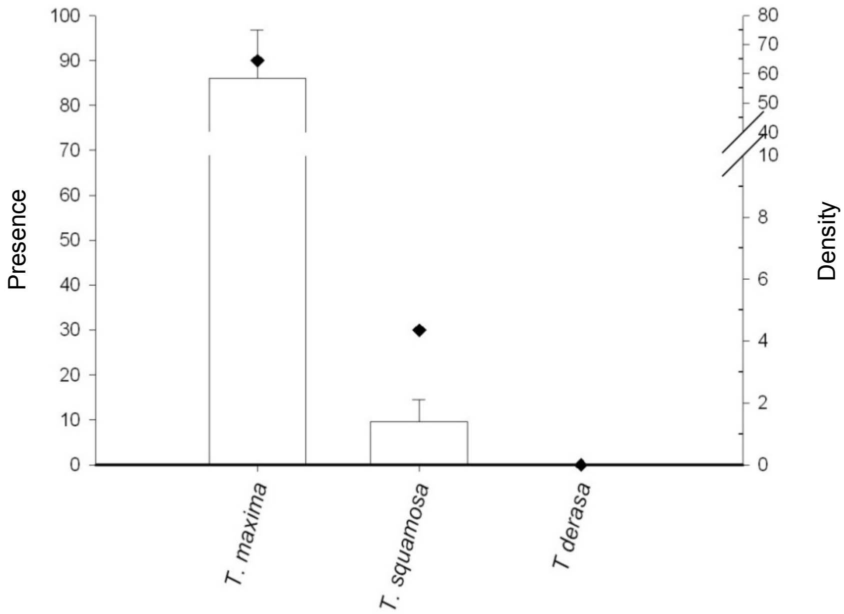

Figure 5.27: Presence and mean density of giant clam species in Lofanga based on broad-scale survey.
Presence is measured as % of stations surveyed where clams were present and denoted by black diamonds; density is measured in numbers per hectare and is represented by bars (+SE).

In standard PROCFish shallow-water broad-scale surveys, *T. maxima* had the widest distribution (found in 9 of the 10 stations, and 44 of 61 transects), followed *T. squamosa* (3 stations and 5 transects). The average station density of *T. maxima* in broad-scale, shallow-water survey transects was 57.7 /ha ±8.7, see Figure 5.27).

Based on the findings of the broad-scale survey, finer-scale surveys targeted specific areas of shallow-water reef habitat (Figure 5.28). In these reef-benthos transect surveys (RBt), *T. maxima* was present in only 63% of stations at a mean density of 36.5 /ha ±12.3.

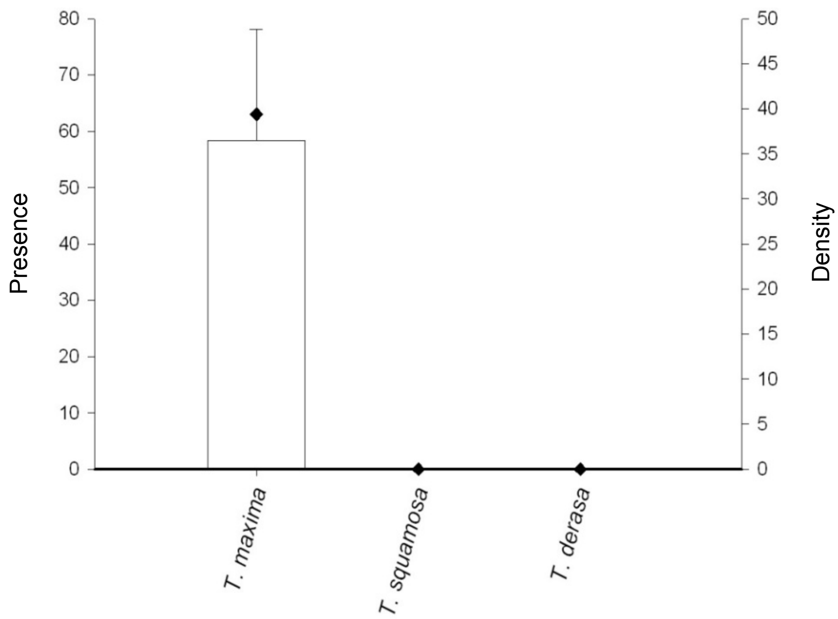

Figure 5.28: Presence and mean density of giant clam species in Lofanga based on fine-scale survey.
Presence is measured as % of stations surveyed where clams were present and denoted by black diamonds; density is measured in numbers per hectare and is represented by bars (+SE).

In general, clams were only moderately common, with five of the eight RBt stations holding clam records. The density of *T. maxima* was relatively low, with no stations returning densities greater than 200 /ha, with the highest average station density reaching only 83 clams/ha.

A total of 497 records were collected during all surveys in Ha'apai (221 at Lofanga only). The average length of *T. maxima* clams taken in reef-benthos transect surveys across Ha'apai was 11.7 cm ±0.6 (n = 40) but 8.7 cm ±1.9 (n = 4) in RBt stations in Lofanga alone (two small clams of 5–6 cm and two more mature clams of 11–13 cm). No *T. squamosa* were recorded in RBt surveys in Lofanga, but five individuals were noted in shallow-water broad-scale surveys (mean 23.2 cm ±2.7). No *T. derasa* clams were noted in RBt stations or shallow-water broad-scale surveys in Lofanga (one found in the Koulo surveys).

A similar result was recorded for the devil's clam *T. tevoroa*. No records originated from shallow water, with only two recorded in deeper-water surveys (mean length of 44 cm ±6).

5.4.2 Mother-of-pearl species (MOP) – trochus and pearl oysters: Lofanga

Ha'apai lies at 19° S and 174° E, which is outside the east–west range of the commercial topshell, *Trochus niloticus* (found naturally on islands as far east as Wallis). As in other eastern Pacific islands, commercial mother-of-pearl shells have been introduced to Ha'apai.

The 1995 transplantation of trochus from the Lau Group in Fiji to Ha'apai is described by Gillett (1995). In this case, the 587 trochus placed in Ha'apai Islands were all placed on the north side of Ava Auhanga Mea between Uoleva and Tataga islands. The location as determined by GPS equipment was 19°51' S, 174°25' W.

At the same time as the introductions of adult shells, maricultured juvenile trochus were established with assistance from Japanese aid, and the reseeding of reefs with hatchery-produced trochus juveniles (mainly released in Tongatapu) was a major part of this programme (Table 4.13).

The reefs at Ha'apai constitute a very extensive benthos suitable for *T. niloticus*, and records show that introductions of adult shells have been sufficient to build up some level of broodstock to create the conditions suitable for more large-scale colonisation.

Table 5.13: Presence and mean density of *Trochus niloticus*, *Tectus pyramis*, *Turbo marmoratus* and *Pinctada margaritifera* in Lofanga
Based on various assessment techniques; mean density measured in numbers per ha (±SE)

	Density	SE	% of stations with species	% of transects or search periods with species
Trochus niloticus				
B-S	0.0	0.0	0/10 = 0	0/61 = 0
RBt	5.2	5.2	1/8 = 13	1/48 = 2
RFs	0	0	0/1 = 0	0/6 = 0
Tectus pyramis				
B-S	5.7	1.8	5/10 = 50	11/61 = 18
RBt	88.5	38.1	5/8 = 63	12/48 = 25
RFs	19.6	-	1/1 = 100	3/6 = 50
Turbo marmoratus				
B-S	0	0	0/10 = 0	0/61 = 0
RBt	0	0	0/8 = 0	0/48 = 0
RFs	3.9	-	1/1 = 100	1/6 = 17
Pinctada margaritifera				
B-S	1.6	0.8	3/10 = 30	4/61 = 7
RBt	0	0	0/8 = 0	0/48 = 0
RFs	0	0	0/1 = 0	0/6 = 0

B-S = broad-scale survey; RBt = reef-benthos transect; RFs = reef-front search.

PROCFish survey work located just 10 live *Trochus niloticus* at Ha'apai, but only one at Lofanga (Table 5.13), although *Tectus pyramis*, a closely related gastropod, was more common (n = 43 individuals at Lofanga alone). This less valuable species of topshell (an algal-grazing gastropod with a similar life history to trochus) was moderately common and at a moderate density at Lofanga, which potentially highlights the suitability of these reefs for the more valuable species.

At Ha'apai the mean size (basal width) of *T. niloticus* was 7.5 cm ±0.9 (n = 8 individuals) and the single specimen recorded at Lofanga was 7.5 cm, while *T. pyramis* was 7.9 cm ±0.5 (n = 10 individuals) and 9.5 cm ±0.5 at Lofanga alone (n = 6). Interestingly, most shells measured less than 9 cm across the base, which indicates that these shells are likely to be the young derived from the reproduction of trochus introduced as adults or juveniles. However, no large recruitment pulse was identified in the survey (Figure 5.29).

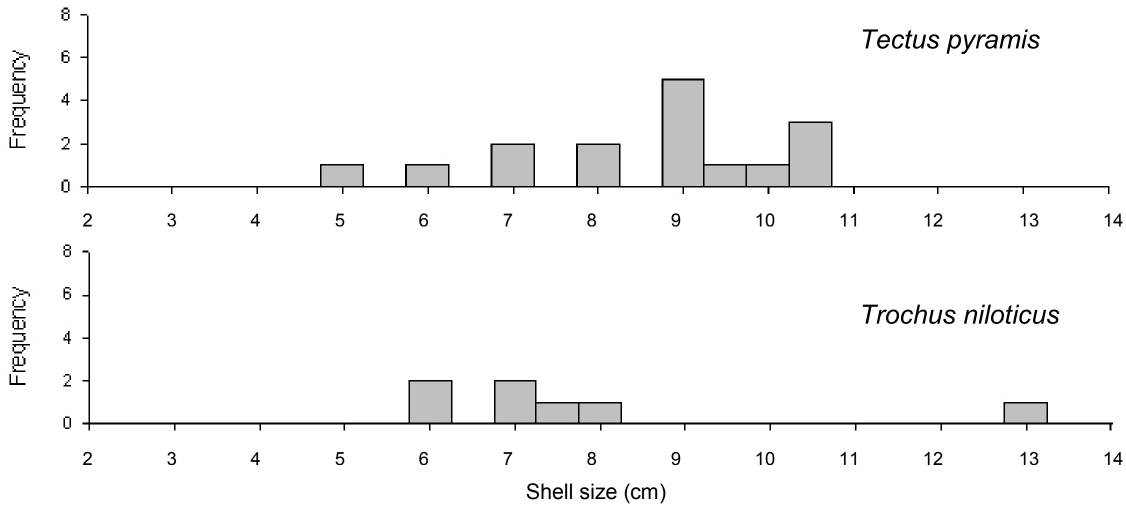

Figure 5.29: Size frequency histogram of trochus (*Trochus niloticus*) and *Tectus pyramis* shell base diameters (cm) for Lofanga.

Green snail (*Turbo marmoratus*) juveniles were also stocked on to the reefs in Ha'apai, close to Lifuka and at a site further west, nearer Lofanga. At the suggestion of local fisheries officers, we searched reefs (RFs stations) that had been stocked with maricultured juveniles, and found a single *T. marmoratus* (The average density for the one station was 3.9 /ha.). However, on a separate search at Uolema point (location not logged), eight green snails were recovered. The size or height of a green snail can be difficult to measure, as the total shell height (See A in Figure 4.32.) is not easy to measure because of the large whorls of the shell (Table 4.15). The best estimation of the measure for the eight green snails measured was 17 cm ±0.3.

Blacklip pearl oysters, *Pinctada margaritifera*, are normally cryptic and sparsely distributed in open lagoon systems. This string of islands did not have any naturally enclosed structures, yet blacklip pearl oysters were not uncommon in the survey of Ha'apai (n = 11 individuals). The mean sizes of these shells were 13.5 cm ±0.3 across all Ha'apai and 14.0 cm ±0.5 (n = 6) at Lofanga alone (dorso–ventral measure).

5.4.3 Infaunal species and groups: Lofanga

No fine-scale soft-benthos surveys or infaunal stations (quadrat surveys) were made at Lofanga. Soft-benthos coastal margins were uncommon at Lofanga and no extensive areas of seagrass or mud, or concentrations of in-ground resources (shell 'beds'), such as arc shells (*Anadara* spp.) or venus shells (*Gafrarium* spp.) were identified.

5.4.4 Other gastropods and bivalves: Lofanga

Seba's spider conch, *Lambis truncata* (the larger of the two common spider conchs) was recorded at low-to-moderate density (n = 13 individuals) across Ha'apai (9 at Lofanga); however, larger numbers were noted in deeper-water surveys for sea cucumbers (n = 30 individuals). In Lofanga, 18 *L. lambis* individuals but no strawberry or red lipped conch (*Strombus luhuanus*) were recorded (Appendices 4.4.1 to 4.4.6).

In addition to *Turbo marmoratus*, a full range of small turban shell species were recorded (e.g. *Turbo argyrostomus*, *T. chrysostomus*, *T. crassus* and *T. setosus*). In reef-benthos transect surveys, the densities were moderate (Table 5.14).

Table 5.14: Presence and mean density of turban shell species in Lofanga
Based on reef-benthos transect assessment technique; mean density measured in numbers per ha (±SE)

Species	Density	SE	% of stations with species	% of transects or search periods with species
Turbo argyrostomus	36.5	16.6	4/8 = 50	7/48 = 15
Turbo crassus	15.6	11.0	2/8 = 25	3/48 = 6
Turbo setosus	26.0	15.6	3/8 = 38	3/48 = 6
Turbo spp.	78.1	52.5	3/8 = 38	4/48 = 18

Other resource species targeted by fishers (e.g. *Astralium*, *Chicoreus*, *Conus*, *Cypraea*, *Latirolagena*, *Ovula*, *Pleuroploca*, *Thais* and *Tutufa*) were also recorded during independent surveys (Appendices 4.4.1 to 4.4.6). Data on other bivalves in broad-scale and fine-scale benthos surveys, such as *Atrina*, *Chama*, *Hyotissa* and *Spondylus*, are also in Appendices 4.4.1 to 4.4.6. No creel survey was conducted at Lofanga.

5.4.5 Lobsters: Lofanga

Lofanga had extensive areas of exposed reef front (barrier reef). This exposed reef, with exposed reef platforms and submerged reef slopes, provides a large amount of habitat suitable for lobsters.

There was no dedicated night reef-front assessment of lobsters (See Methods.). Despite the lack of targeted surveys, the shallow- and deep-water survey work for sea cucumbers was a potential source of lobster recordings. In these surveys, only one lobster (*Panulirus* sp.) was noted.

5.4.6 Sea cucumbers[9]: Lofanga

Lofanga island had no protected shallow-water lagoon system and the low-lying *motu* were separated by channels of deep water. However, fringing reef margins, reef slopes and areas of shallow, mixed hard- and soft-benthos habitat in the lee of islands (suitable habitat for sea cucumbers) were present. Land influence was limited, except close to shore and on extended reef platforms, which pooled water in pseudo-lagoons. Generally, surfaces were without heavy algal and epiphytic growth, although some reef slopes were sufficiently covered with algal epiphytic growth to support surf redfish (*Actinopyga mauritiana*), and some patches of soft benthos around neighbouring islands did support limited amounts of depositional, soft-benthos environments.

In general, the system can be considered to be largely oceanic-influenced, impacted by swell in the east and without extensive protected, enclosed, shallow-water lagoons. As most

[9] There has been a recent change to sea cucumber taxonomy that has changed the name of the black teatfish in the Pacific from *Holothuria* (*Microthele*) *nobilis* to *H. whitmaei*. It is possible that the scientific name for white teatfish may also change in the future. This should be noted when comparing texts, as in this report the 'original' taxonomic names are used.

commercial sea cucumbers are deposit feeders, they generally require richer, more protected depositional environments, where food is in greater supply.

Species presence and density were determined through broad-scale and fine-scale methods (Table 5.15, Appendices 4.4.2 to 4.4.5; also see Methods). In addition to the standard protocol for sampling, a special additional sampling protocol was initiated in Lofanga to respond to a request from the Tongan government. To assist in this endeavour extra staff from Solomon Islands and Papua New Guinea took part in the surveys.

Although survey results by the individual methods are separated for the two PROCFish sites in Ha'apai (Koulo and Lofanga), the joined species list returned 20 commercial species of sea cucumber from all in-water assessments (plus one indicator species, see Table 5.15). The range of sea cucumber species recorded reflected both the varied nature of the habitats present in Ha'apai and the level of management control that had been enforced over these largely exposed, oceanic-influenced islands since the introduction of a moratorium on commercial fishing in 1997.

Sea cucumber species associated with shallow-reef areas, such as the medium-value leopardfish (*Bohadschia argus*) were common (found in 48% of broad-scale transects and 25% of reef-benthos transect stations). The average density recorded was not very high (~20–25 /ha), but consistent with the current low level of fishing.

Stocks of the high-value black teatfish (*Holothuria nobilis*), which is also found in shallow reef and therefore easily targeted by fishers, were uncommon at Lofanga (in 5% of broad-scale transects), and were at low average density (<1 /ha). There is some evidence that this species is highly susceptible to fishing pressure and, once heavily depleted, can take years to recover to reasonable densities of >10 /ha. It is possible that previous heavy fishing around Ha'apai could still be impacting the viability of stocks at Lofanga; as sea cucumbers are single-sexed, broadcast spawners (which release their eggs and sperm into the water column for fertilisation), stocks such as black teatfish, which are generally found at lower ranges of density, are susceptible to the negative effects that occur when overfishing decreases stock densities on the bottom. Fishing pressure affects reproduction success, as individuals become too widely dispersed to effectively maximise fertilisation rates (See Figure 2.35.). Overall, the surveys conducted in Ha'apai show that black teatfish have recovered somewhat since the closure of the fishery, but not substantially, and not to the levels recorded when the fishery was becoming active in 1990 (Figure 4.33).

The faster-growing and medium/high-value greenfish (*Stichopus chloronotus*) was more common, being recorded in most assessments (51% of broad-scale transects), at moderate density (70–150 /ha).

Surf redfish (*Actinopyga mauritiana*) were recorded across the site but, unlike the easterly reef platforms of islands like Lifuka, that faced the prevailing swell, reef slopes and platforms at Lofanga had lower coverage and densities. This species can be recorded at commercial densities of 500–600 /ha in oceanic-influenced atoll islands in French Polynesia and Solomon Islands, and some densities in Ha'apai were also high. In-water surveys in Lofanga revealed surf redfish to be only moderately common and at low density.

More protected areas of reef and soft benthos in lagoonal embayments were not common in Ha'apai. We did not record large numbers of small hairy blackfish (*Actinopyga miliaris*), stonefish (*A. lecanora*), elephant trunkfish (*Holothuria fuscopunctata*) or curryfish (*Stichopus hermanni*) across Ha'apai, although they were noted at low density in areas with partially suitable habitat.

One higher-value species of great importance to Ha'apai is the golden sandfish, which is presently called *Holothuria scabra versicolor* (This scientific Latin name has changed recently to *Holothuria lessoni* but, for consistency in these reports, we have kept the previous name.). This species is concentrated at only a few locations in Ha'apai, predominantly on reef flats where pooled water creates a depositional environment and seagrass and soft benthos predominates. One important fishing area was on the westerly shallows of Oua island, where we went out with village elders to look at the areas that were targeted by fishers. Anecdotal reports tell us that this area was targeted by fishers from other villages initially when the sea cucumber fishery was active; it was only later that fishers from Oua became aware of the value of this product and began fishing themselves. Supposedly, there were large stocks available but in our visit we did not find any golden sandfish, despite 30 minutes of snorkelling in the seagrass areas targeted by fishers. Broad-scale surveys in Lekaleka, Luanamo and Teaupa islands did return some records for this important species, so golden sandfish is not lost to the area. The low number of records (n = 8 individuals) means that continued controls are undoubtedly needed to allow golden sandfish densities to re-establish.

Some lower-value species, e.g. lollyfish (*Holothuria atra*), pinkfish (*H. edulis*) and brown sandfish (*Bohadschia vitiensis*), were also noted at moderate densities at Lofanga.

Mid-water and deep-water assessments were conducted using a broad-scale system on SCUBA (Friedman *et al.* 2004). In these surveys, 240 medium-depth water transects (100 m length, 4 m width, depth range 10–20 m, average depth 13.7 m) and 240 deep-water transects (100 m length, 4 m width, depth range 20–40 m, average depth 24.5 m) were completed to obtain a preliminary abundance estimate for white teatfish (*Holothuria fuscogilva*), prickly redfish (*Thelenota ananas*), amberfish (*T. anax*) and partially for elephant trunkfish (*H. fuscopunctata*) (See Appendix 4.4.3.). Oceanic-influenced benthos in the areas between islands, at the foot of reef slopes and in the passages had suitably dynamic water movement for these species and the density records showed that there had been recovery in the fishery, following the introduction of the moratorium.

The high-value white teatfish (*H. fuscogilva*) was commonly recorded in these surveys in moderately good numbers (6.8 /ha ±0.7) in SCUBA zones, but they were not noted in shallow water. This density is similar to the densities recorded in the 1990 survey (8.6 /ha) and shows a recovery from the 2.2 /ha ±1.1 recorded in 1996, when the fishery was under the greatest pressure from commercialisation.

Deep-water assessments also detected large numbers of amberfish (*T. anax*), while prickly redfish (*T. ananas*) were only moderately common. Both these species were also noted in standard PROCFish shallow-water broad-scale records (Table 5.15), as well as during the deeper surveys.

5.4.7 Other echinoderms: Lofanga

The edible collector urchin (*Tripneustes gratilla*) was present and recorded in a small number of broad-scale replicates (2%). Slate urchins (*Heterocentrotus mammillatus*) were more common, being recorded in 50% of reef-benthos transect stations, at a density of 52.1 ±27.0 /ha.

Other urchins that can be used as a food source or potential indicators of habitat condition (*Echinometra mathaei*, *Diadema* spp. and *Echinothrix* spp.) were also recorded at low levels. The large, black *Echinothrix* species (*E. diadema* and *E. calamaris*) were at low density in reef-benthos transect stations (mean station density 10.4 /ha ±10.4; see Appendices 4.4.2 to 4.4.5).

Starfish were well represented at Lofanga. The common blue starfish (*Linckia laevigata*) and pincushion stars (*Culcita novaeguineae*) were both recorded in 31% of broad-scale transects, but neither species was at high density (<15 /ha in broad-scale survey). Another coralivore (coral eating) starfish, the crown-of-thorns starfish (*Acanthaster planci*) was noted but was rare and at low density. A small aggregation was noted near Alexander reef, south of Limu island (See presence and density estimates in Appendices 4.4.1 to 4.4.5.).

Table 5.15: Sea cucumber species records for Lofanga

Species	Common name	Commercial value [5]	B-S transects n = 61			Reef-benthos stations n = 8			Other stations RFs = 1		
			D [1]	DwP [2]	PP [3]	D	DwP	PP	D	DwP	PP
Actinopyga echinites	Deep-water redfish	M/H									
Actinopyga lecanora	Stonefish	M/H									
Actinopyga mauritiana	Surf redfish	M/H	2.4	29.8	8	26.0	69.4	38	19.6	19.6	100
Actinopyga miliaris	Blackfish	M/H	0.8	16.7	5						
Actinopyga palauensis	Blackfish	M/H									
Bohadschia argus	Leopardfish	M	25.4	53.3	48	20.8	83.3	25			
Bohadschia similis	False sandfish	L	0.3	16.7	2						
Bohadschia vitiensis	Brown sandfish	L	59.3	180.8	33	5.2	41.7	13			
Holothuria atra	Lollyfish	L	3195.6	5907.1	54	151.0	172.6	88			
Holothuria coluber	Snakefish	L	26.5	101.0	26						
Holothuria edulis	Pinkfish	L	488.8	1296.4	38						
Holothuria fuscogilva [4]	White teatfish	H	Present – see mid-water and deep-water survey comments and Appendix 4.4.3								
H. fuscopunctata	Elephant trunkfish	M	2.4	24.8	10						
Holothuria leucospilota	-	L	0.3	16.7	2						
Holothuria nobilis [4]	Black teatfish	H	0.8	16.7	5						
Holothuria scabra versicolor	Golden sandfish	H	2.2	33.3	7						
Stichopus chloronotus	Greenfish	H/M	67.1	132.0	51	156.3	416.7	38			
Stichopus hermanni	Curryfish	H/M	3.8	33.3	11						
Stichopus horrens	Peanutfish	M/L	1.1	0.9	3						
Synapta spp.	-	-	1.1	66.7	2						
Thelenota ananas	Prickly redfish	H	2.4	18.4	13						
Thelenota anax	Amberfish	M	1.6	24.8	7						

[1] D = mean density (numbers/ha); [2] DwP = mean density (numbers/ha) for transects or stations where the species was present; [3] PP = percentage presence (units where the species was found); [4] the scientific name of the black teatfish has recently changed from *Holothuria* (*Microthele*) *nobilis* to *H. whitmaei* and the white teatfish (*H. fuscogilva*) may have also changed name before this report is published. [5] L = low value; M = medium value; H= high value; H/M is higher in value than M/H; B-S transects= broad-scale transects; RFs = reef-front search.

6.4.8 Discussion and conclusions: invertebrate resources in Lofanga

A summary of environmental, stock status and management factors for the main fisheries is given below. Please note that information on other, smaller fisheries and the status of less prominent species groups can be found within the body of the invertebrate chapter.

In summary, data on giant clam habitat, distribution, density and shell size suggest that:

- Reefs at Lofanga had extensive areas of limestone and coral benthos that were suitable for a range of giant clam species. Water movement was dynamic, and shorelines of fringing reef were generally oceanic-influenced. Embayed areas and shoaling reef in mid-water afforded giant clam populations a range of exposure grades, despite the generally exposed nature of reefs at Ha'apai.

- Three species of giant clams were recorded at Lofanga: the elongate clam *Tridacna maxima*, the fluted clam *T. squamosa* and the devil's clam *T. tevoroa*. *T. tevoroa* is a rare, deep-water species that has only been recorded in Tonga, Fiji Islands (and one specimen in New Caledonia). The smooth clam *T. derasa* was also noted in Ha'apai, but not in the shallow-water replicates assigned to the Lofanga study area.

- Giant clam coverage across the study area was not noticeably disrupted (There was no major decline around main settlement areas.), although larger species were not recorded in shallow-water locations. On the other hand, the total number of clams recorded was low. The densities recorded at Lofanga were at best moderate for an exposed oceanic environment such as that found at Lofanga (and Ha'apai as a whole) and such a density is indicative of an impacted clam fishery.

- In an 'open' reef location, such as found in Ha'apai, fishing is likely to have a greater impact on the sustainability of stocks than in lagoon systems, where natural 'trapping' of planktonic larvae is more likely due to the longer water residence time seen in more enclosed, or embayed environments.

- *T. maxima* size classes were difficult to assess due to the small number recorded, but young clams, which indicate successful spawning and recruitment, were still part of the measured stock.

- Giant clams are broadcast spawners that only mature as females at larger size classes (protandric hermaphrodites). This means that, for successful stock management, a percentage of large clams of each species needs to be maintained at high density, to ensure there is sufficient successful spawning taking place to produce new generations of clams for the fishery. Noting the size profile of clams seen at Lofanga (few *T. maxima* clams above 15 cm), and the generally moderate-to-low density of clams, it is likely that stock numbers are in decline.

In summary, data on MOP habitat, presence, distribution, density and shell size suggest that:

- The reefs at Lofanga were extensive, mainly oceanic-influenced and with little lagoon habitat (not enclosed) or land influence. These characteristics are not always advantageous for grazing gastropods, as algal food supply can be low and recruitment can be variable due to the distances between reef systems found in this archipelago (lack of 'interconnectedness').

- The false trochus or green topshell (*Tectus pyramis*) gave an indication that, in general, algal grazing by Trochidae might not be as limited as the oceanic nature of the reefs may suggest (*Tectus pyramis* was successful at colonising the oceanic-influenced reefs at Lofanga.).

- The reefs at Lofanga are outside the natural range of the commercial topshell, *Trochus niloticus*, but now support this species after successful introductions. Introductions have included the movement of both adults (from Fiji Islands) and juveniles (from the hatchery on Tongatapu). A similar situation exists for green snails (*Turbo marmoratus*), which were also introduced as juveniles from hatchery rearing.

- Trochus and green snail were recorded at Lofanga, but only in very small numbers and at low density. Size measures of both trochus and green snail suggest that growth and reproduction of these species is occurring, despite the lack of widespread colonisation of local reefs.

- There is no potential to fish for MOP species in Lofanga at this time. The presence and density records suggest that MOP stocks are below the level at which commercial fishing is recommended, and are in need of ongoing protection to allow time for stocks to build. Trochus need to be protected to ensure there is a future for this fishery, and stocks may need at least another 5–>10 years, or at least enough time to allow the density at the major aggregations to reach at least 500 shells/ha.

- The blacklip pearl oyster, *Pinctada margaritifera*, was not common at Lofanga, but overall results show that the high-energy environment is likely suited to the life habit of this species (Koulo site results returned more reasonable records.), which is a filter feeder characteristically found in low-nutrient reef environments.

In summary, data on the habitat for and distribution and density of sea cucumbers at Lofanga and Ha'apai reveal that:

- The range of sea cucumber species (n = 21) present at Ha'apai was large, despite biogeographical influences (its easterly location and relatively isolated position in the Pacific) and the limited range of protected, shallow-water habitats available in this largely oceanic-influenced reef system.

- Sea cucumbers were relatively common around Lofanga, despite the overall oceanic influence of the system. The density of medium- and high-value species offered some potential for the development of commercial fishing, although other species had not recovered noticeably since the moratorium was implemented.

- The medium-value leopardfish or tigerfish (*Bohadschia argus*) and lower-value lollyfish (*Holothuria atra*) were recorded at reasonably high coverage and density, and there was some recovery of greenfish (*Stichopus chloronotus*) numbers. The high-value black teatfish (*H. nobilis*), which is easily targeted by fishers, was one species that had not recovered markedly around Lofanga since the ban on commercial fishing.

- Surveys targeting deeper-water white teatfish (*H. fuscogilva*) stocks revealed that this high-value species was common and at moderate density. Another deep-water species, the lower-value amberfish (*Thelonata anax*), was at high density at Ha'apai.

- An important species that has seen major disruption from fishing pressure (similar to the black teatfish *H. nobilis*) was the golden sandfish *H. scabra versicolor*. This species has not regained the coverage or density that earlier harvests suggest were present. Both these high-value species require careful management to ensure they recover to 'healthy' densities.

- Ha'apai is one of the few areas in the Pacific that has had three sequential sea cucumber surveys that document the start, collapse and (partial) recovery of stocks in the fishery. This allows for a temporal understanding of both the decline of stocks as a result of fishing and the rates of recovery when the fishery is protected.

- Since the 1996 survey when stocks were shown to be over-fished, most high-value sea cucumber species have again begun to show densities similar to those seen in 1990. However, the black teatfish (*H. nobilis*) stocks are still at depleted levels, and some other species have not recovered as strongly as might be hoped. The recovery in density of commercial species since 1996 needs to be tempered with the local environmental factors, as the low lying islands and oceanic environment found in Ha'apai present a less-than-optimal condition for many of these deposit-feeding resource species. Because of these factors, the potential of the Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

5.5 Overall recommendations for Lofanga

- Lofanga and neighbouring communities on Ha'apai be included in the ongoing community-based fisheries management programme.

- Protected zones or no-take marine parks be established to help recovery and maintenance of finfish and invertebrate resources and habitat condition, with appropriate monitoring and enforcement to ensure compliance.

- Regulations be put in place to control the mesh size of nets and their use.

- A monitoring system be set in place to follow any further changes in finfish resources.

- For successful stock management, a percentage of large clams of each species be maintained at high density, to ensure there is sufficient successful spawning taking place to produce new generations of clams for the fishery.

- Ongoing protection be provided to the trochus stocks for at least another five-to-ten years to allow them to benefit from the increased spawning activity that the high-density base population will provide, thus allowing stocks to rebuild to a minimum of 500–600 shells/ha before commercial harvests are considered.

- The high-value black teatfish (*Holothuria nobilis*) and the golden sandfish (*H. scabra versicolor*) require careful management to ensure they recover to 'healthy' densities.

- The potential of the Tongan bêche-de-mer fisheries in general is likely to be constrained and any re-introduction of a commercial quota must be approached conservatively.

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APPENDIX 1: SURVEY METHODS

1.1 Socioeconomic surveys, questionnaires and average invertebrate wet weights

1.1.1 Socioeconomic survey methods

Preparation

The PROCFish/C socioeconomic survey is planned in close cooperation with local counterparts from national fisheries authorities. It makes use of information gathered during the selection process for the four sites chosen for each of the PROCFish/C participating countries and territories, as well as any information obtained by resource assessments, if these precede the survey.

Information is gathered regarding the target communities, with preparatory work for a particular socioeconomic field survey carried out by the local fisheries counterparts, the project's attachment, or another person charged with facilitating and/or participating in the socioeconomic survey. In the process of carrying out the surveys, training opportunities are provided for local fisheries staff in the PROCFish/C socioeconomic field survey methodology.

Staff are careful to respect local cultural and traditional practices, and follow any local protocols while implementing the field surveys. The aim is to cause minimal disturbance to community life, and surveys have consequently been modified to suit local habits, with both the time interviews are held and the length of the interviews adjusted in various communities. In addition, an effort is made to hold community meetings to inform and brief community members in conjunction with each socioeconomic field survey.

Approach

The design of the socioeconomic survey stems from the project focus, which is on rural coastal communities in which traditional social structures are to some degree intact. Consequently, survey questions assume that the primary sectors (and fisheries in particular) are of importance to communities, and that communities currently depend on coastal marine resources for their subsistence needs. As urbanisation increases, other factors gain in importance, such as migration, as well as external influences that work in opposition to a subsistence-based socioeconomic system in the Pacific (e.g. the drive to maximise income, changes in lifestyle and diet, and increased dependence on imported foods). The latter are not considered in this survey.

The project utilises a 'snapshot approach' that provides 5–7 working days per site (with four sites per country). This timeframe generally allows about 25 households (and a corresponding number of associated finfish and invertebrate fishers) to be covered by the survey. The total number of finfish and invertebrate fishers interviewed also depends on the complexity of the fisheries practised by a particular community, the degree to which both sexes are engaged in finfish and invertebrate fisheries, and the size of the total target population. Data from finfish and invertebrate fisher interviews are grouped by habitat and fishery, respectively. Thus, the project's time and budget and the complexity of a particular site's fisheries are what determine the level of data representation: the larger the population and the number of fishers, and the more diversified the finfish and invertebrate fisheries, the lower the level of representation that can be achieved. It is crucial that this limitation be taken into consideration, because the data gathered through each survey and the emerging distribution patterns are extrapolated to estimate the total annual impact of all fishing activity reported for the entire community at each site.

If possible, people involved in marketing (at local, regional or international scale) who operate in targeted communities are also surveyed (e.g. agents, middlemen, shop owners).

Key informants are targeted in each community to collect general information on the nature of local fisheries and to learn about the major players in each of the fisheries that is of concern, and about fishing rights and local problems. The number of key informants interviewed depends on the complexity and heterogeneity of the community's socioeconomic system and its fisheries.

At each site the extent of the community to be covered by the socioeconomic survey is determined by the size, nature and use of the fishing grounds. This selection process is highly dependent on local marine tenure rights. For example, in the case of community-owned fishing rights, a fishing community includes all villages that have access to a particular fishing ground. If the fisheries of all the villages concerned are comparable, one or two villages may be selected as representative samples, and consequently surveyed. Results will then be extrapolated to include all villages accessing the same fishing grounds under the same marine tenure system.

In an open access system, geographical distance may be used to determine which fishing communities realistically have access to a certain area. Alternatively, in the case of smaller islands, the entire island and its adjacent fishing grounds may be considered as one site. In this case a large number of villages may have access to the fishing ground, and representative villages, or a cross-section of the population of all villages, are selected to be included in the survey.

In addition, fishers (particularly invertebrate fishers) are regularly asked how many people external to the surveyed community also harvest from the same fishing grounds and/or are engaged in the same fisheries. If responses provide a concise pattern, the magnitude of additional impact possibly imposed by these external fishers is determined and discussed.

Sampling

Most of the households included in the survey are chosen by simple random selection, as are the finfish and invertebrate fishers associated with any of these households. In addition, important participants in one or several particular fisheries may be selected for complementary surveying. Random sampling is used to provide an average and representative picture of the fishery situation in each community, including those who do not fish, those engaged in finfish and/or invertebrate fishing for subsistence, and those engaged in fishing activities on a small-scale artisanal basis. This assumption applies provided that selected communities are mostly traditional, relatively small (~100–300 households) and (from a socioeconomic point of view) largely homogenous. Similarly, gender and participation patterns (types of fishers by gender and fishery) revealed through the surveys are assumed to be representative of the entire community. Accordingly, harvest figures reported by male and female fishers participating in a community's various fisheries may be extrapolated to assess the impacts resulting from the entire community, sample size permitting (at least 25–30% of all households).

Data collection and analysis

Data collection is performed using a standard set of questionnaires developed by PROCFish/C's socioeconomic component, which include a household survey (key socioeconomic parameters and consumption patterns), finfish fisheries survey, invertebrate fisheries survey, marketing of finfish survey, marketing of invertebrates survey, and general information questionnaire (for key informants). In addition, further observations and relevant details are noted and recorded in a non-standardised format. The complete set of questionnaires used is attached as Appendix 1.1.2.

Most of the data are collected in the context of face-to-face interviews. Names of people interviewed are recorded on each questionnaire to facilitate cross-identification of fishers and households during data collection and to ensure that each fisher interview is complemented by a household interview. Linking data from household and fishery surveys is essential to permit joint data analysis. However, all names are suppressed once the data entry has been finalised, and thus the information provided by respondents remains anonymous.

Questionnaires are fully structured and closed, although open questions may be added on a case-to-case situation. If translation is required, each interview is conducted jointly by the leader of the project's socioeconomic team and the local counterpart. In cases where no translation is needed, the project's socioeconomist may work individually. Selected interviews may be conducted by trainees receiving advanced field training, but trainees are monitored by project staff in case clarification or support is needed.

The questionnaires are designed to allow a minimum dataset to be developed for each site, one that allows:

- the community's dependency on marine resources to be characterised;
- assessment of the community's engagement in and the possible impact of finfish and invertebrate harvesting; and
- comparison of socioeconomic information with data collected through PROCFish/C resource surveys.

Household survey

The major objectives of the household survey are to:

- **collect recent demographic information** (needed to calculate seafood consumption);
- **determine the number of fishers per household, by gender and type of fishing activity** (needed to assess a community's total fishing impact); and
- **assess the community's relative dependency on marine resources** (in terms of ranked source(s) of income, household expenditure level, agricultural alternatives for subsistence and income (e.g. land, livestock), external financial input (i.e. remittances), assets related to fishing (number and type of boat(s)), and seafood consumption patterns by frequency, quantity and type).

The demographic assessment focuses only on permanent residents, and excludes any family members who are absent more often than they are present, who do not normally share the household's meals or who only join on a short-term visitor basis (for example, students during school holidays, or emigrant workers returning for home leave).

The number of fishers per household distinguishes three categories of adult (≥ 15 years) fishers for each gender: (1) exclusive finfish fishers, (2) exclusive invertebrate fishers, and (3) fishers who pursue both finfish and invertebrate fisheries. This question also establishes the percentage of households that do not fish at all. We use this pattern (i.e. the total number of fishers by type and gender) to determine the number of female and male fishers, and the percentage of these who practise either finfish or invertebrate fisheries exclusively, or who practise both. The share of adult men and women pursuing each of the three fishery categories is presented as a percentage of all fishers. Figures for the total number of people in each fishery category, by gender, are also used to calculate total fishing impact (see below).

The role of fisheries as a source of income in a community is established by a ranking system. Generally, rural coastal communities represent a combined system of traditional (subsistence) and cash-generating activities. The latter are often diversified, mostly involving the primary sector, and are closely associated with traditional subsistence activities. Cash flow is often irregular, tailored to meet seasonal or occasional needs (school and church fees, funerals, weddings, etc.). Ranking of different sources of income by order of importance is therefore a better way to render useful information than trying to quantify total cash income over a certain time period. Depending on the degree of diversification, multiple entries are common. It is also possible for one household to record two different activities (such as fisheries and agriculture) as equally important (i.e. both are ranked as a first source of income, as they equally and importantly contribute to acquisition of cash within the household). In order to demonstrate the degree of diversification and allow for multiple entries, the role that each sector plays is presented as a percentage of the total number of households surveyed. Consequently, the sum of all figures may exceed 100%. Income sources include fisheries, agriculture, salaries, and 'others', with the latter including primarily handicrafts, but sometimes also small private businesses such as shops or kava bars.

Cash income is often generated in parallel by various members of one household and may also be administered by many, making it difficult to establish the overall expenditure level. On the other hand, the head of the household and/or the woman in charge of managing and organising the household are typically aware and in control of a certain amount of money that is needed to ensure basic and common household needs are met. We therefore ask for the level of average household expenditure only, on a weekly, bi-weekly or monthly basis, depending on the payment interval common in a particular community. Expenditures quoted in local currency are converted into US dollars (USD) to enable regional comparison. Conversion factors used are indicated.

Geomorphologic differences between low and high islands influence the role that agriculture plays in a community, but differences in land tenure systems and the particulars of each site are also important, and the latter factors are used in determining the percentage of households that have access to gardens and agricultural land, the average size of these areas, and the type (and if possible number) of livestock that are at the disposal of an average household. A community whose members are equally engaged in agriculture and fisheries will either show distinct groups of fishers and farmers/gardeners, or reveal active and non-active fishing seasons in response to the agricultural calendar.

We can use the frequency and amount of remittances received from family members working elsewhere in the country or overseas to assess the degree to which principles of the MIRAB economy apply. MIRAB was coined to characterise an economy dependent on migration, remittances, foreign aid and government bureaucracy as its major sources of revenue (Small and Dixon 2004; Bertram 1999; Bertram and Watters 1985). A high influx of foreign financing, and in particular remittances, is considered to yield flexible yet stable economic conditions at the community level (Evans 2001), and may also substitute for or reduce the need for local income-generating activities, such as fishing.

The number of boats per household is indicative of the level of isolation, and is generally higher for communities that are located on small islands and far from the nearest regional centre and market. The nature of the boats (e.g. non-motorised, handmade dugout canoes, dugouts equipped with sails, and the number and size of any motorised boats) provides insights into the level of investment, and usually relates to the household expenditure level. Having access to boats that are less sensitive to sea conditions and equipped with outboard engines provides greater choice of which fishing grounds to target, decreases isolation and increases independence in terms of transport, and hence provides fishing and marketing advantages. Larger and more powerful boats may also have a multiplication factor, as they accommodate bigger fishing parties. In this context it should be noted that information on boats is usually complemented by a separate boat inventory performed by interviewing key informants and senior members of the community. If possible, we prefer to use the information from the complementary boat inventory surveys rather than extrapolating data from household surveys, in order to minimise extrapolation errors.

A variety of data are collected to characterise the seafood consumption of each community. We distinguish between fresh fish (with an emphasis on reef and lagoon fish species), invertebrates and canned fish. Because meals are usually prepared for and shared by all household members, and certain dishes may be prepared in the morning but consumed throughout the day, we ask for the average quantity prepared for one day's consumption. In the case of fresh fish we ask for the number of fish per size class, or the total weight, usually consumed. However, the weight is rarely known, as most communities are largely self-sufficient in fresh fish supply and local, non-metric units are used for marketing of fish (heap, string, bag, etc.). Information on the number of size classes consumed allows calculation of weight using length–weight relationships, which are known for most finfish species (FishBase 2000, refer to Letourneur *et al.* 1998; Kulbicki pers. com.). Size classes (using fork length) are identified using size charts (Figure A1.1.1).

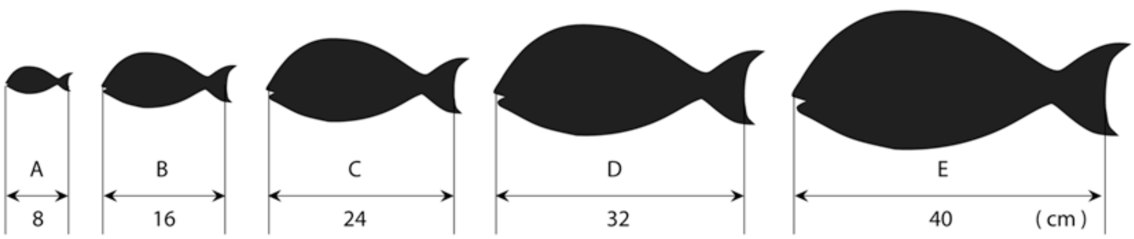

Figure A1.1.1: Finfish size field survey chart for estimating average length of reef and lagoon fish (including five size classes from A = 8 cm to E = 40 cm, in 8 cm intervals).

The frequency of all consumption data is adjusted downwards by 17% (a factor of 0.83 determined on the basis that about two months of the year are not used for fishing due to festivities, funerals and bad weather conditions) to take into account exceptional periods throughout the year when the supply of fresh fish is limited or when usual fish eating patterns are interrupted.

Equation for fresh finfish:

$$F_{wj} = \sum_{i=1}^{n} (N_{ij} \bullet W_i) \bullet 0.8 \bullet F_{dj} \bullet 52 \bullet 0.83$$

F_{wj} = finfish net weight consumption (kg edible meat/household/year) for household$_j$
n = number of size classes
N_{ij} = number of fish of size class$_i$ for household$_j$
W_i = weight (kg) of size class$_i$
0.8 = correction factor for non-edible fish parts
F_{dj} = frequency of finfish consumption (days/week) of household$_j$
52 = total number of weeks/year
0.83 = correction factor for frequency of consumption

For invertebrates, respondents provide numbers and sizes or weight (kg) per species or species groups usually consumed. Our calculation automatically transfers these data entries per species/species group into wet weight using an index of average wet weight per unit and species/species group (Appendix 1.1.3).[1] The total wet weight is then automatically further broken down into edible and non-edible proportions. Because edible and non-edible proportions may vary considerably, this calculation is done for each species/species group individually (e.g. compare an octopus that consists almost entirely of edible parts with a giant clam that has most of its wet weight captured in its non-edible shell).

Equation for invertebrates:

$$Inv_{wj} = \sum_{i=1}^{n} E_{p\,i} \bullet (N_{ij} \bullet W_{wi}) \bullet F_{dj} \bullet 52 \bullet 0.83$$

Inv_{wj} = invertebrate weight consumption (kg edible meat/household/year) of household$_j$
E_{pi} = percentage edible (1 = 100%) for species/species group$_i$ (Appendix 1.1.3)
N_{ij} = number of invertebrates for species/species group$_i$ for household$_j$
n = number of species/species group consumed by household$_j$
W_{wi} = wet weight (kg) of unit (piece) for invertebrate species/species group$_i$
1000 = to convert g invertebrate weight into kg
F_{dj} = frequency of invertebrate consumption (days/week) for household$_j$
52 = total number of weeks/year
0.83 = correction factor for consumption frequency

[1] The index used here mainly consists of estimated average wet weights and ratios of edible and non-edible parts per species/species group. At present, SPC's Reef Fishery Observatory is making efforts to improve this index so as to allow further specification of wet weight and edible proportion as a function of size per species/species group. The software will be updated and users informed about changes once input data are available.

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Equation for canned fish:

Canned fish data are entered as total number of cans per can size consumed by the household at a daily meal, i.e.:

$$CF_{wj} = \sum_{i=1}^{n} (N_{cij} \bullet W_{ci}) \bullet F_{dcj} \bullet 52$$

CF_{wj} = canned fish net weight consumption (kg meat/household/year) of $household_j$
N_{cij} = number of cans of can $size_i$ for $household_j$
n = number and size of cans consumed by $household_j$
W_{ci} = average net weight (kg)/can $size_i$
F_{dcj} = frequency of canned fish consumption (days/week) for $household_j$
52 = total number of weeks/year

Age-gender correction factors are used because simply dividing total household consumption by the number of people in the household will result in underestimating per head consumption. For example, imagine the difference in consumption levels between a 40-year-old man as compared to a five-year-old child. We use simplified gender-age correction factors following the system established and used by the World Health Organization (WHO; Becker and Helsing 1991), i.e. (Kronen *et al.* 2006):

Age (years)	Gender	Factor
≤5	All	0.3
6–11	All	0.6
12–13	Male	0.8
≥12	Female	0.8
14–59	Male	1.0
≥60	Male	0.8

The per capita finfish, invertebrate and canned fish consumptions are then calculated by selecting the relevant formula from the three provided below:

Finfish per capita consumption:

$$F_{pcj} = \frac{F_{wj}}{\sum_{i=1}^{n} AC_{ij} \bullet C_i}$$

F_{pcj} = Finfish net weight consumption (kg/capita/year) for $household_j$
F_{wj} = Finfish net weight consumption (kg/household/year) for $household_j$
n = number of age-gender classes
AC_{ij} = number of people for age class i and household j
C_i = correction factor of age-gender $class_i$

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Invertebrate per capita consumption:

$$Inv_{pcj} = \frac{Inv_{wj}}{\sum_{i=1}^{n} AC_{ij} \bullet C_i}$$

Inv_{pcj} = Invertebrate weight consumption (kg edible meat/capita/year) for $household_j$
Inv_{wj} = Invertebrate weight consumption (kg edible meat/household/year) for $household_j$
n = number of age-gender classes
AC_{ij} = number of people for age class i and household j
C_i = correction factor of age-gender $class_i$

Canned fish per capita consumption:

$$CF_{pcj} = \frac{CF_{wj}}{\sum_{i=1}^{n} AC_{ij} \bullet C_i}$$

CF_{pcj} = canned fish net weight consumption (kg/capita/year) for $household_j$
CF_{wj} = canned fish net weight consumption (kg/household/year) for $household_j$
n = number of age-gender classes
AC_{ij} = number of people for age $class_i$ and $household_j$
C_i = correction factor of age-gender $class_i$

The total finfish, invertebrate and canned fish consumption of a known population is calculated by extrapolating the average per capita consumption for finfish, invertebrates and canned fish of the sample size to the entire population.

Total finfish consumption:

$$F_{tot} = \frac{\sum_{j=1}^{n} F_{pcj}}{n_{ss}} \bullet n_{pop}$$

F_{pcj} = finfish net weight consumption (kg/capita/year) for $household_j$
n_{ss} = number of people in sample size
n_{pop} = number of people in total population

Total invertebrate consumption:

$$Inv_{tot} = \frac{\sum_{j=1}^{n} Inv_{pcj}}{n_{ss}} \bullet n_{pop}$$

Inv_{pcj} = invertebrate weight consumption (kg edible meat/capita/year) for household$_j$
n_{ss} = number of people in sample size
n_{pop} = number of people in total population

Total canned fish consumption:

$$CF_{tot} = \frac{\sum_{j=1}^{n} CF_{pcj}}{n_{ss}} \bullet n_{pop}$$

CF_{pcj} = canned fish net weight consumption (kg/capita/year) of household$_j$
n_{ss} = number of people in sample size
n_{pop} = number of people in total population

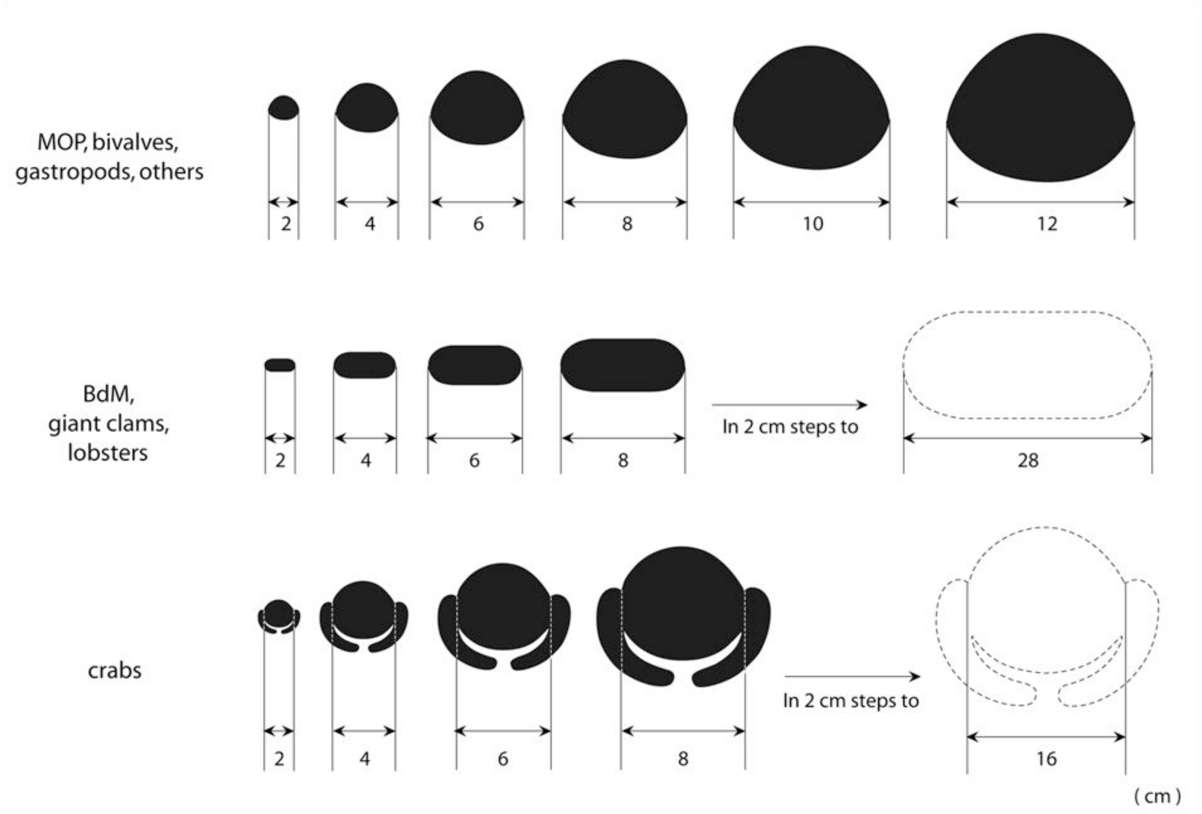

Figure A1.1.2: Invertebrate size field survey chart for estimating average length of different species groups (2 cm size intervals).

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Socioeconomics

Finfish fisher survey

The finfish fisher survey primarily aims to collect the data needed to understand finfish fisheries strategies, patterns and dimensions, and thus possible impacts on the resource. Data collection faces the challenge of retrieving information from local people that needs to match resource survey parameters, in order to make joint data analysis possible. This challenge is highlighted by the following three major issues:

(i) Fishing grounds are classified by habitat, with the latter defined using geomorphologic characteristics. Local people's perceptions of and hence distinctions between fishing grounds often differ substantially from the classifications developed by the project. Also, fishers do not target particular areas according to their geomorphologic characteristics, but instead due to a combination of different factors including time and transport availability, testing of preferred fishing spots, and preferences of members of the fishing party. As a result, fishers may shift between various habitats during one fishing trip. Fishers also target lagoon and mangrove areas, as well as passages if these are available, all of which cannot be included in the resource surveys. It should be noted that a different terminology for reef and other areas fished is needed to communicate with fishers.

These problems are dealt with by asking fishers to indicate the areas they refer to as coastal reef, lagoon, outer-reef and pelagic fishing on hydrologic charts, maps or aerial photographs. In this way we can often further refine the commonly used terms of coastal or outer reef to better match the geomorphologic classification. The proportion of fishers targeting each habitat is provided as a percentage of all fishers surveyed; the socioeconomic analysis refers to habitats by the commonly used descriptive terms for these habitats, rather than the ecological or geomorphologic classifications.

Fishers may travel between various habitats during a single fishing trip, with differing amounts of time spent in each of the combined habitats; the catch that is retrieved from each combined habitat may potentially vary from one trip to the next. If targeting combined habitats is a common strategy practised by most fishers, the resource data for individual geomorphologic habitats need to be lumped to enable comparison of results.

(ii) People usually provide information on fish by vernacular or common names, which are far less specific than (and thus not compatible with) scientific nomenclature. Vernacular name systems are often very localised, changing with local languages, and thus may differ significantly between the sites surveyed in one country alone. As a result, one fish species may be associated with a number of vernacular names, but each vernacular name may also apply to more than one species.

This issue is addressed, as much as possible, through indexing the vernacular names recorded during a survey to the scientific names for those species. However, this is not always possible due to inconsistencies between informants. The use of photographic indices is helpful but can also trigger misleading information, due to the variety of photos presented and the limitations of species recognition using photos alone. In this respect, collaboration with local counterparts from fisheries departments is crucial.

(iii) The assessment of possible fishing impacts is based on the collection of average data. Accordingly, fishers are requested to provide information on a catch that is neither exceptionally good nor exceptionally bad. They are also requested to provide this information concerning the most commonly caught species. This average information suffers from two major shortcomings. Firstly, some fish species are seasonal and may be dominant during a short period of the year but do not necessarily appear frequently in the average catch. Depending on the time of survey implementation this may result in over- or under-representation of these species. Secondly, fishers usually employ more than one technique. Average catches may vary substantially by quantity and quality depending on which technique they use.

We address these problems by recording any fish that plays a seasonal role. This information may be added and helpful for joint interpretation of resource and socioeconomic data. Average catch records are complemented by information on the technique used, and fishers are encouraged to provide the average catch information for the technique that they employ most often.

The design of the finfish fisher survey allows the collection of details on fishing strategies, and quantitative and qualitative data on average catches for each habitat. Targeting men and women fishers allows differences between genders to be established.

Determination of fishing strategies includes:

- frequency of fishing trips
- mode and frequency of transport used for fishing
- size of fishing parties
- duration of the fishing trip
- time of fishing
- months fished
- techniques used
- ice used
- use of catch
- additional involvement in invertebrate fisheries.

The frequency of fishing trips is determined by the number of weekly (or monthly) trips that are regularly made. The average figure resulting from data for all fishers surveyed, per habitat targeted, provides a first impression of the community's engagement in finfish fisheries and shows whether or not different habitats are fished with the same frequency.

Information on the utilisation of non-motorised or motorised boat transport for fishing helps to assess accessibility, availability and choice of fishing grounds. Motorised boats may also represent a multiplication factor as they may accommodate larger fishing parties.

We ask about the size of the fishing party that the interviewee usually joins to learn whether there are particularly active or regular fisher groups, whether these are linked to fishing in certain habitats, and whether there is an association between the size of a fishing party and fishing for subsistence or sale. We also use this information to determine whether information regarding an average catch applies to one or to several fishers.

The duration of a fishing trip is defined as the time spent from any preparatory work through the landing of the catch. This definition takes into account the fact that fishing in a Pacific Island context does not follow a western economic approach of benefit maximisation, but is a more integral component of people's lifestyles. Preparatory time may include up to several hours spent reaching the targeted fishing ground. Fishing time may also include any time spent on the water, regardless of whether there was active fishing going on. The average trip duration is calculated for each habitat fished, and is usually compared to the average frequency of trips to these habitats (see discussion above).

Temporal fishing patterns – the times when most people go fishing – may reveal whether the timing of fishing activities depends primarily on individual time preferences or on the tides. There are often distinct differences between different fisher groups (e.g. those that fish mostly for food or mostly for sale, men and women, and fishers using different techniques). Results are provided in percentage of fishers interviewed for each habitat fished.

To calculate total annual fishing impact, we determine the total number of months that each interviewee fishes. As mentioned earlier, the seasonality of complementary activities (e.g. agriculture), seasonal closing of fishing areas, etc. may result in distinct fishing patterns. To take into account exceptional periods throughout the year when fishing is not possible or not pursued, we apply a correction factor of 0.83 to the total provided by people interviewed (this factor is determined on the basis that about two months of every year – specifically, 304/365 days – are not used for fishing due to festivals, funerals and bad weather conditions).

Knowing the range of techniques used and learning which technique(s) is/are predominantly used helps to identify the possible causes of detrimental impacts on the resource. For example, the predominant use of gillnets, combined with particular mesh sizes, may help to assess the impact on a certain number of possible target species, and on the size classes that would be caught. Similarly, spearfishing targets particular species, and the impacts of spearfishing on the abundance of these species in the habitats concerned may become evident. To reveal the degree to which fishers use a variety of different techniques, the percentage of techniques used refers to the proportion of all fishers who use that technique. Percentages show which techniques are used by most or even all fishers, and which are used by smaller groups. In addition, the data are presented by habitat (what percentage of fishers targeting a habitat use a particular technique, where n = the total number of fishers interviewed by habitat).

The use of ice (whether it is used at all, used infrequently or used regularly) hints at the degree of commercialisation, available infrastructure and investment level. Usually, communities targeted by our project are remote and rather isolated, and infrastructure is rudimentary. Thus, ice needs to be purchased and is often obtained from distant sources, with attendant costs in terms of transport and time. On the other hand, ice may be the decisive input that allows marketing at a regional or urban centre. The availability of ice may also be a decisive factor in determining the frequency of fishing trips.

Determining the use of the catch or shares thereof for various purposes (subsistence, non-monetary exchange and sale) is a necessary prerequisite to providing fishery management advice. Fishing pressure is relatively stable if determined predominantly by the community's subsistence demand. Fishing is limited by the quantity that the community can consume, and changes occur in response to population growth and/or changes in eating habits. In contrast, if fishing is performed mainly for external sale, fishing pressure varies according to outside market demand (which may be dynamic) and the cost-benefit (to fishers) of fishing. Fishing strategies may vary accordingly and significantly. The recorded purposes of fishing are presented as the percentage of all fishers interviewed per habitat fished. We distinguish these figures by habitat so as to allow for the fact that one fisher may fish several habitats but do so for different purposes.

Information on the additional involvement of interviewed fishers in invertebrate fisheries, for either subsistence or commercial purposes, helps us to understand the subsistence and/or commercial importance of various coastal resources. The percentage of finfish fishers who also harvest invertebrates is calculated, with the share of these who do so for subsistence and/or for commercial purposes presented in percentage (the sum of the latter percentages may exceed 100, because fishers may harvest invertebrates for both subsistence and sale).

The average catch per habitat (technique and transport used) is recorded, including:

- a list of species, usually by vernacular names; and
- the kg or number per size class for each species.

These data are used to calculate total weight per species and size class, using a weight–length conversion factor (FishBase 2000, refer to Letourneur *et al.* 1998; Kulbicki pers. com.). This requires using the vernacular/scientific name index to relate (as far as possible) local names to their scientific counterparts. Fish length is reported by using size charts that comprise five major size classes in 8 cm intervals, i.e. 8 cm, 16 cm, 24 cm, 32 cm and 40 cm. The length of any fish that exceeds the largest size class (40 cm) presented in the chart is individually estimated using a tape measure. The length–weight relationship is calculated for each site using a regression on catch records from finfish fishers' interviews weighted by the annual catch. Data used from the catch records consist of scientific names correlated to the vernacular names given by fishers, number of fish, size class (or measured size) and/or weight. In other words, we use the known length–weight relationship for the corresponding species to vernacular names recorded.

Once we have established the average and total weight per species and size class recorded, we provide an overview of the average size for each family. The resulting pattern allows analysis of the degree to which average and relative sizes of species within the various families present at a particular site are homogeneous. The same average distribution pattern is calculated for all families, per habitat, in order to reveal major differences due to the locations where the fish were caught. Finally, we combine all fish records caught, per habitat and site, to determine what proportion of the extrapolated total annual catch is composed of each of the various size classes. This comparison helps to establish the most dominant size class caught overall, and also reveals major differences between the habitats present at a site.

Catch data are further used to calculate the total weight for each family (includes all species reported) and habitat. We then convert these figures into the percentage distribution of the total annual catch, by family and habitat. Comparison of relative catch composition helps to identify commonalities and major differences, by habitat and between those fish families that are most frequently caught.

A number of parameters from the household and fisher surveys are used to calculate the total annual catch volume per site, habitat, gender, and use of the catch (for subsistence and/or commercial purposes).

Appendix 1: Survey methods
Socioeconomics

Data from the household survey regarding the number of fishers (by gender and type of fishery) in each household interviewed are extrapolated to determine the total number of men and women that target finfish, invertebrates, or both.

Data from the fisher survey are used to determine what proportion of men and women fishers target various habitats or combinations of habitats. These figures are assumed to be representative of the community as a whole, and hence are applied to the total number of fishers (as determined by the household survey). The total number of finfish fishers is the sum of all fishers who solely target finfish, and those who target both finfish and invertebrates; the same system is applied for invertebrate fishers (i.e. it includes those who collect only invertebrates and those who target both invertebrates and finfish. These numbers are also disaggregated by gender.

The total annual catch per fisher interviewed is calculated, and the average total annual catch reported for each type of fishing activity/fishery (including finfish and invertebrates) by gender is then multiplied by the total number of fishers (calculated as detailed above, for each type of fishing activity/fishery and both genders). More details on the calculation applied to invertebrate fisheries are provided below.

Total annual catch (t/year):

$$TAC = \sum_{h=1}^{N_h} \frac{Fif_h \bullet Acf_h + Fim_h \bullet Acm_h}{1000}$$

TAC = total annual catch t/year
Fif_h = total number of female fishers for $habitat_h$
Acf_h = average annual catch of female fishers (kg/year) for $habitat_h$
Fim_h = total number of male fishers for $habitat_h$
Acm_h = average annual catch of male fishers (kg/year) for $habitat_h$
N_h = number of habitats

Where:

$$Acf_h = \frac{\sum_{i=1}^{If_h} f_i \bullet 52 \bullet 0.83 \bullet \frac{Fm_i}{12} \bullet Cfi}{If_h} \bullet \frac{\sum_{k=1}^{Rf_h} f_k \bullet 52 \bullet 0.83 \bullet \frac{Fm_k}{12}}{\sum_{i=1}^{If_h} f_i \bullet 52 \bullet 0.83 \bullet \frac{Fm_i}{12}}$$

If_h = number of interviews of female fishers for $habitat_h$ (total number of interviews where female fishers provided detailed information for $habitat_h$)
f_i = frequency of fishing trips (trips/week) as reported on $interview_i$
Fm_i = number of months fished (reported in $interview_i$)
Cf_i = average catch reported in $interview_i$ (all species)
Rf_h = number of targeted habitats as reported by female fishers for $habitat_h$ (total numbers of interviews where female fishers reported targeting $habitat_h$ but did not necessarily provide detailed information)
f_k = frequency of fishing trips (trips/week) as reported for $habitat_k$
Fm_k = number of months fished for reported $habitat_k$ (fishers = sum of finfish fishers and mixed fishers, i.e. people pursuing both finfish and invertebrate fishing)

Thus, we obtain the total annual catch by habitat and gender group. The sum of all catches from all habitats and both genders equals the total annual impact of the community on its fishing ground.

The accuracy of this calculation is determined by reliability of the data provided by interviewees, and the extrapolation procedure. The variability of the data obtained through fisher surveys is illuminated by providing standard errors for the calculated average total annual catches. The size of any error stemming from our extrapolation procedure will vary according to the total population at each site. As mentioned above, this approach is best suited to assess small and predominantly traditional coastal communities. Thus, the risk of over- or underestimating fishing impact increases in larger communities, and those with greater urban influences. We provide both the total annual catch by interviewees (as determined from fisher records) and the extrapolated total impact of the community, so as to allow comparison between recorded and extrapolated data.

The total annual finfish consumption of the surveyed community is used to determine the share of the total annual catch that is used for subsistence, with the remainder being the proportion of the catch that is exported (sold externally).

Total annual finfish export:

$$E = TAC - \left(\frac{F_{tot}}{1000} \bullet \frac{1}{0.8}\right)$$

Where:

E = total annual export (t)
TAC = total annual catch (t)
F_{tot} = total annual finfish consumption (net weight kg)
$\frac{1}{0.8}$ = to calculate total biomass/weight, i.e. compensate for the earlier deduction by 0.8 to determine edible weight parts only

In order to establish fishing pressure, we use the habitat areas as determined by satellite interpretation. However, as already mentioned, resource surveys and satellite interpretation do not include lagoon areas. Thus, we determine the missing areas by calculating the smallest possible polygon (Figure A1.1.3) that encompasses the total fishing ground determined with fishers and local people during the fieldwork. In cases where fishing grounds are gazetted, owned and managed by the community surveyed, the missing areas are determined using the community's fishing ground limits.

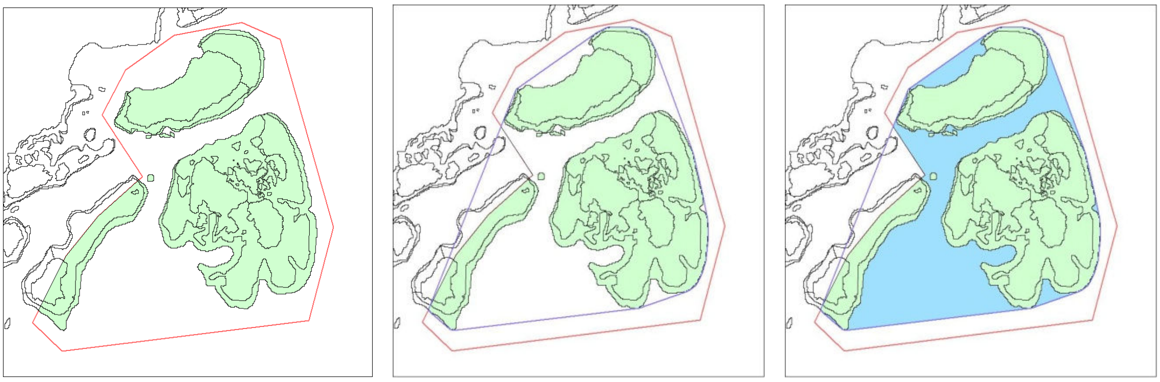

Figure A1.1.3: Determination of lagoon area.
The fishing ground (in red) is initially delineated using information from fishers. Reef areas within the fishing area (in green; interpreted from satellite data) are then identified. The remaining non-reef areas within the fishing grounds are labelled as lagoon (in blue) (Developed using MapInfo).

We use the calculated total annual impact and fishing ground areas to determine relative fishing pressure. Fishing pressure indicators include the following:

- annual catch per habitat
- annual catch per total reef area
- annual catch per total fishing ground area.

Fisher density includes the total number of fishers per km^2 of reef and total fishing ground area, and productivity is the annual catch per fisher. Due to the lack of baseline data, we compare selected indicators, such as fisher density, productivity (catch per fisher and year) and total annual catch (per reef and total fishing ground area), across all sites for each country surveyed. This comparison may also be done at the regional level in the future.

The catch per unit effort (CPUE) is generally acknowledged as an indicator of the status of a resource. If an increasing amount of time is required to obtain a certain catch, degradation of the resource is assumed. However, taking into account that our project is based on a snapshot approach, CPUE is used on a comparative basis between sites within a country, and will be employed later on a regional scale. Its application and interpretation must also take into account the fact that fishing in the Pacific Islands does not necessarily follow efficiency or productivity maximisation strategies, but is often an integral component of people's lifestyles. As a result, CPUE has limited applicability.

In order to capture comparative data, in calculating CPUE we use the entire time spent on a fishing trip, including travel, fishing and landing. Thus, we divide the total average catch per fisher by the total average time spent per fishing trip. CPUE is determined as an overall average figure, by gender and habitat fished.

Invertebrate fisher survey

The objective, purpose and design of the invertebrate fisher survey largely follow those of the finfish fisher survey. Thus, the primary aim of the invertebrate fisher survey is to collect data needed to understand the strategies, patterns and dimensions of invertebrate fisheries, and hence the possible impacts on invertebrate resources. Invertebrate data collection faces several challenges, as retrieval of information from local people needs to match the resource survey parameters in order to enable joint data analysis. Some of the major issues are:

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Socioeconomics

(i) The invertebrate resource survey defines invertebrate fisheries using differing parameters (several are primarily determined by habitat, others by target species). However, these fisheries classifications do not necessarily coincide with the perceptions and fishing strategies of local people. In general, there are two major types of invertebrate fishers: those who walk and collect with simple tools, and those who free-dive using masks, fins, snorkel, hands, simple tools or spears. The latter group is often more commercially oriented, targeting species that are exploited for export (trochus, BdM, lobster, etc.). However, some of the divers may harvest invertebrates as a by-product of spearfishing for finfish. Fishers who primarily walk (some may or may not use non-motorised or even motorised transport to reach fishing grounds) are mainly gleaners targeting available habitats (or a combination of habitats, if convenient). While gleaning is often performed for subsistence needs, it may also be used as a source of income, albeit mostly serving national rather than export markets. While gleaning is an activity that may be performed by both genders, diving is usually men's domain.

We have addressed the problem of collecting information according to fisheries as defined by the resource survey by asking people to report according to the major habitats they target and/or species-specific dive fisheries they engage in. Very often this results in the grouping of various fisheries, as they are jointly targeted or performed on one fishing trip. Where possible, we have disaggregated data for these groups and allocated individuals to specific fisheries. Examples of such data disaggregation are the proportion of all fishers and fishers by gender targeting each of the possible fisheries at one site.

We have also disaggregated some of the catch data, because certain species are always or mostly associated with a particular fishery. However, the disagreement between people's perception and the resource classification becomes visible when comparing species composition per fishery (or combination of fisheries) as reported by interviewed fishers, and the species and total annual wet weight harvested allocated individually by fishery, as defined by the resource survey.

(ii) As is true for finfish, people usually provide information on invertebrate species by vernacular or common names, which are far less specific and thus not directly compatible with scientific nomenclature. Vernacular name systems are often very localised, changing with local languages, and thus may differ significantly between the sites surveyed in one country. Differing from finfish, vernacular names for invertebrates usually combine a group (often a family) of species, and are rarely species specific.

Similar to finfish, the issue of vernacular versus scientific names is addressed by trying to index as many scientific names as possible for any vernacular name recorded during the ongoing survey. Inconsistencies between informants are a limiting factor. The use of photographic indices is very useful, but may trigger misleading information; in addition, some reported species may not be depicted. Again, collaboration with local counterparts from fisheries departments is crucial.

The lack of specificity in the vernacular names used for invertebrates is an issue that cannot be resolved, and specific information regarding particular species that are included with others under one vernacular name cannot be accurately provided.

(iii) The assessment of possible fishing impacts is based on the collection of average data. This means that fishers are requested to provide information on a catch that is neither exceptionally good nor exceptionally bad. They are also requested to provide this information concerning the most commonly caught species. In the case of invertebrate fisheries this results in underestimation of the total number of species caught, and often greater attention is given to commercial species than to rare species that are used mainly for consumption. Seasonality of invertebrate species appears to be a less important issue than when compared to finfish.

We address these problems by encouraging people to also share with us the names of species they may only rarely catch.

(iv) Assessment of possible fishing impact requires knowledge of the size–weight relationship of (at least) the major species groups harvested. Unfortunately, a comparative tool (such as FishBase and others that are used for finfish) is not available for invertebrates. In addition, the proportion of edible and non-edible parts varies considerably among different groups of invertebrates. Further, non-edible parts may still be of value, as for instance in the case of trochus. However, these ratios are also not readily available and hence limit current data analysis.

We have dealt with this limitation by applying average weights (drawn from the literature or field measurements) for certain invertebrate groups. The applied wet weights are listed in Appendix 1.1.3. We used this approach to estimate total biomass (wet weight) removed; we have also listed approximations of the ratio between edible and non-edible biomass for each species.

Information on invertebrate fishing strategies by fishery and gender includes:

- frequency of fishing trips
- duration of an average fishing trip
- time when fishing
- total number of months fished per year
- mode of transport used
- size of fishing parties
- fishing external to the community's fishing grounds
- purpose of the fisheries
- whether or not the fisher also targets finfish.

In addition, for each fishery (or combination of fisheries) the species composition of an average catch is listed, and the average catch for each fishery is specified by number, size and/or total weight. If local units such as bags (plastic bags, flour bags), cups, bottles or buckets are used, the approximate weight of each unit is estimated and/or weighed during the field survey and average weight applied accordingly. For size classes, size charts for different species groups are used (Figure A1.1.2).

The proportion of fishers targeting each fishery (as defined by the resource survey) is presented as a percentage of all fishers. Records of fisheries that are combined in one trip are disaggregated by counting each fishery as a single data entry. The same process is applied to determine the share of women and men fishers per fishery (as defined by the resource survey).

The number of different vernacular names recorded for each fishery is useful to distinguish between opportunistic and specialised harvesting strategies. This distribution is particularly interesting when comparing gleaning fisheries, while commercial dive fisheries are species specific by definition.

The calculation of catch volumes is based on the determination of the total number of invertebrate fishers and fishers targeting both finfish and invertebrates, by gender group and by fishery, as described above.

The average invertebrate catch composition by number, size and species (with vernacular names transferred to scientific nomenclature), and by fishery and gender group, is extrapolated to include all fishers concerned. Conversion of numbers and species by average weight factors (Appendix 1.1.3) results in a determination of total biomass (wet weight) removed, by fishery and by gender. The sum of all weights determines the total annual impact, in terms of biomass removed.

To calculate total annual impact, we determine the total numbers of months fished by each interviewee. As mentioned above, seasonality of complementary activities, seasonal closing of fishing areas, etc. may result in distinct fishing patterns. Based on data provided by interviewees, we apply – as for finfish – a correction factor of 0.83 to take into account exceptional periods throughout the year when fishing is not possible or not pursued (this is determined on the basis that about two months (304/365 days) of each year are not used for fishing due to festivals, funerals and bad weather conditions).

Total annual catch:

$$\text{TACj} = \sum_{h=1}^{N_h} \frac{F_{inv}f_h \bullet Ac_{inv}f_{hj} + F_{inv}m_h \bullet Ac_{inv}m_{hj}}{1000}$$

TACj = total annual catch t/year for species_j
$F_{inv}f_h$ = total number of female invertebrate fishers for habitat_h
$Ac_{inv}f_{hj}$ = average annual catch by female invertebrate fishers (kg/year) for habitat_h and species_j
$F_{inv}m_h$ = total number of male invertebrate fishers for habitat_h
$Ac_{inv}m_{hj}$ = average annual catch by male invertebrate fishers (kg/year) for habitat_h and species_j
N_h = number of habitats

Where:

$$Ac_{inv}f_{hj} = \frac{\sum_{i=1}^{I_{inv}f_h} f_i \bullet 52 \bullet 0.83 \bullet \frac{Fm_i}{12} \bullet Cf_{ij}}{I_{inv}f_h} \bullet \frac{\sum_{k=1}^{R_{inv}f_h} f_k \bullet 52 \bullet 0.83 \bullet \frac{Fm_k}{12}}{\sum_{i=1}^{I_{inv}f_h} f_i \bullet 52 \bullet 0.83 \bullet \frac{Fm_i}{12}}$$

$I_{inv}f_h$ = number of interviews of female invertebrate fishers for habitat_h (total numbers of interviews where female invertebrate fishers provided detailed information for habitat_h)
f_i = frequency of fishing trips (trips/week) as reported in interview_i

Fm_i = number of months fished as reported in interview$_i$
Cf_{ij} = average catch reported for species$_j$ as reported in interview$_i$
$R_{inv}f_h$ = number of targeted habitats reported by female invertebrate fishers for habitat$_h$ (total numbers of interviews where female invertebrate fishers reported targeting habitat$_h$ but did not necessarily provide detailed information)
f_k = frequency of fishing trips (trips/week) as reported for habitat$_k$
Fm_k = number of months fished for reported habitat$_k$

The total annual biomass (t/year) removed is also calculated and presented by species after transferring vernacular names to scientific nomenclature. Size frequency distributions are provided for the most important species, by total annual weight removed, expressed in percentage of each size group of the total annual weight harvested. The size frequency distribution may reveal the impact of fishing pressure for species that are represented by a wide size range (from juvenile to adult state). It may also be a useful parameter to compare the status of a particular species or species group across various sites at the national or even regional level.

To further determine fishing strategies, we also inquire about the purpose of harvesting each species (as recorded by vernacular name). Results are depicted as the proportion (in kg/year) of the total annual biomass (net weight) removed for each purpose: consumption, sale or both. We also provide an index of all species recorded through fisher interviews and their use (in percentage of total annual weight) for any of the three categories.

In order to gain an idea of the productivity of and differences between the fisheries practices used in each site we calculate the average annual catch per fisher, by gender and fishery. This calculation is based on the total biomass (net weight) removed from each fishery and the total number of fishers by gender group.

For invertebrate species that are marketed, detailed information is collected on total numbers (weight and/or combination of number and size), processing level, location of sale or client, frequency of sales and price received per unit sold. At this stage of our project we do not fully analyse this marketing information. However, prices received for major commercial species, as well as an approximation of sale volumes by fishery and fisher, help to assess what role invertebrate fisheries (or a particular fishery) play(s) in terms of income generation for the surveyed community, and in comparison to the possible earnings from finfish fisheries.

We use the calculated total annual impact in combination with the fishing ground area to determine relative fishing pressure. Fishing pressure indicators are calculated as the annual catch per km^2 for each area that is considered to support any of the fisheries present at each study site. In some instances (e.g. intertidal fisheries), areas are replaced by linear km; accordingly, fishing pressure is then related to the length (in km) of the supporting habitat. Due to the lack of baseline data, we compare selected indicators, such as the fisher density (number of fishers per km^2 – or linear km – of fishing ground, for each fishery), productivity (catch per fisher and year) and total annual catch per fishery, across all sites for each country surveyed. This comparison may also be done at the regional level in the future.

The differing nature of invertebrate species that may be caught during one fishing trip, and hence the great variability between edible and non-edible, useful and non-useful parts of species caught, make the determination of CPUE difficult. Substantial differences in the economic value of species add another challenge. We have therefore refrained from calculating CPUE values at this stage of the project.

Data entry and analysis

Data from all questionnaire forms are entered in the Reef Fisheries Integrated Database (RFID) system. All data entered are first verified and 'cleaned' prior to analysis. In the process of data entry, a comprehensive list of vernacular and corresponding scientific names for finfish and invertebrate species is developed.

Database queries have been defined and established that allow automatic retrieval of the descriptive statistics used when summarising results at the site and national levels.

1.1.2 Socioeconomic survey questionnaires

- Household census and consumption survey
- Finfish fishing and marketing survey (for fishers)
- Invertebrate fishing and marketing survey (for fishers)
- Fisheries (finfish and invertebrate and socioeconomics) general information survey

HOUSEHOLD CENSUS AND CONSUMPTION SURVEY

HH NO. ☐

Name of head of household: ________________ Village: _________________

Name of person asked: _____________________ Date: __________________

Surveyor's ID: __________________

1. Who is the head of your household? male ☐ female ☐
   (must be living there; tick box)

2. How old is the head of household? *(enter year of birth)* ☐

3. How many people ALWAYS live in your household? ☐
   (enter number)

4. How many are male and how many are female?
   (*tick box and enter age in years or year of birth)*

male	age	female	age
☐	☐	☐	☐
☐	☐	☐	☐
☐	☐	☐	☐
☐	☐	☐	☐
☐	☐	☐	☐
☐	☐	☐	☐

5. Does this household have any agricultural land?

   yes ☐ no ☐

6. How much (*for this household only*)?

   for permanent/regular cultivation ☐ (unit)

   for permanent/regular livestock ☐ (unit)
   type of animals__________ no. ☐

7. How many fishers live in your household? ☐
(*enter number of people who go fishing/collecting regularly)*

invertebrate fishers		finfish fishers		invertebrate & finfish fishers	
M	F	M	F	M	F
☐	☐	☐	☐	☐	☐

8. Does this household own a boat? yes ☐ no ☐

9a. Canoe	☐	length? ☐	metres/feet		
Sailboat	☐	length? ☐	metres/feet		
Boat with outboard engine	☐	length? ☐	metres/feet	☐	HP
9b. Canoe	☐	length? ☐	metres/feet		
Sailboat	☐	length? ☐	metres/feet		
Boat with outboard engine	☐	length? ☐	metres/feet	☐	HP
9c. Canoe	☐	length? ☐	metres/feet		
Sailboat	☐	length? ☐	metres/feet		
Boat with outboard engine	☐	length? ☐	metres/feet	☐	HP

10. Where does the CASH money in this household come from? (*rank options, 1 = most money, 2 = second important income source, 3 = 3rd important income source, 4 = 4th important income source*)

Fishing/seafood collection ☐

Agriculture (crops & livestock) ☐

Salary ☐

Others (handicrafts, etc.) ☐ specify: ____________________

11. Do you get remittances? yes ☐ no ☐

12. How often?

1 per month	1 per 3 months	1 per 6 months	other *(specify)*
☐	☐	☐	☐

13. How much? *(enter amount)* Every time? (currency) [ ]

14. How much CASH money do you use on average for household expenditures (food, fuel for cooking, school bus, etc.)?

    (currency) [ ] per week/2-weekly/month (or? specify_______)

15. What is the educational level of your household members?

no. of people	having achieved:
[ ]	elementary/primary education
[ ]	secondary education
[ ]	tertiary education (college, university, special schools, etc.)

CONSUMPTION SURVEY

16. During an average/normal week, on how many days do you prepare fish, other seafood and canned fish for your family? *(tick box)*

	7 days	6 days	5 days	4 days	3 days	2 days	1 day	other, specify
Fresh fish	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Other seafood	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Canned fish	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

17. Mainly at	breakfast	lunch	supper
Fresh fish	[ ]	[ ]	[ ]
Other seafood	[ ]	[ ]	[ ]
Canned fish	[ ]	[ ]	[ ]

18. How much do you cook on average per day for your household? *(tick box)*

	number	kg	size: A	B	C	D	E	>E (cm)
Fresh fish	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Other seafood

name:	no.	size	kg	plastic bag ¼	½	¾	1
____________________	☐	☐	☐	☐	☐	☐	☐
____________________	☐	☐	☐	☐	☐	☐	☐
____________________	☐	☐	☐	☐	☐	☐	☐
____________________	☐	☐	☐	☐	☐	☐	☐

19. Canned fish No. of cans: ☐ Size of can: ☐ small
☐ medium
☐ big

20. Where do you normally get your fish and seafood from?

Fish:

☐ caught by myself/member of this household

☐ get it from somebody in the family/village (no money paid)

☐ buy it at ____________________

Which is the most important source? ☐ caught ☐ given ☐ bought

Invertebrates:

☐ caught by myself/member of this household

☐ get it from somebody in the family/village (no money paid)

☐ buy it at ____________________

Which is the most important source? ☐ caught ☐ given ☐ bought

21. Which is the last day you had fish? ____________________

22. Which is the last day you had other seafood? ____________________

–THANK YOU–

FISHING (FINFISH) AND MARKETING SURVEY

Name: ____________________ F ☐ M ☐ **HH NO.** ☐

Name of head of household: _______________________ Village: ______________

Surveyor's name: _____________________ Date: ______________

1. Which areas do you fish?

coastal reef ☐ lagoon ☐ outer reef ☐ mangrove ☐ pelagic ☐

2. Do you go to only one habitat per trip?

Yes ☐ no ☐

3. If no, how many and which habitats do you visit during an average trip?

total no. ☐ habitats: coastal reef ☐ lagoon ☐ mangrove ☐ outer reef ☐

4. How often (days/week) do you fish in each of the habitats visited?

coastal reef	lagoon	mangrove	outer reef	
☐	☐	☐	☐	__________/times per week/month
☐	☐	☐	☐	__________/times per week/month
☐	☐	☐	☐	__________/times per week/month

5. Do you use a boat for fishing?

	Always	sometimes	never
coastal reef	☐	☐	☐
lagoon	☐	☐	☐
mangrove	☐	☐	☐
outer reef	☐	☐	☐

6. If you use a boat, which one?

1 { canoe (paddle) ☐ sailing ☐
motorised ☐ HP outboard ☐ 4-stroke engine ☐ }

coastal reef ☐ lagoon ☐ outer reef ☐

2
- canoe (paddle) ☐ sailing ☐
- motorised ☐ HP outboard ☐ 4-stroke engine ☐

coastal reef ☐ lagoon ☐ outer reef ☐

3
- canoe (paddle) ☐ sailing ☐
- motorised ☐ HP outboard ☐ 4-stroke engine ☐

coastal reef ☐ lagoon ☐ outer reef ☐

7. How many fishers ALWAYS go fishing with you?

Names:____
____
____
____

INFORMATION BY FISHERY **Name of fisher:** ______________ **HH NO.** ☐

coastal reef ☐ lagoon ☐ mangrove ☐ outer reef ☐

1. HOW OFTEN do you normally go out FISHING for this habitat? *(tick box)*

Every Day	5 days/ week	4 days/ week	3 days/ week	2 days/ week	1 day/ week	other, specify:
☐	☐	☐	☐	☐	☐	____________________

2. What time do you spend fishing this habitat per average trip? ____________________
   (if the fisher can't specify, tick a box)

<2 hrs	2–6 hrs	6–12 hrs	>12 hrs
☐	☐	☐	☐

3. WHEN do you go fishing? *(tick box)* day ☐ night ☐ day & night ☐

4. Do you go all year?

   Yes ☐ no ☐

5. If no, which months <u>don't</u> you fish?

Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

6. Which fishing techniques do you use (*in the habitat referred to here*)?

☐ handline

☐ castnet ☐ gillnet

☐ spear (dive) ☐ longline

☐ trolling ☐ spear (handheld) walking ☐ canoe ☐

☐ deep bottom line ☐ poison: which one? ______________

☐ other, specify: ____

7. Do you use more than one technique per trip for this habitat? If yes, which ones usually?

☐ one technique/trip ☐ more than one technique/trip:

____

8. Do you use ice on your fishing trips?

always   sometimes   never

is it homemade?   or bought?

9. What is your average catch (kg) per trip?   Kg <u>OR:</u>

size class:	A	B	C	D	E	>E (cm)
number:						

10. Do you sell fish?   yes   no

11. Do you give fish as a gift (for no money)?   yes   no

12. Do you use your catch for family consumption?   yes   no

13. How much of your usual catch do you keep for family consumption?

kg   <u>OR:</u>

size class	A	B	C	D	E	>E (cm)
no						

and the rest you gift?   yes

how much?   kg   <u>OR:</u>

size class	A	B	C	D	E	>E (cm)
no.						

and/or sell?   yes

how much?   kg   <u>OR</u>:

size class	A	B	C	D	E	>E (cm)
no.						

14. What sizes of fish do you use for your family consumption, what for sale and what do you give away without getting any money?

size classes:	all	A	B	C	D	E	and larger (no. and cm)
consumption							
sale							
give away							

15. You sell where?

☐ inside village ☐ outside village where? ___________________________

and to whom?

market ☐ agents/middlemen ☐ shop owners ☐ others ☐ ___________

16. In an average catch what fish do you catch, and how much of each species? *(write down the species in the table)*

technique usually used:_____________________ boat type usually used:________________
habitat usually fished: ____

Specify the number by size

Name of fish	kg	A	B	C	D	E	>E cm

20. Do you also fish invertebrates?

Yes ☐ no ☐ if yes for consumption? ☐ sale? ☐

–THANK YOU–

INVERTEBRATE FISHING AND MARKETING SURVEY
FISHERS

HH NO. ☐

Name: ______________________________________

Gender: ☐ female ☐ male Age: ☐

Village: ______________________________________

Date: ________________ Surveyor's name: ___________________

Invertebrates = everything that is not a fish with fins!

1. Which type of fisheries do you do?

☐ seagrass gleaning ☐ mangrove & mud gleaning

☐ sand & beach gleaning ☐ reeftop gleaning

☐ bêche-de mer diving ☐ mother-of-pearl diving trochus, pearl shell, etc.

☐ lobster diving ☐ other, such as clams, octopus

2. *(if more than one fishery in question 1):* Do you usually go fishing at only one of the fisheries or do you visit several during one fishing trip?

☐ one only ☐ several

If several fisheries at a time, which ones do you combine?

----

3. How often do you go gleaning/diving (*tick as from questions 1 and 2 above and watch for combinations*) and for how long, and do you also finfish at the same time?

	times/week		duration in hours				glean/dive at			fish no. of months/year
	(if the fisher can't specify, tick the box)									
			<2	2–4	4–6	>6	D	N	D&N	
☐ seagrass gleaning	☐	____	☐	☐	☐	☐	☐	☐	☐	________
☐ mangrove & mud gleaning	☐	____	☐	☐	☐	☐	☐	☐	☐	________
☐ sand & beach gleaning	☐	____	☐	☐	☐	☐	☐	☐	☐	________
☐ reeftop gleaning	☐	____	☐	☐	☐	☐	☐	☐	☐	________
☐ bêche-de-mer diving	☐	____	☐	☐	☐	☐	☐	☐	☐	________
☐ lobster diving	☐	____	☐	☐	☐	☐	☐	☐	☐	________
☐ mother-of-pearl diving trochus, pearl shell, etc.	☐	____	☐	☐	☐	☐	☐	☐	☐	________
☐ other diving (clams, octopus)	☐	____	☐	☐	☐	☐	☐	☐	☐	________

D = day, N = night, D&N = day and night (no preference but fish with tide)

4. Do you sometimes go gleaning/fishing for invertebrates outside your village fishing grounds?

   yes ☐ no ☐

   If yes, where? ____

5. Do you finfish? yes ☐ no ☐

   for: ☐ consumption? ☐ sale?

   at the same time? yes ☐ no ☐

INVERTEBRATE FISHING AND MARKETING SURVEY – FISHERS

GLEANING: seagrass ☐ mangrove & mud ☐ sand & beach ☐ reeftop ☐

DIVING: bêche-de-mer ☐ lobster ☐ mother-of-pearl, trochus, pearl shell, etc. ☐ other (clams, octopus) ☐

SHEET 1: EACH FISHERY PER FISHER INTERVIEWED: ☐ **HH NO. __Name of fisher: ______________** **gender: F** ☐ **M** ☐

What transport do you mainly use? ☐ walk ☐ canoe (no engine) ☐ motorised boat (HP) ☐ sailboat

How many fishers are usually on a trip? (total no.) ☐ walk ☐ canoe (no engine) ☐ motorised boat (HP) ☐ sailboat

Species vernacular/common name and scientific code if possible	**Average quantity/trip**							**Used for** (specify how much from average for each category (cons., given or sold), and the main size for sale and cons. or given) gift = giving away for no money		
	total number/ trip	weight/trip total kg	plastic bag unit 1	3/4	1/2	1/4	average size cm	cons.	gift	sale

Appendix 1: Survey methods
Socioeconomics

Species vernacular/common name and scientific code if possible	**Average quantity/trip**							**Used for** (specify how much from average for each category (cons., given or sold), and the main size for sale and cons. or given) gift = giving away for no money		
	total number/ trip	weight/trip					average size cm	cons.	gift	sale
		total kg	plastic bag unit							
			1	3/4	1/2	1/4				

INVERTEBRATE FISHING AND MARKETING SURVEY – FISHERS

GLEANING: seagrass ☐ mangrove & mud ☐ sand & beach ☐ reeftop ☐

DIVING: bêche-de-mer ☐ lobster ☐ mother-of-pearl, trochus, pearl shell, etc. ☐ other (clams, octopus) ☐

SHEET 2: SPECIES SOLD PER FISHER INTERVIEWED: **HH NO**. ☐ **Name of fisher:** ______________________

Copy all species that have been named for 'SALE' in previous sheet

Who markets your products? ☐ you ☐ your wife ☐ your husband ☐ a group of fishers ☐ other _________________

Species for sale – copy from sheet 2 (for each fishery per fisher) above	Processing level of product sold (see list)	Where do you sell? (see list)	How often? Days/week?	How much each time? Quantity/unit	Price

**FISHERIES (FINFISH AND INVERTEBRATE AND SOCIOECONOMICS)
GENERAL INFORMATION SURVEY**

Target group: key people, groups of fishers, fisheries officers, etc.

1. Are there management rules that apply to your fisheries? Do they specifically target finfish or invertebrates, or do they target both sectors?

a) legal/Ministry of Fisheries

b) traditional/community/village determined:

2. What do you think – do people obey:

traditional/village management rules?

mostly ☐ sometimes ☐ hardly ☐

legal/Ministry of Fisheries management rules?

mostly ☐ sometimes ☐ hardly ☐

3. Are there any particular rules that you know people do not respect or follow at all? And do you know why?

4. What are the main techniques used by the community for:

a) finfishing

gillnets – most-used mesh sizes:

What is usually used for bait? And is it bought or caught?

b) invertebrate fishing → ***see end!***

5. Please give a quick inventory and characteristics of boats used in the community (length, material, motors, etc.).

Seasonality of species

What are the **FINFISH** species that you do not catch during the total year? Can you specify the particular months that they are **NOT** fished?

Vernacular name	Scientific name(s)	Months NOT fished

Seasonality of species

What are the **INVERTEBRATE** species that you do not catch during the total year? Can you specify the particular months that they are **NOT** fished?

Vernacular name	Scientific name(s)	Months NOT fished

Appendix 1: Survey methods
Socioeconomics

How many people carry out the invertebrate fisheries below, from inside and from outside the community?

GLEANING	no. from this village	no.	from village	no.	from village
☐ seagrass gleaning	☐	☐	____	☐	____
☐ mangrove & mud gleaning	☐	☐	____	☐	____
☐ sand & beach gleaning	☐	☐	____	☐	____
☐ reeftop gleaning	☐	☐	____	☐	____
DIVING					
☐ bêche-de-mer diving	☐	☐	____	☐	____
☐ lobster diving	☐	☐	____	☐	____
☐ mother-of-pearl diving trochus, pearl shell, etc.	☐	☐	____	☐	____
☐ other (clams, octopus)	☐	☐	____	☐	____

What gear do invertebrate fishers use? *(tick box of technique per fishery)*

GLEANING (soft bottom = seagrass)

☐ spoon	☐ wooden stick	☐ knife	☐ iron rod	☐ spade
☐ hand net	☐ net	☐ trap	☐ goggles	☐ dive mask
☐ snorkel	☐ fins	☐ weight belt		
☐ air tanks	☐ hookah	☐ other __________		

GLEANING (soft bottom = mangrove & mud)

☐ spoon	☐ wooden stick	☐ knife	☐ iron rod	☐ spade
☐ hand net	☐ net	☐ trap	☐ goggles	☐ dive mask
☐ snorkel	☐ fins	☐ weight belt		
☐ air tanks	☐ hookah	☐ other __________		

GLEANING (soft bottom = sand & beach)

☐ spoon	☐ wooden stick	☐ knife	☐ iron rod	☐ spade
☐ hand net	☐ net	☐ trap	☐ goggles	☐ dive mask
☐ snorkel	☐ fins	☐ weight belt		
☐ air tanks	☐ hookah	☐ other __________		

GLEANING (hard bottom = reeftop)

☐ spoon	☐ wooden stick	☐ knife	☐ iron rod	☐ spade
☐ hand net	☐ net	☐ trap	☐ goggles	☐ dive mask
☐ snorkel	☐ fins	☐ weight belt		
☐ air tanks	☐ hookah	☐ other __________		

DIVING (bêche-de-mer)

☐ spoon	☐ wooden stick	☐ knife	☐ iron rod	☐ spade
☐ hand net	☐ net	☐ trap	☐ goggles	☐ dive mask
☐ snorkel	☐ fins	☐ weight belt		
☐ air tanks	☐ hookah	☐ other __________		

DIVING (lobster)

☐ spoon	☐ wooden stick	☐ knife	☐ iron rod	☐ spade
☐ hand net	☐ net	☐ trap	☐ goggles	☐ dive mask
☐ snorkel	☐ fins	☐ weight belt		
☐ air tanks	☐ hookah	☐ other __________		

DIVING (mother-of-pearl, trochus, pearl shell, etc.)

☐ spoon ☐ wooden stick ☐ knife ☐ iron rod ☐ spade

☐ hand net ☐ net ☐ trap ☐ goggles ☐ dive mask

☐ snorkel ☐ fins ☐ weight belt

☐ air tanks ☐ hookah ☐ other ___________

DIVING (other, such as clams, octopus)

☐ spoon ☐ wooden stick ☐ knife ☐ iron rod ☐ spade

☐ hand net ☐ net ☐ trap ☐ goggles ☐ dive mask

☐ snorkel ☐ fins ☐ weight belt

☐ air tanks ☐ hookah ☐ other ___________

Any traditional/customary/village fisheries?

Name:

Season/occasion:

Frequency:

Quantification of marine resources caught:

Species name	Size	Quantity (unit?)

1.1.3 Average wet weight applied for selected invertebrate species groups

Unit weights used in conversions for invertebrates.

Scientific names	g/piece	% edible part	% non-edible part	Edible part (g/piece)	Group
Acanthopleura gemmata	29	35	65	10.15	Chiton
Actinopyga lecanora	300	10	90	30	BdM [(1)]
Actinopyga mauritiana	350	10	90	35	BdM [(1)]
Actinopyga miliaris	300	10	90	30	BdM [(1)]
Anadara sp.	21	35	65	7.35	Bivalves
Asaphis violascens	15	35	65	5.25	Bivalves
Astralium sp.	20	25	75	5	Gastropods
Atactodea striata, *Donax cuneatus,* *Donax cuneatus*	2.75	35	65	0.96	Bivalves
Atrina vexillum, *Pinctada margaritifera*	225	35	65	78.75	Bivalves
Birgus latro	1000	35	65	350	Crustacean
Bohadschia argus	462.5	10	90	46.25	BdM [(1)]
Bohadschia sp.	462.5	10	90	46.25	BdM [(1)]
Bohadschia vitiensis	462.5	10	90	46.25	BdM [(1)]
Cardisoma carnifex	227.8	35	65	79.74	Crustacean
Carpilius maculatus	350	35	65	122.5	Crustacean
Cassis cornuta, *Thais aculeata,* *Thais aculeata*	20	25	75	5	Gastropods
Cerithium nodulosum, *Cerithium nodulosum*	240	25	75	60	Gastropods
Chama sp.	25	35	65	8.75	Bivalves
Codakia punctata	20	35	65	7	Bivalves
Coenobita sp.	50	35	65	17.5	Crustacean
Conus miles, *Strombus gibberulus gibbosus*	240	25	75	60	Gastropods
Conus sp.	240	25	75	60	Gastropods
Cypraea annulus, *Cypraea moneta*	10	25	75	2.5	Gastropods
Cypraea caputserpensis	15	25	75	3.75	Gastropods
Cypraea mauritiana	20	25	75	5	Gastropods
Cypraea sp.	95	25	75	23.75	Gastropods
Cypraea tigris	95	25	75	23.75	Gastropods
Dardanus sp.	10	35	65	3.5	Crustacean
Dendropoma maximum	15	25	75	3.75	Gastropods
Diadema sp.	50	48	52	24	Echinoderm
Dolabella auricularia	35	50	50	17.5	Others
Donax cuneatus	15	35	65	5.25	Bivalves
Drupa sp.	20	25	75	5	Gastropods
Echinometra mathaei	50	48	52	24	Echinoderm
Echinothrix sp.	100	48	52	48	Echinoderm
Eriphia sebana	35	35	65	12.25	Crustacean
Gafrarium pectinatum	21	35	65	7.35	Bivalves
Gafrarium tumidum	21	35	65	7.35	Bivalves
Grapsus albolineatus	35	35	65	12.25	Crustacean
Hippopus hippopus	500	19	81	95	Giant clams
Holothuria atra	100	10	90	10	BdM [(1)]
Holothuria coluber	100	10	90	10	BdM [(1)]

1.1.3 Average wet weight applied for selected invertebrate species groups (continued)

Unit weights used in conversions for invertebrates.

Scientific names	g/piece	% edible part	% non-edible part	Edible part (g/piece)	Group
Holothuria fuscogilva	2000	10	90	200	BdM (1)
Holothuria fuscopunctata	1800	10	90	180	BdM (1)
Holothuria nobilis	2000	10	90	200	BdM (1)
Holothuria scabra	2000	10	90	200	BdM (1)
Holothuria sp.	2000	10	90	200	BdM (1)
Lambis lambis	25	25	75	6.25	Gastropods
Lambis sp.	25	25	75	6.25	Gastropods
Lambis truncata	500	25	75	125	Gastropods
Mammilla melanostoma, *Polinices mammilla*	10	25	75	2.5	Gastropods
Modiolus auriculatus	21	35	65	7.35	Bivalves
Nerita albicilla, *Nerita polita*	5	25	75	1.25	Gastropods
Nerita plicata	5	25	75	1.25	Gastropods
Nerita polita	5	25	75	1.25	Gastropods
Octopus sp.	550	90	10	495	Octopus
Panulirus ornatus	1000	35	65	350	Crustacean
Panulirus penicillatus	1000	35	65	350	Crustacean
Panulirus sp.	1000	35	65	350	Crustacean
Panulirus versicolor	1000	35	65	350	Crustacean
Parribacus antarcticus	750	35	65	262.5	Crustacean
Parribacus caledonicus	750	35	65	262.5	Crustacean
Patella flexuosa	15	35	65	5.25	Limpet
Periglypta puerpera, *Periglypta reticulate*	15	35	65	5.25	Bivalves
Periglypta sp., *Periglypta* sp., *Spondylus* sp., *Spondylus* sp.,	15	35	65	5.25	Bivalves
Pinctada margaritifera	200	35	65	70	Bivalves
Pitar proha	15	35	65	5.25	Bivalves
Planaxis sulcatus	15	25	75	3.75	Gastropods
Pleuroploca filamentosa	150	25	75	37.5	Gastropods
Pleuroploca trapezium	150	25	75	37.5	Gastropods
Portunus pelagicus	227.83	35	65	79.74	Crustacean
Saccostrea cuccullata	35	35	65	12.25	Bivalves
Saccostrea sp.	35	35	65	12.25	Bivalves
Scylla serrata	700	35	65	245	Crustacean
Serpulorbis sp.	5	25	75	1.25	Gastropods
Sipunculus indicus	50	10	90	5	Seaworm
Spondylus squamosus	40	35	65	14	Bivalves
Stichopus chloronotus	100	10	90	10	BdM (1)
Stichopus sp.	543	10	90	54.3	BdM (1)
Strombus gibberulus gibbosus	25	25	75	6.25	Gastropods
Strombus luhuanus	25	25	75	6.25	Gastropods
Tapes literatus	20	35	65	7	Bivalves
Tectus pyramis, *Trochus niloticus*	300	25	75	75	Gastropods
Tellina palatum	21	35	65	7.35	Bivalves
Tellina sp.	20	35	65	7	Bivalves

1.1.3 Average wet weight applied for selected invertebrate species groups (continued)

Unit weights used in conversions for invertebrates.

Scientific names	g/piece	% edible part	% non-edible part	Edible part (g/piece)	Group
Terebra sp.	37.5	25	75	9.39	Gastropods
Thais armigera	20	25	75	5	Gastropods
Thais sp.	20	25	75	5	Gastropods
Thelenota ananas	2500	10	90	250	BdM (1)
Thelenota anax	2000	10	90	200	BdM (1)
Tridacna maxima	500	19	81	95	Giant clams
Tridacna sp.	500	19	81	95	Giant clams
Trochus niloticus	200	25	75	50	Gastropods
Turbo crassus	80	25	75	20	Gastropods
Turbo marmoratus	20	25	75	5	Gastropods
Turbo setosus	20	25	75	5	Gastropods
Turbo sp.	20	25	75	5	Gastropods

BdM = Bêche-de-mer; (1) edible part of dried Bêche-de-mer, i.e. drying process consumes about 90% of total wet weight; hence 10% are considered as the edible part only.

1.2 Methods used to assess the status of finfish resources

Fish counts

In order to count and size fish in selected sites, we use the **distance-sampling underwater visual census (D-UVC)** method (Kulbicki and Sarramegna 1999, Kulbicki *et al.* 2000), fully described in Labrosse *et al.* (2002). Briefly, the method consists of recording the species name, abundance, body length and the distance to the transect line for each fish or group of fish observed; the transect consists of a 50 m line, represented on the seafloor by an underwater tape (Figure A1.2.1). For security reasons, two divers are required to conduct a survey, each diver counting fish on a different side of the transect. Mathematical models are then used to estimate fish density (number of fish per unit area) and biomass (weight of fish per unit area) from the counts.

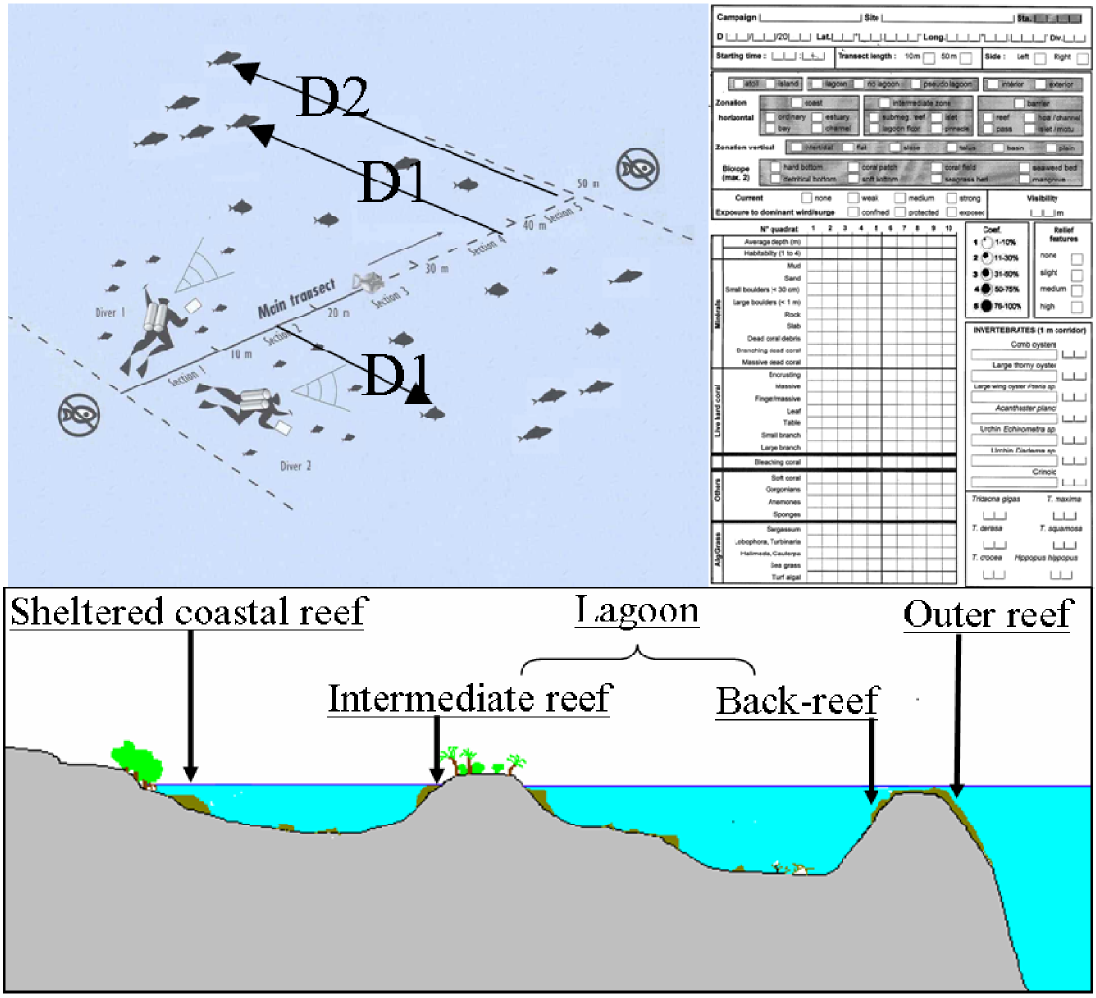

Figure A1.2.1: Assessment of finfish resources and associated environments using distance-sampling underwater visual censuses (D-UVC).
Each diver records the number of fish, fish size, distance of fish to the transect line, and habitat quality, using pre-printed underwater paper. At each site, surveys are conducted along 24 transects, with six transects in each of the four main geomorphologic coral reef structures: sheltered coastal reefs, intermediate reefs and back-reefs (lumped into the 'lagoon reef' category of socioeconomic assessment), and outer reefs. D1 is the distance of an observed fish from the transect line. If a school of fish is observed, D1 is the distance from the transect line to the closest fish; D2 the distance to the furthest fish.

Species selection

Only reef fish of interest for consumption or sale and species that could potentially serve as indicators of coral reef health are surveyed (see Table A1.2.1; Appendix 3.2 provides a full list of counted species and abundance for each site surveyed).

Table A1.2.1: List of finfish species surveyed by distance sampling underwater visual census (D-UVC)
Most frequently observed families on which reports are based are highlighted in yellow.

Family	Selected species
Acanthuridae	All species
Aulostomidae	*Aulostomus chinensis*
Balistidae	All species
Belonidae	All species
Caesionidae	All species
Carangidae	All species
Carcharhinidae	All species
Chaetodontidae	All species
Chanidae	All species
Dasyatidae	All species
Diodontidae	All species
Echeneidae	All species
Ephippidae	All species
Fistulariidae	All species
Gerreidae	*Gerres* spp.
Haemulidae	All species
Holocentridae	All species
Kyphosidae	All species
Labridae	*Bodianus axillaris, Bodianus loxozonus, Bodianus perditio, Bodianus* spp., *Cheilinus:* all species, *Choerodon:* all species, *Coris aygula, Coris gaimard, Epibulus insidiator, Hemigymnus:* all species, *Oxycheilinus diagrammus, Oxycheilinus* spp.
Lethrinidae	All species
Lutjanidae	All species
Monacanthidae	*Aluterus scriptus*
Mugilidae	All species
Mullidae	All species
Muraenidae	All species
Myliobatidae	All species
Nemipteridae	All species
Pomacanthidae	*Pomacanthus semicirculatus, Pygoplites diacanthus*
Priacanthidae	All species
Scaridae	All species
Scombridae	All species
Serranidae	Epinephelinae: all species
Siganidae	All species
Sphyraenidae	All species
Tetraodontidae	*Arothron*: all species
Zanclidae	All species

Analysis of percentage occurrence in surveys at both regional and national levels indicates that of the initial 36 surveyed families, only 15 families are frequently seen in country counts.

Appendix 1: Survey methods
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Since low percentage occurrence could either be due to rarity (which is of interest) or low detectability (representing a methodological bias), we decided to restrict our analysis to the 15 most frequently observed families, for which we can guarantee that D-UVC is an efficient resource assessment method.

These are:

- Acanthuridae (surgeonfish)
- Balistidae (triggerfish)
- Chaetodontidae (butterflyfish)
- Holocentridae (squirrelfish)
- Kyphosidae (drummer and seachubs)
- Labridae (wrasse)
- Lethrinidae (sea bream and emperor)
- Lutjanidae (snapper and seaperch)
- Mullidae (goatfish)
- Nemipteridae (coral bream and butterfish)
- Pomacanthidae (angelfish)
- Scaridae (parrotfish)
- Serranidae (grouper, rockcod, seabass)
- Siganidae (rabbitfish)
- Zanclidae (moorish idol).

Substrate

We used the **medium-scale approach** (MSA) to record substrate characteristics along transects where finfish were counted by D-UVC. MSA has been developed by Clua *et al.* (2006) to specifically complement D-UVC surveys. Briefly, the method consists of recording depth, habitat complexity, and 23 substrate parameters within ten 5 m x 5 m quadrats located on each side of a 50 m transect, for a total of 20 quadrats per transect (Figure A1.2.1). The transect's habitat characteristics are then calculated by averaging substrate records over the 20 quadrats.

Parameters of interest

In this report, the status of finfish resources has been characterised using the following seven parameters:

- **biodiversity –** the number of families, genera and species counted in D-UVC transects;
- **density** (fish/m^2) – estimated from fish abundance in D-UVC;
- **size** (cm fork length) – direct record of fish size by D-UVC;
- **size ratio** (%) – the ratio between fish size and maximum reported size of the species. This ratio can range from nearly zero when fish are very small to nearly 100 when a given fish has reached the greatest size reported for the species. Maximum reported size (and source of reference) for each species are stored in our database;
- **biomass** (g/m^2) – obtained by combining densities, size, and weight–size ratios (Weight–size ratio coefficients are stored in our database and were provided by Mr Michel Kulbicki, IRD Noumea, Coreus research unit);
- **community structure –** density, size and biomass compared among families; and

- **trophic structure –** density, size and biomass compared among trophic groups. Trophic groups are stored in our database and were provided by Mr Michel Kulbicki, IRD Noumea, Coreus research unit. Each species was classified into one of five broad trophic groups: 1) carnivore (feed predominantly on zoobenthos), 2) detritivore (feed predominantly on detritus), 3) herbivore (feed predominantly on plants), 4) piscivore (feed predominantly on nekton, other fish and cephalopods) and 5) plankton feeder (feed predominantly on zooplankton). More details on fish diet can be found online at: http://www.fishbase.org/manual/english/FishbaseThe_FOOD_ITEMS_Table.htm.

The relationship between environment quality and resource status has not been fully explored at this stage of the project, as this task requires complex statistical analyses on the regional dataset. Rather, the living resources assessed at all sites in each country are placed in an environmental context via the description of several crucial habitat parameters. These are obtained by grouping the original 23 substrate parameters recorded by divers into the following six parameters:

- **depth** (m)
- **soft bottom** (% cover) – sum of substrate components:
  (1) mud (sediment particles <0.1 mm), and
  (2) sand and gravel (0.1 mm <hard particles <30 mm)
- **rubble and boulders** (% cover) – sum of substrate components:
  (3) dead coral debris (carbonated structures of heterogeneous size, broken and removed from their original locations),
  (4) small boulders (diameter <30 cm), and
  (5) large boulders (diameter <1 m)
- **hard bottom** (% cover) – sum of substrate components:
  (6) slab and pavement (flat hard substratum with no relief), rock (massive minerals) and eroded dead coral (carbonated edifices that have lost their coral colony shape),
  (7) dead coral (dead carbonated edifices that are still in place and retain a general coral shape), and
  (8) bleaching coral
- **live coral** (% cover) – sum of substrate components:
  (9) encrusting live coral,
  (10) massive and sub-massive live corals,
  (11) digitate live coral,
  (12) branching live coral,
  (13) foliose live coral,
  (14) tabulate live coral, and
  (15) *Millepora* spp.
- **soft coral** (% cover) – substrate component:
  (16) soft coral.

Sampling design

Coral reef ecosystems are complex and diverse. The NASA Millennium Coral Reef Mapping Project (MCRMP) has identified and classified coral reefs of the world in about 1000 categories. These very detailed categories can be used directly to try to explain the status of living resources or be lumped into more general categories to fit a study's particular needs. For the needs of the finfish resource assessment, MCRMP reef types were grouped into the four main coralline geomorphologic structures found in the Pacific (Figure A1.2.2):

- **sheltered coastal reef**: reef that fringes the land but is located inside a lagoon or a pseudo-lagoon
- **lagoon reef**:
  - **intermediate reef** – patch reef that is located inside a lagoon or a pseudo-lagoon, and
  - **back-reef** – inner/lagoon side of outer reef
- **outer reef**: ocean side of fringing or barrier reefs.

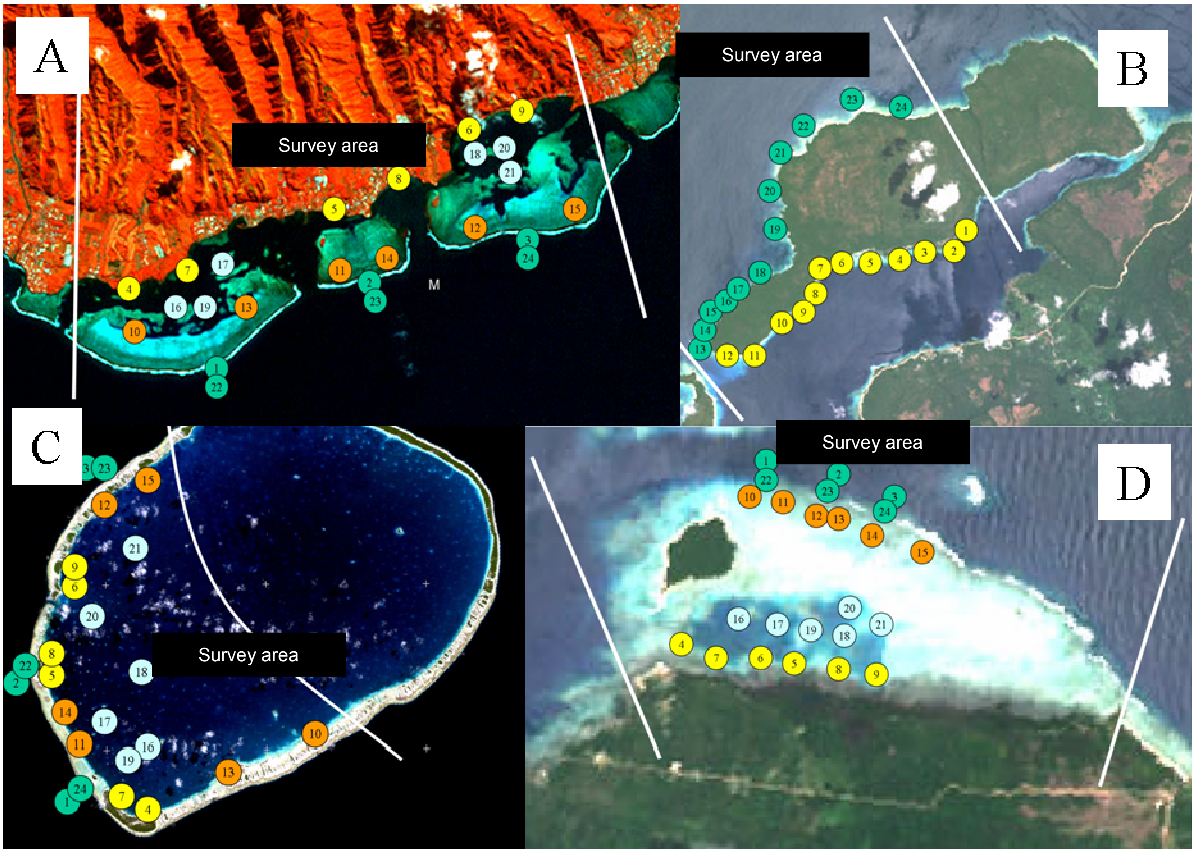

Figure A1.2.2: Position of the 24 D-UVC transects surveyed in A) an island with a lagoon, B) an island with a pseudo-lagoon C) an atoll and D) an island with an extensive reef enclosing a small lagoon pool.
Sheltered coastal reef transects are in yellow, lagoon intermediate-reef transects in blue, lagoon back-reef transects in orange and outer-reef transects in green. Transect locations are determined using satellite imagery prior to going into the field, which greatly enhances fieldwork efficiency. The white lines delimit the borders of the survey area.

Fish and associated habitat parameters are recorded along 24 transects per site, with a balanced design among the main geomorphologic structures present at a given site (Figure A1.2.2). For example, our design results in at least six transects in each of the sheltered coastal, lagoon intermediate, lagoon back-reef, and outer reefs of islands with lagoons (Figure A1.2.2A) or 12 transects in each of the sheltered coastal and outer reefs of islands with pseudo-lagoons (Figure A1.2.2B). This balanced, stratified and yet flexible sampling design was chosen to optimise the quality of the assessment, given the logistical and time constraints that stem from the number and diversity of sites that have to be covered over the life of the project. The exact position of transects is determined in advance using satellite imagery, to assist in locating the exact positions in the field; this maximises accuracy and allows replication for monitoring purposes (Figure A1.2.2).

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Scaling

Maps from the Millennium Project allow the calculation of reef areas in each studied site, and those areas can be used to scale (using weighted averages) the resource assessment at any spatial level. For example, the average biomass (or density) of finfish at site (i.e. village) level would be calculated by relating the biomass (or density) recorded in each of the habitats sampled at the site ('the data') to the proportion of surface of each type of reef over the total reef present in the site ('the weights'), by using a weighted average formula. The result is a village-level figure for finfish biomass that is representative of both the intrinsic characteristics of the resource and its spatial distribution. Technically, the weight given to the average biomass (or density) of each habitat corresponds to the ratio between the total area of that reef habitat (e.g. the area of sheltered coastal reef) and the total area of reef present (e.g. the area of sheltered coastal reef + the area of intermediate reef, etc.). Thus the calculated weighted biomass value for the site would be:

$$B_{Vk} = \sum j_l \, [B_{Hj} \bullet S_{Hj}] \, / \sum_j S_{Hj}$$

Where:

B_{Vk} = computed biomass or fish stock for village k
B_{Hj} = average biomass in habitat H_j
S_{Hj} = surface of that habitat H_j

A comparative approach only

Density and biomass estimated by D-UVC for each species recorded in the country are given in Appendix 3.2. However, it should be stressed that, since estimates of fish density and biomass (and other parameters) are largely dependent upon the assessment method used (this is true for any assessment), the resource assessment provided in this report can only be used for management in a comparative manner. Densities, biomass and other figures given in this report provide only estimates of the available resource; it would be a great mistake (possibly leading to mismanagement) to consider these as true indicators of the actual available resource.

Campaign |__________| Site |______________| Diver |__|__| Transect |__|__|__|

D |__|__|/|__|__|/20|__|__| Lat.|__|__|°|__|__|,|__|__|__|' Long.|__|__|__|°|__|__|,|__|__|__|' WT |__|__|__|

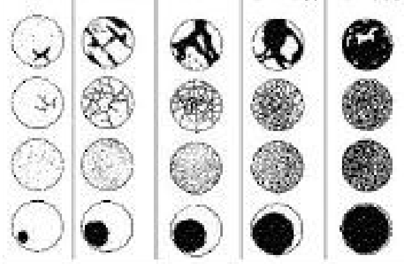
Starting time : |__|__| :|__|__|	Visibility |__|__| m	Side : Left ☐ Right ☐

☐ coast		☐ intermediate zone		☐ barrier	
☐ linear	☐ cape	☐ submerg. reef	☐ pinnacle	☐ outer slope	☐ pass
☐ bay mouth	☐ back of bay	☐ near surf. reef	☐ islet lagoon	☐ reef crest	☐ hoa/channel
☐ estuary	☐ channel	☐ lagoon floor	☐ islet fringing reef	☐ back reef	☐ motu

☐ intertidal ☐ flat ☐ gentle slope ☐ steep slope ☐ talus ☐ basin ☐ lagoon plain

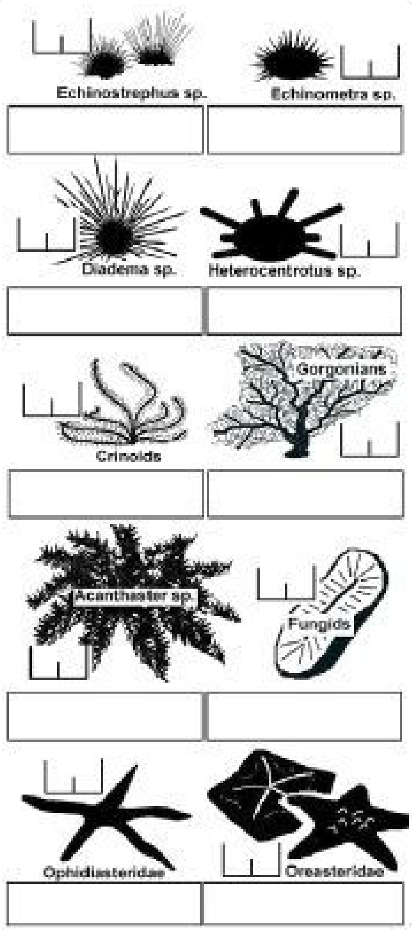
☐ hard bottom	☐ large coral patches	☐ small coral patches	☐ coral field	☐ seaweed bed
☐ detritical bottom	☐ soft bottom		☐ seagrass bed	☐ mangrove

	current	relief features	exposure to dominant wind	oceanic influence	terrigenous influence
none	☐	☐	☐	☐	☐
medium	☐	☐	☐	☐	☐
strong	☐	☐	☐	☐	☐



Quadrat limits 0 5 10 15 20 25 30 35 40 45 50

	Average depth (m)										
	Habitability (1 to 4)										
General coverage	Mud										
General coverage	Sand										
General coverage	Dead coral debris										
General coverage	Small boulders (< 30 cm)										
General coverage	Large boulders (< 1 m)										
General coverage	Eroded dead coral, rock										
General coverage	Old dead coral in place										
General coverage	Bleaching coral										
General coverage	(1) Live corals										
General coverage	(2) Soft invertebrates										
(1) Live corals	Encrusting										
(1) Live corals	Massive										
(1) Live corals	Digitate										
(1) Live corals	Branch										
(1) Live corals	Foliose										
(1) Live corals	Tabulate										
(1) Live corals	*Millepora sp.*										
(2)	Soft corals										
(2)	Sponges										
Grass/alg	Cyanophyceae										
Grass/alg	Sea grass										
Grass/alg	Encrusting algae										
Grass/alg	Small macro-algae										
Grass/alg	Large macro-algae										
Grass/alg	Drifting algae										
	Micro-algae, Turf										
	Others :										



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Finfish

Campaign |__________________| Site |____________________________| Diver |__|__| Transect |__|__|__|

D |__|__|/|__|__|/20|__|__| Lat.|__|__|°|__|__|,|__|__|__|’ Long.|__|__|__|°|__|__|,|__|__|__|’ Left ☐ Right ☐

ST	SCIENTIFIC NAME	NBER	LGT	D1	D2	COMMENTS

1.3 Invertebrate resource survey methods

1.3.1 Methods used to assess the status of invertebrate resources

Introduction

Coastal communities in the Pacific access a range of invertebrate resources. Within the PROCFish/C study, a range of survey methods were used to provide information on key invertebrate species commonly targeted. These provide information on the status of resources at scales relevant to species (or species groups) and the fishing grounds being studied that can be compared across sites, countries and the region, in order to assess relative status.

Species data resulting from the resource survey are combined with results from the socioeconomic survey of fishing activity to describe invertebrate fishing activity within specific 'fisheries'. Whereas descriptions of commercially orientated fisheries are generally recognisable in the literature (e.g. the sea cucumber fishery), results from non-commercial stocks and subsistence-orientated fishing activities (e.g. general reef gleaning) will also be presented as part of the results, so as to give managers a general picture of invertebrate fishery status at study sites.

Field methods

We examined invertebrate stocks (and fisheries) for approximately seven days at each site, with at least two research officers (SPC Invertebrate Biologist and Fisheries Officer) plus officers from the local fisheries department. The work completed at each site was determined by the availability of local habitats and access to fishing activity.

Two types of survey were conducted: fishery-dependent surveys and fishery independent surveys.

- Fishery-dependent surveys rely on information from those engaged in the fishery, e.g. catch data;
- Fishery-independent surveys are conducted by the researchers independently of the activity of the fisheries sector.

Fishery-dependent surveys were completed whenever the opportunity arose. This involved accompanying fishers to target areas for the collection of invertebrate resources (e.g. reef-benthos, soft-benthos, trochus habitat). The location of the fishing activity was marked (using a GPS) and the catch composition and catch per unit effort (CPUE) recorded (kg/hour).

This record was useful in helping to determine the species complement targeted by fishers, particularly in less well-defined 'gleaning' fisheries. A CPUE record, with related information on individual animal sizes and weights, provided an additional dataset to expand records from reported catches (as recorded by the socioeconomic survey). In addition, size and weight measures collected through fishery-dependent surveys were compared with records from fishery-independent surveys, in order to assess which sizes fishers were targeting.

For a number of reasons, not all fisheries lend themselves to independent snapshot assessments: density measures may be difficult to obtain (e.g. crab fisheries in mangrove systems) or searches may be greatly influenced by conditions (e.g. weather, tide and lunar conditions influence lobster fishing). In the case of crab or shoreline fisheries, searches are very subjective and weather and tidal conditions affect the outcome. In such cases, observed and reported catch records were used to determine the status of species and fisheries.

A further reason for accompanying groups of fishers was to gain a first-hand insight into local fishing activities and facilitate the informal exchange of ideas and information. By talking to fishers in the fishing grounds, information useful for guiding independent resource assessment was generally more forthcoming than when trying to gather information using maps and aerial photographs while in the village. Fishery-independent surveys were not conducted randomly over a defined site 'study' area. Therefore assistance from knowledgeable fishers in locating areas where fishing was common was helpful in selecting areas for fishery-independent surveys.

A series of fishery-independent surveys (direct, in-water resource assessments) were conducted to determine the status of targeted invertebrate stocks. These surveys needed to be wide ranging within sites to overcome the fact that distribution patterns of target invertebrate species can be strongly influenced by habitat, and well replicated as invertebrates are often highly aggregated (even within a single habitat type).

PROCFish/C assessments do not aim to determine the size of invertebrate populations at study sites. Instead, these assessments aim to determine the status of invertebrates within the main fishing grounds or areas of naturally higher abundance. The implications of this approach are important, as the haphazard measures taken in main fishing grounds are indicative of stock health in these locations only and should not be extrapolated across all habitats within a study site to gain population estimates.

This approach was adopted due to the limited time allocated for surveys and the study's goal of 'assessing the status of invertebrate resources' (as opposed to estimating the standing stock). Making judgements on the status of stocks from such data relies on the assumption that the state of these estimates of 'unit stock'[2] reflects the health of the fishery. For example, an overexploited trochus fishery would be unlikely to have high-density 'patches' of trochus, just as a depleted shallow-reef gleaning fishery would not hold high densities of large clams. Conversely, a fishery under no stress would be unlikely to be depleted or show skewed size ratios that reflected losses of the adult component of the stock.

In addition to examining the density of species, information on spatial distribution and size/weight was collected, to add confidence to the study's inferences.

The basic assumption that looking at a unit stock will give a reliable picture of the status of that stock is not without weaknesses. Resource stocks may appear healthy within a much-restricted range following stress from fishing or environmental disturbance (e.g. a cyclone), and historical information on stock status is not usually available for such remote locations. The lack of historical datasets also precludes speculation on 'missing' species, which may be 'fished-out' or still remain in remnant populations at isolated locations within study sites.

[2] As used here, 'unit stock' refers to the biomass and cohorts of adults of a species in a given area that is subject to a well-defined fishery, and is believed to be distinct and have limited interchange of adults from biomasses or cohorts of the same species in adjacent areas (Gulland 1983).

As mentioned, specific independent assessments were not conducted for mud crab and shore crabs (mangrove fishery), lobster or shoreline stocks (e.g. nerites, surf clams and crabs), as limited access or the variability of snapshot assessments would have limited relevance for comparative assessments.

Generic terminology used for surveys: site, station and replicates

Various methods were used to conduct fishery-independent assessments. At each site, surveys were generally made within specific areas (termed 'stations'). At least six replicate measures were made at each station (termed 'transects', 'searches' or 'quadrats', depending on the resource and method) (Figure A1.3.1).

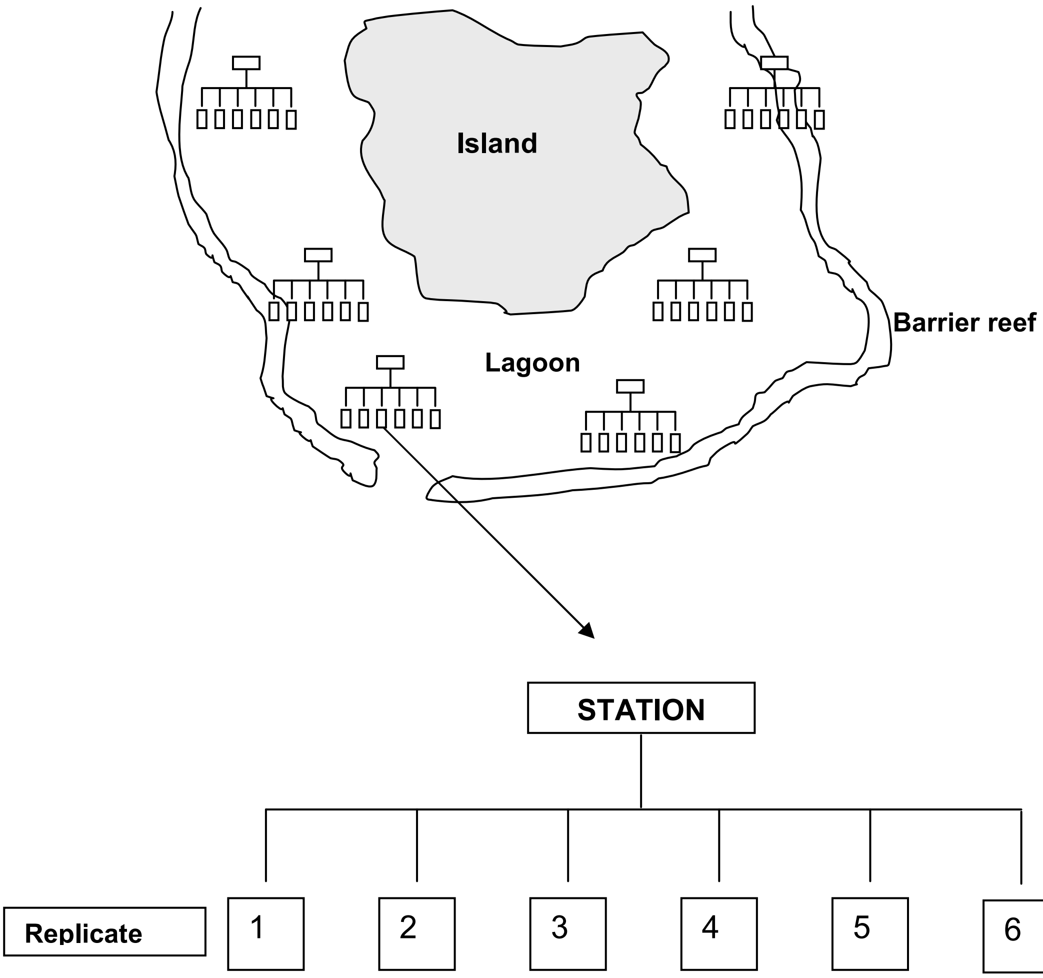


Figure A1.3.1: Stations and replicate measures at a given site.
A replicate measure could be a transect, search period or quadrat group.

Invertebrate species diversity, spatial distribution and abundance were determined using fishery-independent surveys at stations over broad-scale and more targeted surveys. Broad-scale surveys aimed to record a range of macro invertebrates across sites, whereas more targeted surveys concentrated on specific habitats and groups of important resource species.

Recordings of habitat are generally taken for all replicates within stations (see Appendix 1.3.3). Comparison of species complements and densities among stations and sites does not factor in fundamental differences in macro and micro habitat, as there is presently no established method that can be used to make allowances for these variations. The complete dataset from PROCFish/C will be a valuable resource to assess such habitat effects, and by identifying salient habitat factors that reliably affect resource abundance, we may be able to account for these habitat differences when inferring 'status' of important species groups. This will be examined once the full Pacific dataset has been collected.

More detailed explanations of the various survey methods are given below.

Broad-scale survey

Manta 'tow-board' transect surveys

A general assessment of large sedentary invertebrates and habitat was conducted using a tow-board technique adapted from English *et al.* (1997), with a snorkeller towed at low speed (<2.5 km/hour). This is a slower speed than is generally used for manta transects, and is less than half the normal walking pace of a pedestrian.

Where possible, manta surveys were completed at 12 stations per site. Stations were positioned near land masses on fringing reefs (inner stations), within the lagoon system (middle stations) and in areas most influenced by oceanic conditions (outer stations). Replicate measures within stations (called transects) were conducted at depths between 1 m and <10 m of water (mostly 1.5–6 m), covering broken ground (coral stone and sand) and at the edges of reefs. Transects were not conducted in areas that were too shallow for an outboard-powered boat (<1 m) or adjacent to wave-impacted reef.

Each transect covered a distance of ~300 m (thus the total of six transects covered a linear distance of ~2 km). This distance was calibrated using the odometer function within the trip computer option of a Garmin 76Map® GPS. Waypoints were recorded at the start and end of each transect to an accuracy of ≤ 10 m. The abundance and size estimations for large sedentary invertebrates were taken within a 2 m swathe of benthos for each transect. Broad-based assessments at each station took approximately one hour to complete (7–8 minutes per transect × 6, plus recording and moving time between transects). Hand tally counters and board-mounted bank counters (three tally units) were used to assist with enumerating common species.

The tow-board surveys differed from traditional manta surveys by utilising a lower speed and concentrating on a smaller swathe on the benthos. The slower speed, reduced swathe and greater length of tows used within PROCFish/C protocols were adopted to maximise efficiency when spotting and identifying cryptic invertebrates, while covering areas that were large enough to make representative measures.

Targeted surveys

Reef- and soft-benthos transect surveys (RBt and SBt), and soft-benthos quadrats (SBq)

To assess the range, abundance, size and condition of invertebrate species and their habitat with greater accuracy at smaller scales, reef- and soft-benthos assessments were conducted within fishing areas and suitable habitat. Reef benthos and soft benthos are not mutually exclusive, in that coral reefs generally have patches of sand, while soft-benthos seagrass areas can be strewn with rubble or contain patches of coral. However, these survey stations (each covering approximately 5000 m^2) were selected in areas representative of the habitat (those generally accessed by fishers, although MPAs were examined on occasion). Six 40 m transects (1 m swathe) were examined per station to record most epi-benthic invertebrate resources and some sea stars and urchin species (as potential indicators of habitat condition). Transects were randomly positioned but laid across environmental gradients where possible (e.g. across reefs and not along reef edges). A single waypoint was recorded for each station (to an accuracy of ≤ 10 m) and habitat recordings were made for each transect (see Figure A1.3.2 and Appendix 1.3.2).

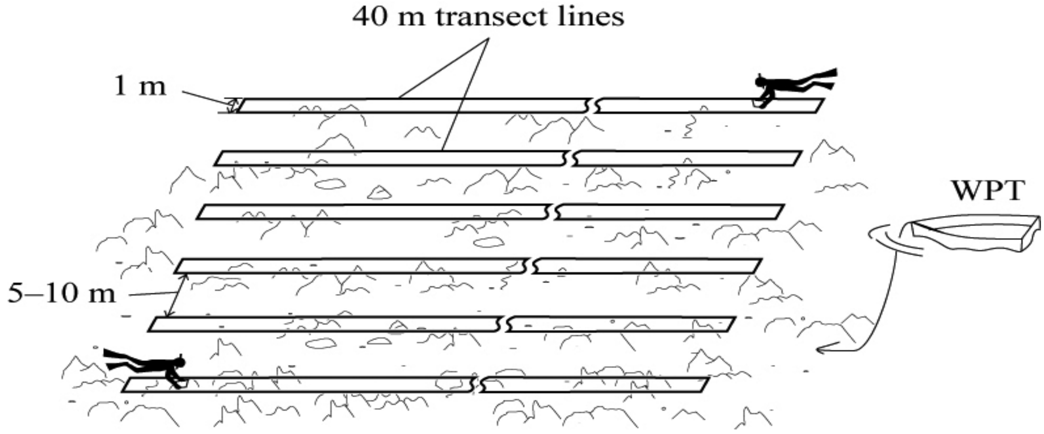


Figure A1.3.2: Example of a reef-benthos transect station (RBt).

To record infaunal resources, quadrats (SBq) were used within a 40 m × 2 m strip transect to measure densities of molluscs (mainly bivalves) in soft-benthos 'shell bed' areas. Four 25 cm x 25 cm quadrats (one quadrat group) were dug to approximately 5–8 cm to retrieve and measure infaunal target species and potential indicator species. Eight randomly spaced quadrat groups were sampled along the 40 m transect line (Figure A1.3.3). A single waypoint and habitat recording was taken for each infaunal station.

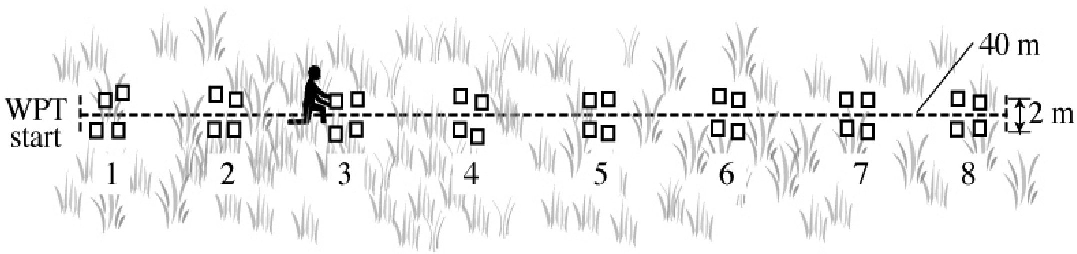


Figure A1.3.3: Soft-benthos (infaunal) quadrat station (SBq).
Single quadrats are 25 cm x 25 cm in size and four make up one 'quadrat group'.

<u>Mother-of-pearl (MOP) or sea cucumber (BdM) fisheries</u>

To assess fisheries such as those for trochus or sea cucumbers, results from broad-scale, reef- and soft-benthos assessments were used. However, other specific surveys were incorporated into the work programme, to more closely target species or species groups not well represented in the primary assessments.

<u>Reef-front searches (RFs and RFs_w)</u>

If swell conditions allowed, three 5-min search periods (conducted by two snorkellers, i.e. 30 min total) were conducted along exposed reef edges (RFs) where trochus (*Trochus niloticus*) and surf redfish (*Actinopyga mauritiana*) generally aggregate (Figure A1.3.4). Due to the dynamic conditions of the reef front, it was not generally possible to lay transects, but the start and end waypoints of reef-front searches were recorded, and two snorkellers recorded the abundance (generally not size measures) of large sedentary species (concentrating on trochus, surf redfish, gastropods and clams).

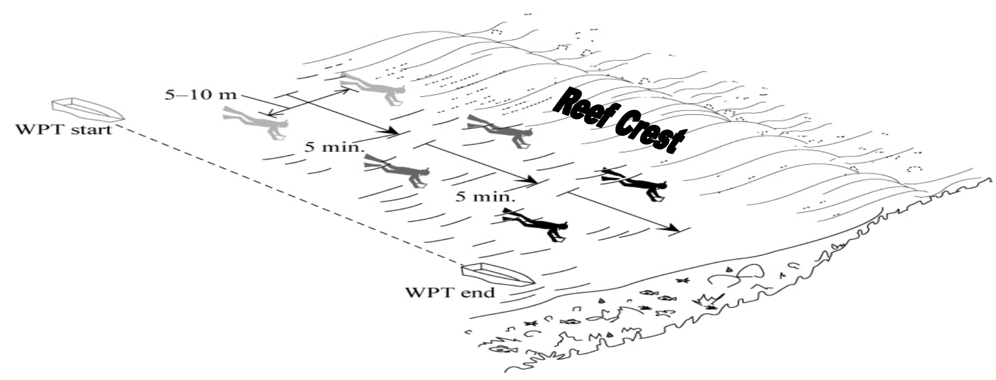


Figure A1.3.4: Reef-front search (RFs) station.

On occasions when it was too dangerous to conduct in-water reef-front searches (due to swell conditions or limited access) and the reeftop was accessible, searches were conducted on foot along the top of the reef front (RFs_w). In this case, two officers walked side by side (5–10 m apart) in the pools and cuts parallel to the reef front. This search was conducted at low tide, as close as was safe to the wave zone. In this style of assessment, reef-front counts of sea cucumbers, gastropod shells, urchins and clams were made during three 5-min search periods (total of 30 minutes search per station).

In the case of *Trochus niloticus*, reef-benthos transects, reef-front searches and local advice (trochus areas identified by local fishers) led us to reef-slope and shoal areas that were surveyed using SCUBA. Initially, searches were undertaken using SCUBA, although SCUBA transects (greater recording accuracy for density) were adopted if trochus were shown to be present at reasonable densities.

Mother-of-pearl search (MOPs)

Initially, two divers (using SCUBA) actively searched for trochus for three 5-min search periods (30 min total). Distance searched was estimated from marked GPS start and end waypoints. If more than three individual shells were found on these searches, the stock was considered dense enough to proceed with the more defined area assessment technique (MOPt).

Mother-of-pearl transects (MOPt)

Also on SCUBA, this method used six 40-m transects (2 m swathe) run perpendicular to the reef edge and not exceeding 15 m in depth (Figure A1.3.5). In most cases the depth ranged between 2 and 6 m, although dives could reach 12 m at some sites where more shallow-water habitat or stocks could not be found. In cases where the reef dropped off steeply, more oblique transect lines were followed. On MOP transect stations, a hip-mounted (or handheld) Chainman® measurement system (thread release) was used to measure out the 40 m. This allowed a hands-free mode of survey and saved time and energy in the often dynamic conditions where *Trochus niloticus* are found.

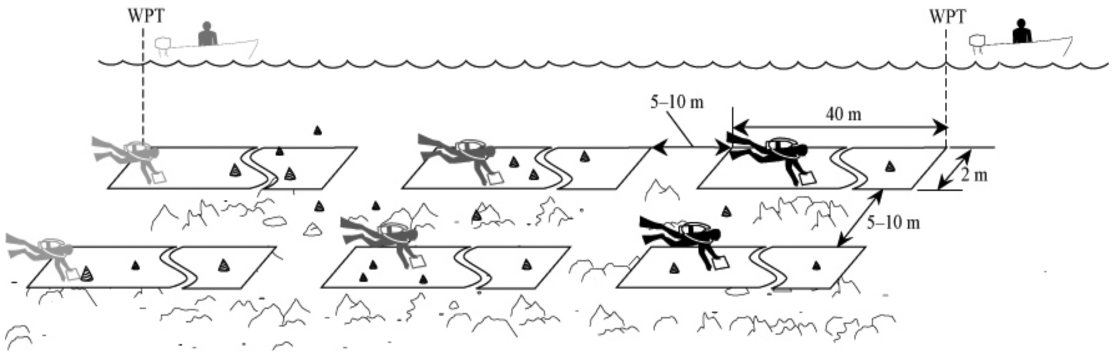


Figure A1.3.5: Mother-of-pearl transect station (MOPt).

Sea cucumber day search (Ds)

When possible, dives to 25–35 m were made to establish if white teatfish (*Holothuria (Microthele) fuscogilva*) populations were present and give an indication of abundance. In these searches two divers recorded the number and sizes of valuable deep-water sea cucumber species within three 5-min search periods (30 min total). This assessment from deep water does not yield sufficient presence/absence data for a very reliable inference on the status (i.e. 'health') of this and other deeper-water species.

Sea cucumber night search (Ns)

In the case of sea cucumber fisheries, dedicated night searches (Ns) for sea cucumbers and other echinoderms were conducted using snorkel for predominantly nocturnal species (blackfish *Actinopyga miliaris*, *A. lecanora*, and *Stichopus horrens*). Sea cucumbers were collected for three 5-min search periods by two snorkellers (30 min total), and if possible weighed (length and width measures for *A. miliaris* and *A. lecanora* are more dependent on the condition than the age of an individual).

Reporting style

For country site reports, results highlight the presence and distribution of species of interest, and their density at scales that yield a representative picture. Generally speaking, mean densities (average of all records) are presented, although on occasion mean densities for areas of aggregation ('patches') are also given. The later density figure is taken from records (stations or transects, as stated) where the species of interest is present (with an abundance >zero). Presentation of the relative occurrence and densities (without the inclusion of zero records) can be useful when assessing the status of aggregations within some invertebrate stocks.

An example and explanation of the reporting style adopted for invertebrate results follows.

1. The mean density range of *Tridacna* spp. on broad-scale stations (n = 8) was 10–120 per ha.

Density range includes results from all stations. In this case, replicates in each station are added and divided by the number of replicates for that station to give a mean. The lowest and highest station averages (here 10 and 120) are presented for the range. The number in brackets (n = 8) highlights the number of stations examined.

2. The mean density (per ha, ±SE) of all *Tridacna* clam species observed in broad-scale transects (n = 48) was 127.8 ±21.8 (occurrence in 29% of transects).

Mean density is the arithmetic mean, or average of measures across all replicates taken (in this case broad-scale transects). On occasion mean densities are reported for stations or transects where the species of interest is found at an abundance greater than zero. In this case the arithmetic mean would only include stations (or replicates) where the species of interest was found (excluding zero replicates). If this was presented for stations, even stations with a single clam from six transects would be included. (Note: a full breakdown of data is presented in the appendices.)

Written after the mean density figure is a descriptor that highlights variability in the figures used to calculate the mean. Standard error[3] (SE) is used in this example to highlight variability in the records that generated the mean density (SE = (standard deviation of records)/√n). This figure provides an indication of the dispersion of the data when trying to estimate a population mean (the larger the standard error, the greater variation of data points around the mean presented).

Following the variability descriptor is a presence/absence indicator for the total dataset of measures. The presence/absence figure describes the percentage of stations or replicates with a recording >0 in the total dataset; in this case 29% of all transects held *Tridacna* spp., which equated to 14 of a possible 48 transects (14/48*100 = 29%).

3. The mean length (cm, ±SE) of *T. maxima* was 12.4 ±1.1 (n = 114).

The number of units used in the calculation is indicated by *n*. In the last case, 114 clams were measured.

[3] In order to derive confidence limits around the mean, a transformation (usually y = log (x+1)) needs to be applied to data, as samples are generally non-normally distributed. Confidence limits of 95% can be generated through other methods (bootstrapping methods) and will be presented in the final report where appropriate.

1.3.2 General fauna invertebrate recording sheet with instructions to users

	DATE						RECORDER									Pg No		
STATION NAME																		
WPT - WIDTH																		
RELIEF / COMPLEXITY **1–5**																		
OCEAN INFLUENCE **1–5**																		
DEPTH (M)																		
% SOFT SED (M – S – CS)																		
% RUBBLE / BOULDERS																		
% CONSOL RUBBLE / PAVE																		
% CORAL *LIVE*																		
% CORAL *DEAD*																		
SOFT / SPONGE / FUNGIDS																		
ALGAE *CCA*																		
CORALLINE																		
OTHER																		
GRASS																		
EPIPHYTES **1–5** / SILT **1–5**																		
bleaching: % of																		
entered /																		

Figure A1.3.6: Sample of the invertebrate fauna survey sheet.

The sheet above (Figure A1.3.6) has been modified to fit on this page (the original has more line space (rows) for entering species data). When recording abundance or length data against species names, columns are used for individual transects or 5-min search replicates. If more space is needed, more than a single column can be used for a single replicate.

A separate sheet is used by a recorder in the boat to note information from handheld GPS equipment. In addition to the positional information, this boat sheet has space for manta transect distance (from GPS odometer function) and for sketches and comments.

1.3.3 Habitat section of invertebrate recording sheet with instructions to users

Figure A1.3.7 depicts the habitat part of the form used during invertebrate surveys; it is split into seven broad categories.

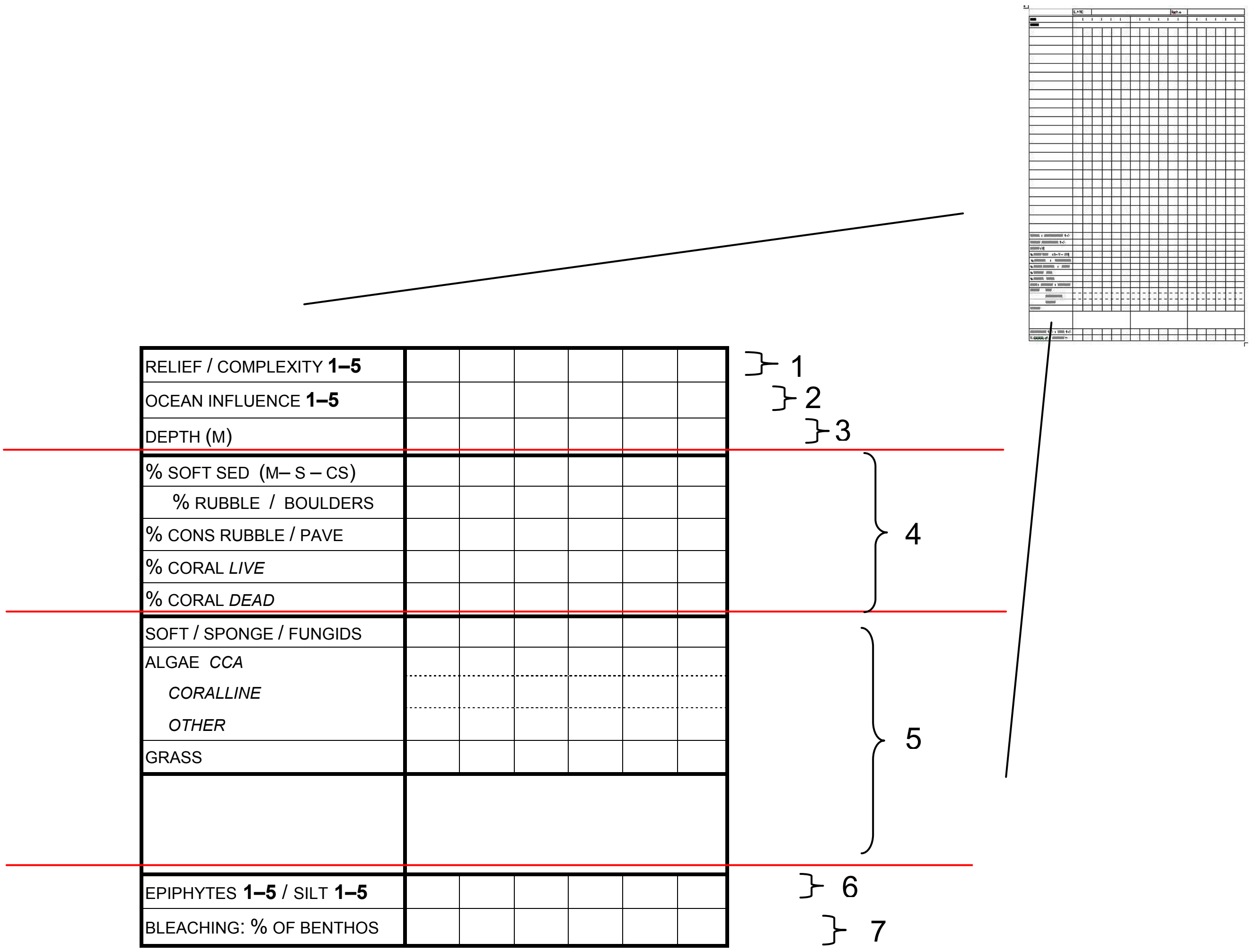


Figure A1.3.7: Sample of the invertebrate habitat part of survey form.

Relief and complexity (section 1 of form)

Each is on a scale of 1 to 5. If a record is written as 1/5, relief is 1 and complexity is 5, with the following explanation.

Relief describes average height variation for hard (and soft) benthos transects:

1 = flat (to ankle height)
2 = ankle up to knee height
3 = knee to hip height
4 = hip to shoulder/head height
5 = over head height

Complexity describes average surface variation for substrates (relative to places for animals to find shelter) for hard (and soft) benthos transects:

1 = smooth – no holes or irregularities in substrate
2 = some complexity to the surfaces but generally little

3 = generally complex surface structure
4 = strong complexity in surface structure, with cracks, spaces, holes, etc.
5 = very complex surfaces with lots of spaces, nooks, crannies, under-hangs and caves

Ocean influence (section 2 of form)

1 = riverine, or land-influenced seawater with lots of allochthonous input
2 = seawater with some land influence
3 = ocean and land-influenced seawater
4 = water mostly influenced by oceanic water
5 = oceanic water without land influence

Depth (section 3 of form)

Average depth in metres

Substrate – bird's-eye view of what's there (section 4 of form)

All of section 4 must make up 100%. Percentage substrate is estimated in units of 5% so, e.g. 5, 10, 15, 20 (%) etc. and not 2, 13, 17, 56.

Elements to consider:

Soft substrate	Soft sediment – mud
Soft substrate	Soft sediment – mud and sand
Soft substrate	Soft sediment – sand
Soft substrate	Soft sediment – coarse sand
Hard substrate	Rubble
Hard substrate	Boulders
Hard substrate	Consolidated rubble
Hard substrate	Pavement
Hard substrate	Coral live
Hard substrate	Coral dead

Mud, sand, coarse sand: The sand is not sieved – it is estimated visually and manually. Surveyors can use the 'drop test', where sand drops through the water column and mud stays in suspension. Patchy settled areas of silt/clay/mud in very thin layers on top of coral, pavement, etc. are not listed as soft substrate unless the layer is significant (>a couple of cm).

Rubble is small (<25–30 cm) fragments of coral (reef), pieces of coral stone and limestone debris. AIMS' definition is very similar to that for Reefcheck (found on the 'C-nav' interactive CD): 'pieces of coral (reef) between 0.5 and 15 cm. If smaller, it is sand; if larger, then rock or whatever organism is growing upon it'.

Boulders are detached, big pieces (>30 cm) of stone, coral stone and limestone debris.

Consolidated rubble is attached, cemented pieces of coral stone and limestone debris. We tend to use 'rubble' for pieces or piles loose in the sediment of seagrass, etc., and 'consolidated rubble' for areas that are not flat pavement but concreted rubble on reeftops and cemented talus slopes.

Appendix 1: Survey methods
Invertebrates

Pavement is solid, substantial, fixed, flat stone (generally limestone) benthos.

Coral live is any live hard coral.

Coral dead is coral that is recognisable as coral even if it is long dead. Note that long-dead and *eroded* coral that is found in flat pavements is called 'pavement' and when it is found in loose pieces or blocks it is termed 'rubble' or 'boulders' (depending on size).

Cover – what is on top of the substrate (section 5 of form)

This cannot exceed 100%, but can be anything from 0 to 100%. Surveyors give scores in blocks of 5%, so e.g. 5, 10, 15, 20 (%) etc. and not 2, 13, 17, 56.

Elements to consider:

Cover	Soft coral
Cover	Sponge
Cover	Fungids
Cover	Crustose-nongeniculate coralline algae
Cover	Coralline algae
Cover	Other (algae like *Sargassum*, *Caulerpa* and *Padina* spp.)
Cover	Seagrass

Soft coral is all soft corals but not Zoanthids or anemones.

Sponge includes half-buried sponges in seagrass beds – only sections seen on the surface are noted.

Fungids are fungids.

Crustose – nongeniculate coralline algae are pink rock. Crustose or nongeniculate coralline algae (NCA) are red algae that deposit calcium carbonate in their cell walls. Generally they are members of the division Rhodophyta.

Coralline algae – halimeda are red coralline algae (often seen in balls – *Galaxaura*). (Note: AIMS lists *halimeda* and other coralline algae as macro algae along with fleshy algae not having $CaCo_3$ deposits.)

Other algae include fleshy algae such as *Turbinaria*, *Padina* and *Dictyota*. Surveyors describe coverage by taking a bird's-eye view of what is covered, not by delineating the spatial area of the algae colony within the transect (i.e. differences in very low or high density are accounted for). The large space on the form is used to write species information if known.

Seagrass includes seagrass spp. such as *Halodule*, *Thalassia*, *Halophila* and *Syringodium*. Surveyors note types by species if possible or by structure (i.e. flat versus reed grass), and describe coverage by taking a bird's-eye view of what benthos is covered, not by delineating the spatial area of the grass meadow within the transect (i.e. differences in very low or high density are accounted for).

Cover continued – epiphytes and silt (section 6 of form)

Epiphytes 1–5 grade are mainly turf algae – turf that grows on hard and soft substrates, but also on algae and grasses. The growth is usually fine-stranded filamentous algae that have few noticeable distinguishing features (more like fuzz).

1 = none
2 = small areas or light coverage
3 = patchy, medium coverage
4 = large areas or heavier coverage
5 = very strong coverage, long and thick almost choking epiphytes – normally including strands of blue-green algae as well

Silt 1–5 grade (or a similar fine-structured material sometimes termed 'marine snow') consists of fine particles that slowly settle out from the water but are easily re-suspended. When re-suspended, silt tends to make the water murky and does not settle quickly like sand does. Sand particles are not silt and should not be included here when seen on outer-reef platforms that are wave affected.

1 = clear surfaces
2 = little silt seen
3 = medium amount of silt-covered surfaces
4 = large areas covered in silt
5 = surfaces heavily covered in silt

Bleaching (section 7 of form)

The percentage of bleached live coral is recorded in numbers from 1 to 100% (Not 5% blocks). This is the percentage of benthos that is dying hard coral (just-bleached) or very recently dead hard coral showing obvious signs of recent bleaching.

APPENDIX 2: SOCIOECONOMIC SURVEY DATA

2.1 Ha'atafu socioeconomic survey data

2.1.1 Annual catch (kg) of fish groups per habitat – Ha'atafu
(includes only catch data reported by interviewed finfish fishers)

Vernacular name	Family	Scientific name	Total weight (kg)	% of reported catch
Sheltered coastal reef & lagoon				
Koango	Lethrinidae	*Lethrinus nebulosus*	1406	25.4
Hoputu	Lethrinidae	*Lethrinus* spp.	1101	19.9
Tanutanu	Lethrinidae	*Lethrinus harak*	870	15.7
Lupo	Carangidae	*Caranx* spp.	389	7.0
Kulapo	Lethrinidae	*Lethrinus* spp.	324	5.9
Matu	Gerreidae	*Gerres* spp.	243	4.4
Olomea	Scaridae	*Scarus ghobban*	223	4.0
Fangamea	Lutjanidae	*Lutjanus bohar*	200	3.6
Hohomo	Scaridae	*Scarus* spp.	182	3.3
Meai	Labridae	*Thalassoma* spp.	175	3.2
Ngatala	Serranidae	*Epinephelus merra*	156	2.8
Pone	Acanthuridae	*Acanthurus* spp.	114	2.1
Kanahe	Mugilidae	*Valamugil seheli*	106	1.9
Kavakava			39	0.7
Total:			**5527**	**100.0**
Outer reef				
Hoputu	Lethrinidae	*Lethrinus* spp.	281	37.5
Koango	Lethrinidae	*Lethrinus nebulosus*	267	35.6
Mu	Lethrinidae	*Gymnocranius* spp.	139	18.5
Ngatala	Serranidae	*Epinephelus merra*	62	8.3
Total:			**750**	**100.0**
Outer reef & passage				
Hoputu	Lethrinidae	*Lethrinus* spp.	794	23.1
Koango	Lethrinidae	*Lethrinus nebulosus*	708	20.6
Mu	Lethrinidae	*Gymnocranius* spp.	359	10.5
Manga	Lethrinidae	*Lethrinus* spp.	328	9.6
Hohomo	Scaridae	*Scarus* spp.	287	8.4
Tanutanu	Lethrinidae	*Lethrinus harak*	263	7.7
Ngatala	Serranidae	*Epinephelus merra*	247	7.2
Nue	Kyphosidae	*Kyphosus* spp.	231	6.7
Lupo	Carangidae	*Caranx* spp.	213	6.2
Total:			**3430**	**100.0**

2.1.2 Invertebrate species caught by fishery, with the percentage of annual wet weight caught – Ha'atafu

Fishery	Vernacular name	Scientific name	% annual catch (weight)
Other	Octopus	*Octopus* spp.	
Reeftop	Octopus	*Octopus* spp.	44.9
	Tukumisi	*Tripneustes gratilla*	30.6
	Elili	*Turbo crassus*	24.5
Reeftop & other	Octopus	*Octopus* spp.	67.9
	Tukumisi	*Tripneustes gratilla*	16.9
	Mulione	*Dolabella auricularia*	15.2
Soft benthos	Tukumisi	*Tripneustes gratilla*	63.5
	Elili	*Turbo crassus*	25.4
	Mulione	*Dolabella auricularia*	11.1
	Mehingo		
Soft benthos & reeftop	Lomu	*Holothuria* spp.	37.2
	Ngoua	*Holothuria* spp.	22.3
	Tukumisi	*Tripneustes gratilla*	12.3
	Kelea	*Strombus gibberulus gibbosus*	11.2
	Elili	*Turbo crassus*	10.9
	Mulione	*Dolabella auricularia*	3.5
	Octopus	*Octopus* spp.	2.2
	Hulihuli	*Cryptoplax* spp.	0.4
	Kaloama	*Anadara* spp.	0.1
	Limu		
	Iapola		
	Mehingo		
Soft benthos & reeftop & other	Octopus	*Octopus* spp.	64.0
	Elili	*Turbo crassus*	27.9
	Hulihuli	*Cryptoplax* spp.	4.1
	Mulione	*Dolabella auricularia*	4.1

2.1.3 Average length-frequency distribution for invertebrates, with percentage of annual total catch weight – Ha'atafu

Vernacular name	Scientific name	Size class	% of total catch (weight)
Elili	*Turbo crassus*	04-06 cm	54.7
		04-08 cm	1.3
		05-06 cm	19.1
		08 cm	24.9
Hulihuli	*Cryptoplax* spp.	04-05 cm	100.0
Iapola		08 cm	
Kaloama	*Anadara* spp.	06 cm	100.0
Kelea	*Strombus gibberulus gibbosus*	06 cm	100.0
Limu		01 cm	
Lomu	*Holothuria* spp.	12-14 cm	100.0
Mehingo		04 cm	
		04-06 cm	
		06-08 cm	
Mulione	*Dolabella auricularia*	08-10 cm	6.3
		08-12 cm	4.2
		10 cm	5.2
		10-12 cm	12.6
		10-14 cm	8.3
		12 cm	10.4
		12-14 cm	42.5
		14-16 cm	10.4
Ngoua	*Holothuria* spp.	10-12 cm	33.3
		12-14 cm	66.7
Octopus	*Octopus* spp.	06-08 cm	
		06-10 cm	
		08-12 cm	6.4
		12-14 cm	16.5
		12-16 cm	77.1
Tukumisi	*Tripneustes gratilla*	08 cm	8.3
		08-10 cm	2.2
		10 cm	19.9
		10-12 cm	25.0
		12-14 cm	44.6

2.2 Manuka socioeconomic survey data

2.2.1 Annual catch (kg) of fish groups per habitat – Manuka
(includes only catch data reported by interviewed finfish fishers)

Vernacular name	Family	Scientific name	Total weight (kg)	% of reported catch
Sheltered coastal reef & lagoon				
Ume	Acanthuridae	*Naso unicornis*	2271	29.2
Hohomo	Scaridae	*Scarus* spp.	1840	23.7
Ma'ava	Siganidae	*Siganus argenteus*	1233	15.9
Pone	Acanthuridae	*Acanthurus* spp.	761	9.8
Tanutanu	Lethrinidae	*Lethrinus harak*	401	5.2
Hoputu	Lethrinidae	*Lethrinus* spp.	299	3.9
Ta'a	Holocentridae	*Sargocentron spiniferum*	235	3.0
O	Siganidae	*Siganus spinus*	217	2.8
Ngatala	Serranidae	*Epinephelus merra*	184	2.4
Lalafi	Labridae	*Cheilinus* spp.	144	1.9
Humu	Balistidae	*Balistes* spp.	132	1.7
Unomoa			52	0.7
Total:			**7769**	**100.0**
Outer reef				
Hoputu	Lethrinidae	*Lethrinus* spp.	2276	29.4
Koango	Lethrinidae	*Lethrinus nebulosus*	1101	14.2
Ngatala	Serranidae	*Epinephelus merra*	1097	14.2
Mu	Lethrinidae	*Gymnocranius* spp.	1033	13.3
Tanutanu	Lethrinidae	*Lethrinus harak*	603	7.8
Fangamea	Lutjanidae	*Lutjanus bohar*	521	6.7
Fate	Lutjanidae	*Lutjanus kasmira*	330	4.3
Utu	Lutjanidae	*Aprion virescens*	249	3.2
Lupo	Carangidae	*Caranx* spp.	208	2.7
Ngungutoa	Lethrinidae	*Lethrinus obsoletus*	126	1.6
Manga	Lethrinidae	*Lethrinus* spp.	92	1.2
Kulapo	Lethrinidae	*Lethrinus* spp.	75	1.0
Ta'a	Holocentridae	*Sargocentron spiniferum*	35	0.4
Total:			**7746**	**100.0**

2.2.2 Invertebrate species caught by fishery, with the percentage of annual wet weight caught – Manuka

Fishery	Vernacular name	Scientific name	% annual catch (weight)
Lobster & other	Lobster	*Panulirus* spp.	100.0
	Octopus	*Octopus* spp.	
Soft benthos	Kelea	*Strombus gibberulus gibbosus*	54.5
	Ngoua	*Holothuria* spp.	43.6
	Mulione	*Dolabella auricularia*	1.0
	Tukumisi	*Tripneustes gratilla*	0.7
	Anga'anga	*Lambis lambis*	0.1
	Kaloa'a	*Anadara* spp.	
Soft benthos & other	Ngoua	*Holothuria* spp.	84.9
	Vasuva	*Tridacna* spp.	12.7
	Mulione	*Dolabella auricularia*	1.5
	Tukumisi	*Tripneustes gratilla*	0.8
	Kaloa'a	*Anadara* spp.	
Soft benthos & reeftop	Ngoua	*Holothuria* spp.	70.7
	Tukumisi	*Tripneustes gratilla*	11.0
	Elili	*Turbo crassus*	7.8
	Mulione	*Dolabella auricularia*	6.4
	Kaloa'a	*Anadara* spp.	2.2
	Anga'anga	*Lambis lambis*	1.9

2.2.3 Average length-frequency distribution for invertebrates, with percentage of annual total catch weight – Manuka

Vernacular name	Scientific name	Size class	% of total catch (weight)
Anga'anga	*Lambis lambis*	12-14 cm	53.2
		12-16 cm	25.5
		14 cm	8.5
		14-18 cm	12.8
Elili	*Turbo crassus*	04-08 cm	81.8
		06-08 cm	18.2
Kaloa'a	*Anadara* spp.	04-06 cm	16.7
		06 cm	83.3
Kelea	*Strombus gibberulus gibbosus*	04 cm	100.0
Lobster	*Panulirus* spp.	16 cm	100.0
Mulione	*Dolabella auricularia*	08-12 cm	16.0
		10 cm	8.0
		10-14 cm	20.0
		12 cm	0.1
		12-14 cm	22.4
		14 cm	3.2
		14-16 cm	6.4
		16-18 cm	24.0
Ngoua	*Holothuria* spp.	06-08 cm	27.7
		10 cm	44.7
		10-12 cm	27.7
Octopus	*Octopus sp.*	10 cm	
Tukumisi	*Tripneustes gratilla*	08-10 cm	14.9
		10 cm	7.5
		10-12 cm	25.4
		10-14 cm	22.4
		12-14 cm	29.8
Vasuva	*Tridacna* spp.	12-14 cm	100.0

2.3 Koulo socioeconomic survey data

2.3.1 Annual catch (kg) of fish groups per habitat – Koulo
(includes only catch data reported by interviewed finfish fishers)

Vernacular name	Family	Scientific name	Total weight (kg)	% of reported catch
Sheltered coastal reef				
Hohomo	Scaridae	*Scarus* spp.	1342	17.2
Ngatala	Serranidae	*Epinephelus merra*	1265	16.3
Ume	Acanthuridae	*Naso unicornis*	1009	13.0
Ngungutoa	Lethrinidae	*Lethrinus rubrioperculatus*	854	11.0
Ma'ava	Siganidae	*Siganus argenteus*	673	8.6
Pone	Acanthuridae	*Acanthurus* spp.	587	7.5
Vete	Mullidae	*Mulloidichthys* spp.	267	3.4
Hoputu	Lethrinidae	*Lethrinus* spp.	182	2.3
Palu kula	Lutjanidae	*Etelis coruscans*	176	2.3
Koango	Lethrinidae	*Lethrinus nebulosus*	176	2.3
Kulapo	Lethrinidae	*Lethrinus* spp.	172	2.2
Lupo	Carangidae	*Caranx* spp.	162	2.1
Manini	Acanthuridae	*Acanthurus triostegus*	127	1.6
Palu hina	Lutjanidae	*Aphareus furca*	122	1.6
Palu tavaki	Lutjanidae	*Etelis coruscans*	122	1.6
Tanutanu	Lethrinidae	*Lethrinus harak*	121	1.6
Ta'a	Holocentridae	*Sargocentron spiniferum*	81	1.0
Sokisoki	Diodontidae	*Diodon hystrix*	72	0.9
Pose	Scaridae	*Scarus* spp.	55	0.7
Tafauli	Labridae	*Cheilinus undulatus*	54	0.7
O	Siganidae	*Siganus spinus*	50	0.6
Ufu	Scaridae	*Leptoscarus vaigiensis*	32	0.4
Matu	Gerreidae	*Gerres* spp.	29	0.4
Sifisifi	Chaetodontidae	*Heniochus monoceros*	29	0.4
Fotua	Haemulidae	*Plectorhinchus chaetodonoides*, *Plectorhinchus pictus*	28	0.4
Total:			**7785**	**100.0**
Lagoon				
Palu kula	Lutjanidae	*Etelis coruscans*	1007	25.8
Palu hina	Lutjanidae	*Aphareus furca*	684	17.5
Nue	Kyphosidae	*Kyphosus* spp.	420	10.8
Hoputu	Lethrinidae	*Lethrinus* spp.	344	8.8
Kanahe	Mugilidae	*Valamugil seheli*	340	8.7
Vete	Mullidae	*Mulloidichthys* spp.	265	6.8
Lupo	Carangidae	*Caranx* spp.	261	6.7
Ngatala kula	Serranidae	*Epinephelus merra*	178	4.6
Ufu	Scaridae	*Leptoscarus vaigiensis*	166	4.3
Tafauli	Labridae	*Cheilinus undulatus*	83	2.1
Fangamea	Lutjanidae	*Lutjanus bohar*	83	2.1
Manini	Acanthuridae	*Acanthurus triostegus*	36	0.9
Hapi	Acanthuridae	*Acanthurus guttatus*	36	0.9
Total:			**3904**	**100.0**

2.3.2 Invertebrate species caught by fishery, with the percentage of annual wet weight caught – Koulo

Fishery	Vernacular name	Scientific name	% annual catch (weight)
Reeftop	Ngoua	*Holothuria* spp.	43.2
	Octopus	*Octopus* spp.	20.7
	Kukukuku	*Tridacna maxima*	19.1
	Tukumisi	*Tripneustes gratilla*	7.0
	Matamata	*Bohadschia argus*	5.5
	Umana	*Heteractis* spp., *Stichodactyla* spp.	1.9
	Mokohunu	*Actinopyga lecanora*	1.0
	Elili	*Turbo crassus*	0.8
	Hulihuli	*Cryptoplax* spp.	0.5
	Mulione	*Dolabella auricularia*	0.3

2.3.3 Average length-frequency distribution for invertebrates, with percentage of annual total catch weight – Koulo

Vernacular name	Scientific name	Size class	% of total catch (weight)
Elili	*Turbo crassus*	06 cm	100.0
Hulihuli	*Cryptoplax* spp.	04 cm	100.0
Kukukuku	*Tridacna maxima*	06 cm	14.2
		08 cm	27.7
		12 cm	14.2
		14 cm	44.0
Matamata	*Bohadschia argus*	16 cm	100.0
Mokohunu	*Actinopyga lecanora*	18 cm	100.0
Mulione	*Dolabella auricularia*	12 cm	100.0
Ngoua	*Holothuria* spp.	06 cm	44.4
		12 cm	55.6
Octopus	*Octopus* spp.	06 cm	15.3
		08 cm	67.5
		10 cm	17.2
Tukumisi	*Tripneustes gratilla*	06 cm	34.1
		10 cm	38.6
		12 cm	27.3
Umana	*Heteractis* spp., *Stichodactyla* spp.	06 cm	100.0

2.4 Lofanga socioeconomic survey data

2.4.1 Annual catch (kg) of fish groups per habitat – Lofanga
(includes only catch data reported by interviewed finfish fishers)

Vernacular name	Family	Scientific name	Total weight (kg)	% of reported catch
Sheltered coastal reef				
Manini	Acanthuridae	*Acanthurus triostegus*	583.4	19.1
Hoputu	Lethrinidae	*Lethrinus* spp.	273.4	9.0
Palu kula	Lutjanidae	*Etelis coruscans*	255.7	8.4
Koango	Lethrinidae	*Lethrinus nebulosus*	255.7	8.4
Ngungutoa	Lethrinidae	*Lethrinus rubrioperculatus*	218.0	7.1
Pone	Acanthuridae	*Acanthurus* spp.	187.7	6.1
Ngatala kula	Serranidae	*Epinephelus merra*	164.3	5.4
Ma'ava	Siganidae	*Siganus argenteus*	140.8	4.6
Vete	Mullidae	*Mulloidichthys* spp.	140.8	4.6
Tokonifusi	Lethrinidae	*Lethrinus xanthochilus*	117.3	3.8
Kulapo	Lethrinidae	*Lethrinus* spp.	107.5	3.5
Manga	Lethrinidae	*Lethrinus* spp.	107.5	3.5
Ngatala pulepule	Serranidae	*Epinephelus* spp.	107.5	3.5
Palu hina	Lutjanidae	*Aphareus furca*	107.5	3.5
Utu	Lutjanidae	*Aprion virescens*	107.5	3.5
Haku	Belonidae	*Tylosurus crocodilus crocodilus*	102.3	3.3
Fa'apuku	Serranidae	*Epinephelus polyphekadion*	53.8	1.8
Meai	Labridae	*Thalassoma* spp.	23.5	0.8
Total:			**3054.3**	**100.0**
Lagoon / outer reef				
Ngatala kula	Serranidae	*Epinephelus merra*	4251.1	15.4
Ume	Acanthuridae	*Naso unicornis*	3148.3	11.4
Hohomo	Scaridae	*Scarus* spp.	2511.9	9.1
Hoputu	Lethrinidae	*Lethrinus* spp.	2334.3	8.4
Tokonifusi	Lethrinidae	*Lethrinus xanthochilus*	2020.1	7.3
Kulapo	Lethrinidae	*Lethrinus* spp.	1757.1	6.3
Manga	Lethrinidae	*Lethrinus* spp.	1631.1	5.9
Ngungutoa	Lethrinidae	*Lethrinus rubrioperculatus*	1496.1	5.4
Sikatoki	Scaridae	*Chlorurus microrhinos*	997.9	3.6
Pone	Acanthuridae	*Acanthurus* spp.	932.7	3.4
Ma'ava	Siganidae	*Siganus argenteus*	915.4	3.3
Palu kula	Lutjanidae	*Etelis coruscans*	690.4	2.5
Ngatala pulepule	Serranidae	*Epinephelus* spp.	661.4	2.4
Palu hina	Lutjanidae	*Aphareus furca*	585.2	2.1
Koango	Lethrinidae	*Lethrinus nebulosus*	393.2	1.4
Mohuafi	Serranidae	*Cephalopholis miniata*	383.6	1.4
Tanutanu	Lethrinidae	*Lethrinus harak*	328.5	1.2
Palu malau	Lutjanidae	*Etelis carbunculus*	306.8	1.1
Palu polosi	Lutjanidae	*Aphareus rutilans*	306.8	1.1
Valumaka	Carangidae	*Seriola rivoliana*	306.8	1.1
Palu maka	Lutjanidae	*Etelis* spp.	306.8	1.1
Ta'a	Holocentridae	*Sargocentron spiniferum*	301.1	1.1
Palu	Lutjanidae	*Lutjanus* spp.	255.7	0.9
Tafauli	Labridae	*Cheilinus undulatus*	204.6	0.7

2.4.1 Annual catch (kg) of fish groups per habitat – Lofanga (continued)
(includes only catch data reported by interviewed finfish fishers)

Vernacular name	Family	Scientific name	Total weight (kg)	% of reported catch
Lagoon / outer reef (continued)				
Lalafi	Labridae	*Cheilinus* spp.	204.6	0.7
Mu	Lethrinidae	*Gymnocranius* spp.	201.6	0.7
Vete	Mullidae	*Mulloidichthys* spp.	115.9	0.4
Ume lei	Acanthuridae	*Naso lituratus*	70.4	0.3
Tukuleia	Mullidae	*Parupeneus* spp.	70.4	0.3
Total:			**27,689.7**	**100.0**

2.4.2 Invertebrate species caught by fishery, with the percentage of annual wet weight caught – Lofanga

Fishery	Vernacular name	Scientific name	% annual catch (weight)
Other	Kukukuku	*Tridacna maxima*	52.4
	Vasuva	*Tridacna* spp.	28.6
	Tokanoa	*Tridacna derasa*	9.5
	Tukumisi	*Tripneustes gratilla*	9.5
Reeftop	Octopus	*Octopus* spp.	40.1
	Kukukuku	*Tridacna maxima*	33.1
	Tukumisi	*Tripneustes gratilla*	12.1
	Elili	*Turbo crassus*	8.1
	Vasuva	*Tridacna* spp.	2.4
	Hulihuli	*Cryptoplax* spp.	1.9
	Tokanoa	*Tridacna derasa*	1.9
	Loli	*Holothuria atra*	0.3
	Limu		
	Teve		

2.4.3 Average length-frequency distribution for invertebrates, with percentage of annual total catch weight – Lofanga

Vernacular name	Scientific name	Size class	% of total catch (weight)
Elili	*Turbo crassus*	04-06 cm	19.0
		06 cm	47.6
		08 cm	4.8
		10 cm	28.6
Hulihuli	*Cryptoplax* spp.	08 cm	100.0
Kukukuku	*Tridacna maxima*	04-06 cm	20.7
		06 cm	7.8
		08 cm	4.1
		08-10 cm	3.6
		08-20 cm	7.8
		10-18 cm	10.4
		12 cm	14.5
		14 cm	10.4
		16 cm	20.7
Loli	*Holothuria atra*	20 cm	42.9
		22 cm	57.1
Octopus	*Octopus* spp.	04 cm	3.9
		06 cm	24.3
		06-10 cm	3.9
		08 cm	61.8
		10 cm	5.9
Teve		08 cm	
Tokanoa	*Tridacna derasa*	22 cm	44.4
		24 cm	55.6
Tukumisi	*Tripneustes gratilla*	08 cm	9.9
		08-10 cm	13.2
		10 cm	52.0
		12 cm	24.8
Vasuva	*Tridacna* spp.	12-16 cm	25.0
		24 cm	75.0

APPENDIX 3: FINFISH SURVEY DATA

3.1 Ha'atafu finfish survey data

3.1.1 Coordinates (WGS84) of the 12 D-UVC transects used to assess finfish resource status in Ha'atafu

Station name	Habitat	Latitude	Longitude
TRA01	Coastal reef	21°04'22.6812" S	175°18'27.8388" W
TRA02	Coastal reef	21°04'12.9" S	175°18'00.72" W
TRA03	Coastal reef	21°03'55.0188" S	175°16'53.94" W
TRA04	Outer reef	21°03'10.98" S	175°18'59.04" W
TRA05	Outer reef	21°02'56.22" S	175°18'30.96" W
TRA06	Outer reef	21°01'55.4412" S	175°16'04.8" W
TRA07	Outer reef	21°01'01.4988" S	175°13'27.9588" W
TRA08	Outer reef	21°01'12.1188" S	175°14'20.4612" W
TRA09	Outer reef	21°00'11.0412" S	175°12'57.24" W
TRA10	Back-reef	21°02'53.9412" S	175°15'36.54" W
TRA11	Back-reef	21°03'26.5212" S	175°14'52.8612" W
TRA12	Coastal reef	21°04'33.7188" S	175°14'35.34" W

3.1.2 Weighted average density and biomass of all finfish species recorded in Ha'atafu (using distance-sampling underwater visual censuses (D-UVC))

Family	Species	Density (fish/m²)	Biomass (g/m²)
Acanthuridae	*Acanthurus blochii*	0.00045	0.0791
Acanthuridae	*Acanthurus lineatus*	0.00132	0.2048
Acanthuridae	*Acanthurus nigricans*	0.00023	0.0135
Acanthuridae	*Acanthurus nigrofuscus*	0.01012	0.2179
Acanthuridae	*Acanthurus pyroferus*	0.00022	0.0132
Acanthuridae	*Ctenochaetus striatus*	0.09100	7.9626
Acanthuridae	*Ctenochaetus strigosus*	0.00022	0.0020
Acanthuridae	*Naso lituratus*	0.00335	0.2622
Acanthuridae	*Naso unicornis*	0.00313	0.0941
Acanthuridae	*Zebrasoma scopas*	0.04605	1.4050
Acanthuridae	*Zebrasoma veliferum*	0.00469	0.2763
Balistidae	*Balistapus undulatus*	0.00005	0.0043
Balistidae	*Rhinecanthus aculeatus*	0.00045	0.0485
Balistidae	*Sufflamen bursa*	0.00066	0.0401
Balistidae	*Sufflamen chrysopterum*	0.00022	0.0202
Chaetodontidae	*Chaetodon auriga*	0.00067	0.0214
Chaetodontidae	*Chaetodon bennetti*	0.00113	0.0231
Chaetodontidae	*Chaetodon citrinellus*	0.00379	0.0406
Chaetodontidae	*Chaetodon ephippium*	0.00070	0.0238
Chaetodontidae	*Chaetodon flavirostris*	0.00022	0.0098
Chaetodontidae	*Chaetodon lineolatus*	0.00005	0.0090
Chaetodontidae	*Chaetodon lunulatus*	0.00768	0.2436
Chaetodontidae	*Chaetodon melannotus*	0.00439	0.0808
Chaetodontidae	*Chaetodon mertensii*	0.00099	0.0193
Chaetodontidae	*Chaetodon pelewensis*	0.00289	0.0207
Chaetodontidae	*Chaetodon plebeius*	0.00053	0.0018

3.1.2 Weighted average density and biomass of all finfish species recorded in Ha'atafu (continued)

(using distance-sampling underwater visual censuses (D-UVC))

Family	Species	Density (fish/m²)	Biomass (g/m²)
Chaetodontidae	*Chaetodon rafflesii*	0.00132	0.0450
Chaetodontidae	*Chaetodon reticulatus*	0.00043	0.0167
Chaetodontidae	*Chaetodon trifascialis*	0.00153	0.0257
Chaetodontidae	*Chaetodon ulietensis*	0.00199	0.0616
Chaetodontidae	*Chaetodon unimaculatus*	0.00088	0.0308
Chaetodontidae	*Chaetodon vagabundus*	0.00247	0.0976
Chaetodontidae	*Forcipiger longirostris*	0.00106	0.0499
Chaetodontidae	*Heniochus chrysostomus*	0.00015	0.0048
Chaetodontidae	*Heniochus monoceros*	0.00033	0.0470
Chaetodontidae	*Heniochus singularius*	0.00046	0.0853
Chaetodontidae	*Heniochus varius*	0.00098	0.0409
Holocentridae	*Myripristis berndti*	0.00114	0.1854
Holocentridae	*Myripristis kuntee*	0.00323	0.3466
Holocentridae	*Myripristis murdjan*	0.00045	0.0439
Holocentridae	*Sargocentron caudimaculatum*	0.00061	0.0535
Holocentridae	*Sargocentron spiniferum*	0.00060	0.0685
Labridae	*Bodianus loxozonus*	0.00056	0.0930
Labridae	*Cheilinus chlorourus*	0.00415	0.3921
Labridae	*Cheilinus trilobatus*	0.00027	0.0531
Labridae	*Epibulus insidiator*	0.00073	0.1879
Labridae	*Hemigymnus fasciatus*	0.00072	0.0233
Labridae	*Hemigymnus melapterus*	0.00112	0.0829
Labridae	*Oxycheilinus digramma*	0.00067	0.0522
Lethrinidae	*Lethrinus atkinsoni*	0.00112	0.0532
Lethrinidae	*Lethrinus harak*	0.00089	0.1677
Lutjanidae	*Lutjanus fulviflamma*	0.00097	0.1208
Lutjanidae	*Lutjanus fulvus*	0.00089	0.1704
Mullidae	*Mulloidichthys flavolineatus*	0.00756	0.6482
Mullidae	*Parupeneus barberinoides*	0.00156	0.1090
Mullidae	*Parupeneus barberinus*	0.00089	0.0447
Mullidae	*Parupeneus ciliatus*	0.00022	0.0286
Mullidae	*Parupeneus cyclostomus*	0.00094	0.0374
Mullidae	*Parupeneus multifasciatus*	0.00374	0.2727
Mullidae	*Parupeneus pleurostigma*	0.00023	0.0102
Mullidae	*Parupeneus trifasciatus*	0.00023	0.0391
Nemipteridae	*Scolopsis bilineata*	0.00270	0.2196
Pomacanthidae	*Pygoplites diacanthus*	0.00023	0.0346
Scaridae	*Chlorurus sordidus*	0.02564	2.2817
Scaridae	*Hipposcarus longiceps*	0.00022	0.0046
Scaridae	*Scarus altipinnis*	0.00067	0.0699
Scaridae	*Scarus chameleon*	0.00067	0.0524
Scaridae	*Scarus forsteni*	0.00046	0.0774
Scaridae	*Scarus frenatus*	0.00127	0.2078
Scaridae	*Scarus ghobban*	0.00045	0.0956
Scaridae	*Scarus globiceps*	0.00136	0.1507
Scaridae	*Scarus niger*	0.00083	0.1898

3.1.2 Weighted average density and biomass of all finfish species recorded in Ha'atafu (continued)

(using distance-sampling underwater visual censuses (D-UVC))

Family	Species	Density (fish/m²)	Biomass (g/m²)
Scaridae	*Scarus oviceps*	0.00050	0.0205
Scaridae	*Scarus psittacus*	0.01490	1.1049
Scaridae	*Scarus rivulatus*	0.00258	0.2955
Scaridae	*Scarus schlegeli*	0.00939	1.1331
Scaridae	*Scarus* spp.	0.00022	0.0423
Scaridae	*Scarus spinus*	0.00055	0.0896
Serranidae	*Cephalopholis urodeta*	0.00050	0.0389
Serranidae	*Epinephelus macrospilos*	0.00022	0.0395
Serranidae	*Epinephelus merra*	0.00068	0.0422
Serranidae	*Epinephelus polyphekadion*	0.00022	0.0331
Siganidae	*Siganus argenteus*	0.02881	0.4470
Siganidae	*Siganus spinus*	0.01318	0.3206
Zanclidae	*Zanclus cornutus*	0.00270	0.1688

3.2 Manuka finfish survey data

3.2.1 Coordinates (WGS84) of the 12 D-UVC transects used to assess finfish resource status in Manuka

Station	Habitat	Latitude	Longitude
TRA13	Back-reef	21°04'07.7988" S	175°06'19.98" W
TRA24	Outer reef	21°04'07.7988" S	175°06'19.98" W
TRA14	Back-reef	21°04'54.12" S	175°04'23.7" W
TRA15	Back-reef	21°05'14.64" S	175°01'34.86" W
TRA16	Coastal reef	21°07'05.2788" S	175°10'05.4012" W
TRA17	Back-reef	21°05'34.3788" S	175°05'39.9012" W
TRA18	Back-reef	21°04'58.3788" S	175°09'37.3212" W
TRA19	Back-reef	21°00'15.3612" S	175°00'31.0212" W
TRA20	Back-reef	21°01'22.1412" S	175°00'46.1988" W
TRA21	Back-reef	21°02'33.2988" S	175°00'17.1" W
TRA22	Outer reef	21°02'20.5188" S	175°06'47.52" W
TRA23	Outer reef	21°01'31.9188" S	175°06'12.7188" W

3.2.2 Weighted average density and biomass of all finfish species recorded in Manuka (using distance-sampling underwater visual censuses (D-UVC))

Family	Species	Density (fish/m²)	Biomass (g/m²)
Acanthuridae	*Acanthurus blochii*	0.00030	0.0278
Acanthuridae	*Acanthurus nigricauda*	0.00040	0.0305
Acanthuridae	*Acanthurus nigrofuscus*	0.01330	0.6969
Acanthuridae	*Acanthurus pyroferus*	0.00015	0.0087
Acanthuridae	*Acanthurus triostegus*	0.00030	0.0092
Acanthuridae	*Acanthurus xanthopterus*	0.00015	0.0186
Acanthuridae	*Ctenochaetus binotatus*	0.00044	0.0342
Acanthuridae	*Ctenochaetus flavicauda*	0.00045	0.0199
Acanthuridae	*Ctenochaetus striatus*	0.05565	5.4587
Acanthuridae	*Naso lituratus*	0.00045	0.0207
Acanthuridae	*Naso unicornis*	0.00027	0.0096
Acanthuridae	*Zebrasoma scopas*	0.02213	0.7925
Balistidae	*Rhinecanthus aculeatus*	0.00015	0.0021
Balistidae	*Sufflamen chrysopterum*	0.00044	0.0401
Chaetodontidae	*Chaetodon auriga*	0.00331	0.1387
Chaetodontidae	*Chaetodon citrinellus*	0.00605	0.0775
Chaetodontidae	*Chaetodon ephippium*	0.00037	0.0253
Chaetodontidae	*Chaetodon flavirostris*	0.00072	0.0308
Chaetodontidae	*Chaetodon lunulatus*	0.01001	0.2548
Chaetodontidae	*Chaetodon melannotus*	0.00094	0.0196
Chaetodontidae	*Chaetodon mertensii*	0.00178	0.0819
Chaetodontidae	*Chaetodon pelewensis*	0.00345	0.0553
Chaetodontidae	*Chaetodon plebeius*	0.00301	0.0607
Chaetodontidae	*Chaetodon trifascialis*	0.00237	0.0604
Chaetodontidae	*Chaetodon unimaculatus*	0.00163	0.0663
Chaetodontidae	*Heniochus chrysostomus*	0.00030	0.0159
Holocentridae	*Myripristis berndti*	0.00015	0.0285
Holocentridae	*Myripristis violacea*	0.00015	0.0187

3.2.2 Weighted average density and biomass of all finfish species recorded in Manuka (continued)

(using distance-sampling underwater visual censuses (D-UVC))

Family	Species	Density (fish/m²)	Biomass (g/m²)
Holocentridae	*Neoniphon opercularis*	0.00015	0.0101
Holocentridae	*Neoniphon sammara*	0.00015	0.0202
Holocentridae	*Sargocentron caudimaculatum*	0.00045	0.0525
Holocentridae	*Sargocentron spiniferum*	0.00045	0.0841
Labridae	*Bodianus loxozonus*	0.00015	0.0154
Labridae	*Cheilinus chlorourus*	0.00506	0.5154
Labridae	*Coris aygula*	0.00015	0.0341
Labridae	*Epibulus insidiator*	0.00012	0.0102
Labridae	*Hemigymnus fasciatus*	0.00015	0.0227
Labridae	*Hemigymnus melapterus*	0.00057	0.2012
Labridae	*Oxycheilinus digramma*	0.00044	0.0461
Labridae	*Oxycheilinus unifasciatus*	0.00015	0.0216
Lethrinidae	*Lethrinus harak*	0.00015	0.0452
Lethrinidae	*Lethrinus obsoletus*	0.00015	0.0222
Lethrinidae	*Monotaxis grandoculis*	0.00015	0.0291
Lutjanidae	*Lutjanus fulvus*	0.00325	0.6269
Lutjanidae	*Lutjanus kasmira*	0.00012	0.0084
Mullidae	*Parupeneus barberinoides*	0.00027	0.0108
Mullidae	*Parupeneus barberinus*	0.00030	0.0165
Mullidae	*Parupeneus ciliatus*	0.00266	0.4879
Mullidae	*Parupeneus multifasciatus*	0.00235	0.2655
Mullidae	*Parupeneus trifasciatus*	0.00015	0.0152
Nemipteridae	*Scolopsis bilineata*	0.00353	0.2774
Scaridae	*Chlorurus sordidus*	0.01464	1.7563
Scaridae	*Hipposcarus longiceps*	0.00044	0.1094
Scaridae	*Scarus altipinnis*	0.00074	0.1029
Scaridae	*Scarus chameleon*	0.00059	0.0593
Scaridae	*Scarus niger*	0.00012	0.0127
Scaridae	*Scarus oviceps*	0.00012	0.0174
Scaridae	*Scarus psittacus*	0.01089	0.9058
Scaridae	*Scarus rivulatus*	0.01272	2.0957
Scaridae	*Scarus schlegeli*	0.00421	0.3835
Scaridae	*Scarus spinus*	0.00141	0.1282
Serranidae	*Cephalopholis argus*	0.00044	0.2057
Serranidae	*Epinephelus merra*	0.00074	0.0442
Siganidae	*Siganus argenteus*	0.00030	0.0062
Siganidae	*Siganus spinus*	0.01030	0.3194
Zanclidae	*Zanclus cornutus*	0.00089	0.0626

3.3 Koulo finfish survey data

3.3.1 Coordinates (WGS84) of the 13 D-UVC transects used to assess finfish resource status in Koulo

Station	Habitat	Latitude	Longitude
TRA10	Back-reef	19°45'08.0388" S	174°19'58.9188" W
TRA09	Outer reef	19°47'11.3388" S	174°21'40.2012" W
TRA01	Back-reef	19°50'06" S	174°25'07.2588" W
TRA05	Outer reef	19°45'05.6988" S	174°22'26.8212" W
TRA13	Outer reef	19°42'58.5" S	174°20'20.4612" W
TRA08	Outer reef	19°46'55.4988" S	174°23'18.8988" W
TRA12	Back-reef	19°44'36.06" S	174°19'26.3388" W
TRA11	Outer reef	19°45'05.94" S	174°20'13.9812" W
TRA07	Outer reef	19°46'39.6012" S	174°23'08.16" W
TRA03	Back-reef	19°48'29.34" S	174°22'11.1612" W
TRA04	Outer reef	19°46'09.66" S	174°21'15.48" W
TRA06	Back-reef	19°47'13.92" S	174°20'56.2812" W
TRA02	Back-reef	19°49'11.7012" S	174°22'31.1412" W

3.3.2 Weighted average density and biomass of all finfish species recorded in Koulo (using distance-sampling underwater visual censuses (D-UVC))

Family	Species	Density (fish/m²)	Biomass (g/m²)
Acanthuridae	*Acanthurus lineatus*	0.00465	1.4826
Acanthuridae	*Acanthurus nigricans*	0.00011	0.0196
Acanthuridae	*Acanthurus nigrofuscus*	0.03088	1.6038
Acanthuridae	*Acanthurus nigroris*	0.00011	0.0303
Acanthuridae	*Acanthurus triostegus*	0.00927	0.2918
Acanthuridae	*Ctenochaetus flavicauda*	0.00027	0.0037
Acanthuridae	*Ctenochaetus striatus*	0.07940	13.7488
Acanthuridae	*Ctenochaetus strigosus*	0.00043	0.0115
Acanthuridae	*Naso caesius*	0.00013	0.0629
Acanthuridae	*Naso lituratus*	0.00153	0.3149
Acanthuridae	*Naso unicornis*	0.00114	0.1661
Acanthuridae	*Zebrasoma scopas*	0.01533	1.0003
Acanthuridae	*Zebrasoma veliferum*	0.00005	0.0052
Balistidae	*Balistapus undulatus*	0.00005	0.0037
Balistidae	*Rhinecanthus rectangulus*	0.00005	0.0046
Balistidae	*Sufflamen chrysopterum*	0.00087	0.1737
Chaetodontidae	*Chaetodon auriga*	0.00108	0.0993
Chaetodontidae	*Chaetodon citrinellus*	0.01023	0.2406
Chaetodontidae	*Chaetodon ephippium*	0.00087	0.0679
Chaetodontidae	*Chaetodon kleinii*	0.00163	0.0194
Chaetodontidae	*Chaetodon lunula*	0.00005	0.0070
Chaetodontidae	*Chaetodon lunulatus*	0.00525	0.1440
Chaetodontidae	*Chaetodon melannotus*	0.00222	0.1079
Chaetodontidae	*Chaetodon mertensii*	0.00114	0.0320
Chaetodontidae	*Chaetodon ornatissimus*	0.00108	0.1428
Chaetodontidae	*Chaetodon pelewensis*	0.00048	0.0116
Chaetodontidae	*Chaetodon plebeius*	0.00011	0.0031

3.3.2 Weighted average density and biomass of all finfish species recorded in Koulo (continued)
(using distance-sampling underwater visual censuses (D-UVC))

Family	Species	Density (fish/m²)	Biomass (g/m²)
Chaetodontidae	*Chaetodon rafflesii*	0.00027	0.0166
Chaetodontidae	*Chaetodon reticulatus*	0.00032	0.0316
Chaetodontidae	*Chaetodon trifascialis*	0.00926	0.3710
Chaetodontidae	*Chaetodon ulietensis*	0.00005	0.0033
Chaetodontidae	*Chaetodon unimaculatus*	0.00179	0.2373
Chaetodontidae	*Chaetodon vagabundus*	0.00146	0.1250
Chaetodontidae	*Forcipiger flavissimus*	0.00011	0.0053
Chaetodontidae	*Heniochus chrysostomus*	0.00005	0.0073
Chaetodontidae	*Heniochus varius*	0.00011	0.0073
Holocentridae	*Myripristis kuntee*	0.00177	0.2177
Holocentridae	*Myripristis murdjan*	0.00102	0.1728
Holocentridae	*Myripristis violacea*	0.00011	0.0135
Holocentridae	*Neoniphon opercularis*	0.00005	0.0061
Holocentridae	*Neoniphon sammara*	0.00134	0.1606
Holocentridae	*Sargocentron caudimaculatum*	0.00059	0.0681
Holocentridae	*Sargocentron diadema*	0.00005	0.0048
Holocentridae	*Sargocentron spiniferum*	0.00038	0.0961
Labridae	*Bodianus loxozonus*	0.00005	0.0179
Labridae	*Cheilinus chlorourus*	0.00243	0.3310
Labridae	*Cheilinus fasciatus*	0.00005	0.0033
Labridae	*Coris aygula*	0.00027	0.0543
Labridae	*Epibulus insidiator*	0.00016	0.0330
Labridae	*Hemigymnus fasciatus*	0.00049	0.0467
Labridae	*Hemigymnus melapterus*	0.00276	0.1618
Labridae	*Oxycheilinus celebicus*	0.00005	0.0121
Labridae	*Oxycheilinus digramma*	0.00027	0.0100
Labridae	*Oxycheilinus unifasciatus*	0.00005	0.0091
Lethrinidae	*Monotaxis grandoculis*	0.00092	0.2324
Lutjanidae	*Lutjanus fulvus*	0.00038	0.1387
Lutjanidae	*Lutjanus monostigma*	0.00005	0.0124
Mullidae	*Mulloidichthys flavolineatus*	0.00419	0.5931
Mullidae	*Mulloidichthys vanicolensis*	0.00080	0.1387
Mullidae	*Parupeneus barberinus*	0.00027	0.0551
Mullidae	*Parupeneus ciliatus*	0.00027	0.0413
Mullidae	*Parupeneus multifasciatus*	0.00292	0.3312
Mullidae	*Parupeneus trifasciatus*	0.00059	0.0851
Nemipteridae	*Scolopsis bilineata*	0.00395	0.6345
Scaridae	*Chlorurus frontalis*	0.00005	0.0499
Scaridae	*Chlorurus sordidus*	0.03563	4.3405
Scaridae	*Scarus altipinnis*	0.00027	0.1985
Scaridae	*Scarus chameleon*	0.00217	0.4211
Scaridae	*Scarus dimidiatus*	0.00016	0.0514
Scaridae	*Scarus forsteni*	0.00005	0.0170
Scaridae	*Scarus frenatus*	0.00108	0.2342
Scaridae	*Scarus ghobban*	0.00027	0.1008
Scaridae	*Scarus globiceps*	0.00027	0.0966

3.3.2 Weighted average density and biomass of all finfish species recorded in Koulo (continued)

(using distance-sampling underwater visual censuses (D-UVC))

Family	Species	Density (fish/m²)	Biomass (g/m²)
Scaridae	*Scarus niger*	0.00027	0.0995
Scaridae	*Scarus oviceps*	0.00032	0.0677
Scaridae	*Scarus psittacus*	0.01738	2.6516
Scaridae	*Scarus rivulatus*	0.00244	0.3465
Scaridae	*Scarus schlegeli*	0.00065	0.1240
Scaridae	*Scarus spinus*	0.00455	0.4580
Serranidae	*Cephalopholis argus*	0.00016	0.0543
Serranidae	*Cephalopholis urodeta*	0.00011	0.0161
Serranidae	*Epinephelus fasciatus*	0.00027	0.0725
Serranidae	*Epinephelus merra*	0.00011	0.0138
Siganidae	*Siganus spinus*	0.01158	0.8162
Zanclidae	*Zanclus cornutus*	0.00103	0.1160

3.4 Lofanga finfish survey data

3.4.1 Coordinates (WGS84) of the 13 D-UVC transects used to assess finfish resource status in Lofanga

Station	Habitat	Latitude	Longitude
TRA04	Outer reef	19°44'50.5788" S	174°35'15.9" W
TRA05	Back-reef	19°45'54.2988" S	174°33'45.6588" W
TRA12	Outer reef	19°50'46.86" S	174°30'43.1388" W
TRA06	Back-reef	19°46'05.6388" S	174°32'46.32" W
TRA02	Back-reef	19°45'30.3012" S	174°36'38.9412" W
TRA03	Back-reef	19°45'09.2988" S	174°35'56.6412" W
TRA09	Outer reef	19°49'24.24" S	174°33'47.6388" W
TRA08	Outer reef	19°46'21.54" S	174°31'45.66" W
TRA13	Outer reef	19°50'29.3388" S	174°31'49.8612" W
TRA11	Outer reef	19°49'18.1812" S	174°32'38.58" W
TRA10	Outer reef	19°49'13.08" S	174°33'19.8" W
TRA07	Outer reef	19°46'40.26" S	174°32'58.6212" W
TRA01	Outer reef	19°46'34.9212" S	174°37'30.2988" W

3.4.2 Weighted average density and biomass of all finfish species recorded in Lofanga (using distance-sampling underwater visual censuses (D-UVC))

Family	Species	Density (fish/m²)	Biomass (g/m²)
Acanthuridae	*Acanthurus lineatus*	0.01663	3.5092
Acanthuridae	*Acanthurus nigricauda*	0.00047	0.1169
Acanthuridae	*Acanthurus nigrofuscus*	0.03417	1.4259
Acanthuridae	*Acanthurus olivaceus*	0.00017	0.0411
Acanthuridae	*Acanthurus triostegus*	0.00300	0.2308
Acanthuridae	*Ctenochaetus binotatus*	0.00022	0.0065
Acanthuridae	*Ctenochaetus striatus*	0.09128	16.5246
Acanthuridae	*Ctenochaetus strigosus*	0.00056	0.0291
Acanthuridae	*Naso lituratus*	0.00231	0.3919
Acanthuridae	*Naso unicornis*	0.00025	0.0340
Acanthuridae	*Zebrasoma scopas*	0.01286	0.9285
Acanthuridae	*Zebrasoma veliferum*	0.00337	0.2685
Balistidae	*Balistapus* spp.	0.00025	0.0594
Balistidae	*Balistapus undulatus*	0.00045	0.0553
Balistidae	*Melichthys vidua*	0.00022	0.0230
Balistidae	*Sufflamen bursa*	0.00011	0.0041
Chaetodontidae	*Chaetodon auriga*	0.00297	0.1978
Chaetodontidae	*Chaetodon baronessa*	0.00011	0.0102
Chaetodontidae	*Chaetodon citrinellus*	0.00566	0.0834
Chaetodontidae	*Chaetodon ephippium*	0.00092	0.0886
Chaetodontidae	*Chaetodon lineolatus*	0.00022	0.0187
Chaetodontidae	*Chaetodon lunula*	0.00045	0.0313
Chaetodontidae	*Chaetodon lunulatus*	0.00367	0.1650
Chaetodontidae	*Chaetodon melannotus*	0.00022	0.0185
Chaetodontidae	*Chaetodon pelewensis*	0.00370	0.1119
Chaetodontidae	*Chaetodon plebeius*	0.00045	0.0102
Chaetodontidae	*Chaetodon rafflesii*	0.00161	0.1031

3.4.2 Weighted average density and biomass of all finfish species recorded in Lofanga (continued)

(using distance-sampling underwater visual censuses (D-UVC))

Family	Species	Density (fish/m²)	Biomass (g/m²)
Chaetodontidae	*Chaetodon reticulatus*	0.00078	0.0500
Chaetodontidae	*Chaetodon trifascialis*	0.00056	0.0191
Chaetodontidae	*Chaetodon ulietensis*	0.00117	0.0608
Chaetodontidae	*Chaetodon vagabundus*	0.00156	0.0988
Chaetodontidae	*Forcipiger longirostris*	0.00033	0.0156
Chaetodontidae	*Heniochus chrysostomus*	0.00056	0.0426
Chaetodontidae	*Heniochus varius*	0.00022	0.0091
Holocentridae	*Myripristis berndti*	0.00011	0.0249
Holocentridae	*Myripristis kuntee*	0.00506	0.8654
Holocentridae	*Myripristis murdjan*	0.00553	0.6457
Holocentridae	*Myripristis violacea*	0.00011	0.0168
Holocentridae	*Neoniphon argenteus*	0.00050	0.0221
Holocentridae	*Neoniphon opercularis*	0.00089	0.1188
Holocentridae	*Neoniphon sammara*	0.00801	0.5474
Holocentridae	*Sargocentron caudimaculatum*	0.00272	0.4376
Holocentridae	*Sargocentron spiniferum*	0.00250	0.4729
Kyphosidae	*Kyphosus cinerascens*	0.00025	0.0403
Labridae	*Bodianus loxozonus*	0.00022	0.0656
Labridae	*Cheilinus chlorourus*	0.00267	0.3839
Labridae	*Cheilinus trilobatus*	0.00011	0.0125
Labridae	*Coris aygula*	0.00036	0.1468
Labridae	*Coris gaimard*	0.00011	0.0169
Labridae	*Epibulus insidiator*	0.00036	0.2186
Labridae	*Hemigymnus fasciatus*	0.00022	0.0510
Labridae	*Oxycheilinus celebicus*	0.00022	0.0104
Labridae	*Oxycheilinus unifasciatus*	0.00033	0.0395
Lethrinidae	*Gnathodentex aureolineatus*	0.00738	0.6282
Lethrinidae	*Lethrinus lentjan*	0.00011	0.0168
Lethrinidae	*Monotaxis grandoculis*	0.00425	1.0762
Lutjanidae	*Aphareus furca*	0.00022	0.0752
Lutjanidae	*Lutjanus fulvus*	0.00050	0.1188
Lutjanidae	*Lutjanus kasmira*	0.00175	0.1109
Mullidae	*Mulloidichthys flavolineatus*	0.00422	0.6733
Mullidae	*Mulloidichthys vanicolensis*	0.01307	2.9950
Mullidae	*Parupeneus barberinus*	0.00022	0.0458
Mullidae	*Parupeneus cyclostomus*	0.00112	0.1278
Mullidae	*Parupeneus multifasciatus*	0.00392	0.3874
Mullidae	*Parupeneus pleurostigma*	0.00025	0.0212
Mullidae	*Parupeneus trifasciatus*	0.00100	0.3049
Nemipteridae	*Scolopsis bilineata*	0.00350	0.3846
Scaridae	*Calotomus spinidens*	0.00011	0.0112
Scaridae	*Chlorurus microrhinos*	0.00011	0.1282
Scaridae	*Chlorurus sordidus*	0.01084	2.3422
Scaridae	*Scarus altipinnis*	0.00779	3.6357
Scaridae	*Scarus chameleon*	0.00011	0.0276
Scaridae	*Scarus frenatus*	0.00355	1.6039

3.4.2 Weighted average density and biomass of all finfish species recorded in Lofanga (continued)

(using distance-sampling underwater visual censuses (D-UVC))

Family	Species	Density (fish/m²)	Biomass (g/m²)
Scaridae	*Scarus globiceps*	0.00070	0.1689
Scaridae	*Scarus niger*	0.00434	1.1067
Scaridae	*Scarus oviceps*	0.00033	0.0652
Scaridae	*Scarus psittacus*	0.00300	0.6954
Scaridae	*Scarus schlegeli*	0.00434	0.9210
Scaridae	*Scarus* spp.	0.00033	0.0191
Scaridae	*Scarus spinus*	0.00045	0.0920
Serranidae	*Cephalopholis argus*	0.00045	0.1105
Serranidae	*Cephalopholis urodeta*	0.00200	0.2226
Siganidae	*Siganus argenteus*	0.00350	0.1244
Siganidae	*Siganus niger*	0.00067	0.0757
Siganidae	*Siganus spinus*	0.00100	0.1076
Siganidae	*Siganus uspi*	0.00033	0.0227
Zanclidae	*Zanclus cornutus*	0.00322	0.3409

APPENDIX 4: INVERTEBRATE SURVEY DATA

4.1 Ha'atafu invertebrate survey data

4.1.1 Invertebrate species recorded in different assessments in Ha'atafu

Group	Species	Broad scale	Reef benthos	Soft benthos	Others
Bêche-de-mer	*Actinopyga echinites*	+			
Bêche-de-mer	*Actinopyga lecanora*	+			+
Bêche-de-mer	*Actinopyga mauritiana*	+	+		+
Bêche-de-mer	*Actinopyga miliaris*	+			+
Bêche-de-mer	*Bohadschia argus*	+	+		+
Bêche-de-mer	*Bohadschia similis*	+		+	+
Bêche-de-mer	*Bohadschia vitiensis*	+	+	+	+
Bêche-de-mer	*Holothuria atra*	+	+	+	+
Bêche-de-mer	*Holothuria coluber*	+			+
Bêche-de-mer	*Holothuria edulis*	+		+	+
Bêche-de-mer	*Holothuria fuscogilva*	+			
Bêche-de-mer	*Holothuria fuscopunctata*	+			+
Bêche-de-mer	*Holothuria leucospilota*	+	+	+	
Bêche-de-mer	*Holothuria nobilis*	+			+
Bêche-de-mer	*Holothuria scabra versicolor*	+		+	
Bêche-de-mer	*Stichopus chloronotus*	+	+		+
Bêche-de-mer	*Stichopus hermanni*	+			+
Bêche-de-mer	*Stichopus hermanni-horrens*	+			+
Bêche-de-mer	*Synapta* spp.	+		+	+
Bêche-de-mer	*Thelenota ananas*	+			+
Bêche-de-mer	*Thelenota anax*	+			+
Bivalve	*Anadara antiquata*			+	
Bivalve	*Atrina* spp.	+			+
Bivalve	*Chama* spp.	+			+
Bivalve	*Fragum fragum*			+	
Bivalve	*Pinctada margaritifera*	+			+
Bivalve	*Pinna* spp.			+	
Bivalve	*Spondylus* spp.	+			+
Bivalve	*Tridacna maxima*	+	+		+
Bivalve	*Tridacna squamosa*	+			+
Cnidarians	*Cassiopea andromeda*			+	
Cnidarians	*Cassiopea* spp.			+	
Cnidarians	*Stichodactyla* spp.	+	+		+
Crustacean	*Calappa hepatica*			+	
Crustacean	*Panulirus* spp.	+			+
Gastropod	*Astralium* spp.		+		+
Gastropod	*Charonia tritonis*				+
Gastropod	*Conus* spp.	+	+	+	+
Gastropod	*Conus vexillum*		+		+
Gastropod	*Cryptoplax* spp.		+		
Gastropod	*Cypraea annulus*		+		
Gastropod	*Cypraea arabica*		+		
Gastropod	*Cypraea argus*			+	
Gastropod	*Cypraea caputserpensis*		+		

+ = presence of the species.

Appendix 4: Invertebrate survey data
Ha'atafu

4.1.1 Invertebrate species recorded in different assessments in Ha'atafu (continued)

Group	Species	Broad scale	Reef benthos	Soft benthos	Others
Gastropod	*Cypraea moneta*			+	
Gastropod	*Cypraea tigris*		+		
Gastropod	*Dolabella auricularia*	+		+	
Gastropod	*Drupa morum*		+		
Gastropod	*Lambis crocata*				+
Gastropod	*Lambis lambis*	+	+		+
Gastropod	*Lambis truncata*				+
Gastropod	*Latirolagena smaragdula*		+		+
Gastropod	*Mammilla melanostoma*			+	
Gastropod	*Nassarius* spp.			+	
Gastropod	*Pleuroploca filamentosa*		+		+
Gastropod	*Strombus gibberulus gibbosus*			+	
Gastropod	*Strombus mutabilis*			+	
Gastropod	*Strombus* spp.			+	
Gastropod	*Tectus pyramis*		+		+
Gastropod	*Thais aculeata*				+
Gastropod	*Thais* spp.		+		
Gastropod	*Trochus maculata*		+		
Gastropod	*Trochus niloticus*	+			+
Gastropod	*Trochus* spp.		+		
Gastropod	*Turbo argyrostomus*		+		+
Gastropod	*Turbo crassus*		+		+
Gastropod	*Turbo setosus*		+		+
Gastropod	*Tutufa rubeta*		+		
Gastropod	*Vasum ceramicum*				+
Gastropod	*Vasum turbinellum*		+		
Star	*Acanthaster planci*	+	+		+
Star	*Choriaster granulatus*	+			+
Star	*Culcita novaeguineae*	+	+		+
Star	*Linckia laevigata*	+	+	+	+
Star	*Protoreaster nodosus*	+	+		+
Urchin	*Diadema* spp.	+	+		+
Urchin	*Echinometra mathaei*	+	+	+	+
Urchin	*Echinothrix calamaris*		+		
Urchin	*Echinothrix diadema*	+	+		+
Urchin	*Heterocentrotus mammillatus*	+	+		+
Urchin	*Tripneustes gratilla*	+	+	+	

+ = presence of the species.

4.1.2 Ha'atafu broad-scale assessment data review

Station: Six 2 m x 300 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Acanthaster planci	0.8	0.4	71	13.8	2.1	4	0.8	0.4	12	3.1	0.8	3
Actinopyga echinites	0.5	0.3	71	16.7	2.2	2	0.5	0.3	12	2.8	0.2	2
Actinopyga lecanora	1.1	0.8	71	26.7	11.6	3	1.2	0.7	12	4.6	1.9	3
Actinopyga mauritiana	0.2	0.2	71	16.7		1	0.3	0.3	12	4.2		1
Actinopyga miliaris	1.6	1.0	71	28.1	12.9	4	1.7	1.1	12	6.9	2.9	3
Atrina spp.	0.6	0.4	71	14.9	1.4	3	0.6	0.3	12	2.4	0.3	3
Bohadschia argus	23.3	4.1	71	42.3	5.9	39	25.4	7.9	12	27.7	8.2	11
Bohadschia similis	0.7	0.5	71	25.1	8.4	2	0.5	0.4	12	3.3	0.5	2
Bohadschia vitiensis	30.0	7.1	71	66.7	13.1	32	31.3	12.3	12	37.5	13.9	10
Chama spp.	0.2	0.2	71	16.7		1	0.2	0.2	12	2.8		1
Choriaster granulatus	0.5	0.5	71	33.3		1	0.5	0.5	12	5.6		1
Conus spp.	1.1	0.6	71	18.8	5.3	4	0.9	0.7	12	5.4	2.2	2
Culcita novaeguineae	12.2	4.1	71	51.0	13.6	17	13.8	7.3	12	23.7	11.3	7
Diadema spp.	1.6	0.7	71	19.0	2.8	6	1.7	0.8	12	5.1	1.1	4
Dolabella auricularia	0.5	0.5	71	33.6		1	0.3	0.3	12	3.8		1
Echinometra mathaei	5.2	4.7	71	183.3	150.0	2	5.1	5.1	12	61.1		1
Echinothrix diadema	10.8	5.7	71	109.7	45.5	7	10.2	9.5	12	61.5	53.1	2
Heterocentrotus mammillatus	60.4	21.4	71	285.8	79.2	15	58.6	50.1	12	175.9	144.0	4
Holothuria atra	555.9	158.1	71	858.0	232.9	46	543.5	336.7	12	724.7	437.5	9
Holothuria coluber	462.3	117.0	71	1058.8	228.3	31	454.1	264.8	12	908.2	475.6	6
Holothuria edulis	780.8	253.8	71	1179.5	371.3	47	762.4	553.0	12	914.9	658.0	10
Holothuria fuscopunctata	3.5	1.1	71	20.8	3.5	12	3.8	1.6	12	9.1	2.2	5
Holothuria leucospilota	20.9	7.5	71	106.1	28.7	14	20.7	17.4	12	82.6	64.0	3
Holothuria nobilis	1.3	0.9	71	30.2	13.5	3	0.7	0.4	12	2.8	0.0	3
Holothuria scabra versicolor	0.2	0.2	71	11.2		1	0.2	0.2	12	2.2		1
Lambis lambis	2.9	1.1	71	23.0	5.7	9	2.7	1.0	12	5.4	1.2	6
Linckia laevigata	24.8	8.8	71	97.6	28.9	18	25.4	18.4	12	43.6	30.5	7
Panulirus spp.	0.2	0.2	71	16.7		1	0.2	0.2	12	2.8		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.1.2 Ha'atafu broad-scale assessment data review (continued)

Station: Six 2 m x 300 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Pinctada margaritifera	2.3	0.8	71	16.5	2.3	10	2.4	1.1	12	5.8	1.7	5
Protoreaster nodosus	0.5	0.5	71	33.3		1	0.5	0.5	12	5.6		1
Spondylus spp.	0.9	0.7	71	33.3	16.7	2	0.9	0.9	12	11.1		1
Stichodactyla spp.	0.7	0.5	71	25.0	8.3	2	0.7	0.5	12	4.2	1.4	2
Stichopus chloronotus	26.9	8.1	71	53.1	14.8	36	23.6	6.8	12	25.7	7.0	11
Stichopus hermanni	8.7	1.9	71	26.8	3.4	23	8.8	2.8	12	13.2	3.1	8
Stichopus hermanni-horrens	2.8	2.2	71	66.7	41.9	3	1.5	1.3	12	9.0	6.2	2
Synapta spp.	0.2	0.2	71	16.7		1	0.2	0.2	12	2.8		1
Thelenota ananas	1.3	0.6	71	18.8	4.2	5	1.6	1.1	12	6.5	3.2	3
Thelenota anax	1.7	1.0	71	30.0	12.3	4	1.7	1.2	12	6.9	3.5	3
Tridacna maxima	3.6	1.0	71	19.6	2.7	13	4.1	2.1	12	8.3	3.4	6
Tridacna squamosa	0.7	0.4	71	16.7	0.0	3	0.8	0.6	12	4.9	0.7	2
Tripneustes gratilla	0.7	0.5	71	26.2	7.3	2	0.5	0.4	12	3.2	0.6	2
Trochus niloticus	0.2	0.2	71	16.7		1	0.2	0.2	12	2.8		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.1.3 Ha'atafu medium- and deep-water broad-scale assessment data review

Station: Twelve 4 m x 100 m transects on SCUBA towed by broad-scale board in mid-to-deep waters.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Actinopyga echinites	3.1	1.7	24	25.0	0.0	3	3.1	3.1	2	6.3		1
Actinopyga miliaris	9.4	3.6	24	37.5	5.6	6	9.4	9.4	2	18.8		1
Bohadschia argus	8.3	2.9	24	28.6	3.6	7	8.3	2.1	2	8.3	2.1	2
Choriaster granulatus	29.2	9.1	24	53.8	13.5	13	29.2	20.8	2	29.2	20.8	2
Culcita novaeguineae	6.3	2.7	24	30.0	5.0	5	6.3	2.1	2	6.3	2.1	2
Holothuria atra	1.0	1.0	24	25.0		1	1.0	1.0	2	2.1		1
Holothuria edulis	3.1	2.3	24	37.5	12.5	2	3.1	3.1	2	6.3		1
Holothuria fuscogilva	2.1	1.4	24	25.0	0.0	2	2.1	0.0	2	2.1	0.0	2
Holothuria fuscopunctata	3.1	1.7	24	25.0	0.0	3	3.1	3.1	2	6.3		1
Holothuria nobilis	3.1	1.7	24	25.0	0.0	3	3.1	3.1	2	6.3		1
Linckia laevigata	1.0	1.0	24	25.0		1	1.0	1.0	2	2.1		1
Stichodactyla spp.	4.2	2.5	24	33.3	8.3	3	4.2	0.0	2	4.2	0.0	2
Thelenota ananas	10.4	3.7	24	35.7	5.1	7	10.4	6.3	2	10.4	6.3	2
Thelenota anax	16.7	4.7	24	40.0	5.5	10	16.7	10.4	2	16.7	10.4	2
Tridacna squamosa	1.0	1.0	24	25.0		1	1.0	1.0	2	2.1		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.1.4 Ha'atafu reef-benthos transect (RBt) assessment data review

Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Acanthaster planci	16.7	8.1	60	250.0	0.0	4	16.7	9.2	10	55.6	13.9	3
Actinopyga mauritiana	8.9	6.3	60	267.9	17.9	2	8.9	6.0	10	44.6	3.0	2
Astralium spp.	26.2	10.3	60	261.9	7.5	6	26.2	14.7	10	87.3	24.4	3
Bohadschia argus	8.3	5.8	60	250.0	0.0	2	8.3	5.6	10	41.7	0.0	2
Bohadschia vitiensis	8.3	5.8	60	250.0	0.0	2	8.3	8.3	10	83.3		1
Conus spp.	47.6	14.8	60	285.7	31.9	10	47.6	13.5	10	68.0	12.7	7
Conus vexillum	16.7	10.1	60	333.3	83.3	3	16.7	12.7	10	83.3	41.7	2
Cryptoplax spp.	4.8	4.8	60	285.7		1	4.8	4.8	10	47.6		1
Culcita novaeguineae	4.2	4.2	60	250.0		1	4.2	4.2	10	41.7		1
Cypraea annulus	19.0	9.3	60	285.7	0.0	4	19.0	19.0	10	190.5		1
Cypraea arabica	4.2	4.2	60	250.0		1	4.2	4.2	10	41.7		1
Cypraea caputserpensis	61.9	27.2	60	619.0	136.4	6	61.9	61.9	10	619.0		1
Cypraea tigris	8.9	6.3	60	267.9	17.9	2	8.9	6.0	10	44.6	3.0	2
Diadema spp.	125.0	81.4	60	1071.4	623.7	7	125.0	81.0	10	312.5	172.2	4
Drupa morum	33.3	23.6	60	1000.0	142.9	2	33.3	33.3	10	333.3		1
Echinometra mathaei	2171.4	499.3	60	4202.8	815.2	31	2171.4	920.2	10	2412.7	992.8	9
Echinothrix calamaris	45.8	41.8	60	1375.0	1125.0	2	45.8	41.4	10	229.2	187.5	2
Echinothrix diadema	16.7	10.1	60	333.3	83.3	3	16.7	12.7	10	83.3	41.7	2
Heterocentrotus mammillatus	1287.5	270.9	60	2340.9	411.0	33	1287.5	495.5	10	1839.3	597.5	7
Holothuria atra	203.0	42.1	60	529.5	67.6	23	203.0	56.7	10	253.7	57.7	8
Holothuria leucospilota	12.5	7.1	60	250.0	0.0	3	12.5	6.4	10	41.7	0.0	3
Lambis lambis	4.8	4.8	60	285.7		1	4.8	4.8	10	47.6		1
Latirolagena smaragdula	170.2	49.0	60	851.2	108.5	12	170.2	95.9	10	425.6	181.1	4
Linckia laevigata	51.2	17.9	60	383.9	44.1	8	51.2	29.2	10	128.0	55.8	4
Pleuroploca filamentosa	14.3	10.6	60	428.6	142.9	2	14.3	14.3	10	142.9		1
Protoreaster nodosus	4.8	4.8	60	285.7		1	4.8	4.8	10	47.6		1
Stichodactyla spp.	8.3	5.8	60	250.0	0.0	2	8.3	5.6	10	41.7	0.0	2
Stichopus chloronotus	75.0	28.7	60	500.0	117.9	9	75.0	61.7	10	250.0	187.9	3

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.1.4 Ha'atafu reef-benthos transect (RBt) assessment data review (continued)

Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Tectus pyramis	76.8	21.1	60	354.4	43.8	13	76.8	22.2	10	96.0	23.0	8
Thais spp.	4.8	4.8	60	285.7		1	4.8	4.8	10	47.6		1
Tridacna maxima	38.1	15.7	60	381.0	53.5	6	38.1	11.6	10	63.5	8.9	6
Tripneustes gratilla	9.5	6.7	60	285.7	0.0	2	9.5	6.3	10	47.6	0.0	2
Trochus maculata	100.0	56.3	60	1500.0	486.2	4	100.0	100.0	10	1000.0		1
Trochus spp.	4.8	4.8	60	285.7		1	4.8	4.8	10	47.6		1
Turbo argyrostomus	117.9	32.7	60	505.1	75.7	14	117.9	71.5	10	294.6	144.8	4
Turbo chrysostomus	171.4	73.5	60	1285.7	370.2	8	171.4	161.1	10	857.1	761.9	2
Turbo crassus	105.4	34.6	60	486.3	108.0	13	105.4	49.8	10	175.6	70.6	6
Turbo setosus	356.0	150.4	60	2669.6	740.4	8	356.0	346.7	10	1186.5	1144.8	3
Tutufa rubeta	4.2	4.2	60	250.0		1	4.2	4.2	10	41.7		1
Vasum turbinellum	14.3	10.6	60	428.6	142.9	2	14.3	10.2	10	71.4	23.8	2

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.1.5 Ha'atafu soft-benthos transect (SBt) assessment data review

Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Anadara antiquata	22.0	8.7	78	285.7	0.0	6	22.0	6.9	13	47.6	0.0	6
Bohadschia similis	29.3	9.9	78	285.7	0.0	8	29.3	10.1	13	63.5	10.0	6
Bohadschia vitiensis	14.7	7.2	78	285.7	0.0	4	14.7	11.3	13	95.2	47.6	2
Calappa hepatica	11.0	8.1	78	428.6	142.9	2	11.0	7.9	13	71.4	23.8	2
Cassiopea spp.	3.7	3.7	78	285.7		1	3.7	3.7	13	47.6		1
Cassiopea andromeda	3.7	3.7	78	285.7		1	3.7	3.7	13	47.6		1
Conus spp.	33.0	12.8	78	367.3	52.7	7	33.0	13.6	13	85.7	17.8	5
Dolabella auricularia	289.4	40.2	78	564.3	47.4	40	289.4	69.4	13	342.0	70.9	11
Echinometra mathaei	36.6	14.1	78	357.1	71.4	8	36.6	15.4	13	95.2	21.3	5
Fragum fragum	3.7	3.7	78	285.7		1	3.7	3.7	13	47.6		1
Holothuria atra	326.0	57.3	78	747.9	89.5	34	326.0	110.2	13	423.8	128.3	10
Holothuria edulis	7.3	5.1	78	285.7	0.0	2	7.3	5.0	13	47.6	0.0	2
Holothuria leucospilota	25.6	11.9	78	400.0	70.0	5	25.6	15.8	13	111.1	42.0	3
Holothuria scabra	7.3	5.1	78	285.7	0.0	2	7.3	7.3	13	95.2		1
Synapta spp.	95.2	20.6	78	353.7	39.0	21	95.2	29.0	13	154.8	32.1	8
Tripneustes gratilla	106.2	20.3	78	360.2	26.7	23	106.2	21.0	13	115.1	20.7	12

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.1.6 Ha'atafu soft-benthos quadrat (SBq) assessment data review

Station: 8 quadrat groups (4 quadrats/group).

Species	Quadrat groups			Quadrat groups _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Anadara antiquata	0.1	0.1	88	4.0	0.0	2	0.1	0.1	11	0.5	0.0	2
Conus spp.	0.4	0.1	88	4.5	0.5	8	0.4	0.1	11	0.9	0.1	5
Cypraea argus	0.0	0.0	88	4.0		1	0.0	0.0	11	0.5		1
Cypraea moneta	0.1	0.1	88	6.0	2.0	2	0.1	0.1	11	1.5		1
Dolabella auricularia	0.3	0.1	88	4.0	0.0	6	0.3	0.2	11	1.0	0.3	3
Echinometra mathaei	0.1	0.1	88	4.0	0.0	2	0.1	0.1	11	0.5	0.0	2
Linckia laevigata	0.0	0.0	88	4.0		1	0.0	0.0	11	0.5		1
Mammilla melanostoma	0.1	0.1	88	4.0	0.0	2	0.1	0.1	11	0.5	0.0	2
Nassarius spp.	0.1	0.1	88	4.0	0.0	2	0.1	0.1	11	0.5	0.0	2
Pinna spp.	0.1	0.1	88	4.0	0.0	2	0.1	0.1	11	0.5	0.0	2
Strombus gibberulus gibbosus	17.6	3.2	88	44.2	5.5	35	17.6	7.0	11	32.3	9.2	6
Strombus mutabilis	1.0	0.3	88	8.4	1.5	11	1.0	0.6	11	3.8	0.8	3
Strombus spp.	4.0	0.8	88	12.4	1.8	28	4.0	1.6	11	7.3	2.2	6

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.1.7 Ha'atafu reef-front search (RFs) assessment data review
Station: Six 5-min search periods.

Species	Search period			Search period _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Acanthaster planci	4.5	4.2	57	129.2	110.8	2	6.2	5.7	7	21.5	18.5	2
Actinopyga mauritiana	1.0	0.7	57	28.0	4.0	2	0.9	0.6	7	3.1	0.4	2
Astralium spp.	2.9	1.3	57	32.7	4.0	5	2.6	1.1	7	4.5	1.1	4
Bohadschia argus	11.2	4.5	57	91.5	18.4	7	15.1	9.7	7	35.1	17.5	3
Conus spp.	0.5	0.5	57	29.1		1	0.5	0.5	7	3.2		1
Culcita novaeguineae	0.6	0.6	57	36.8		1	0.9	0.9	7	6.1		1
Diadema spp.	0.7	0.5	57	21.2	2.8	2	0.8	0.5	7	2.9	0.2	2
Echinometra mathaei	0.5	0.5	57	30.7		1	0.5	0.5	7	3.4		1
Heterocentrotus mammillatus	3.3	1.5	57	38.0	5.2	5	3.6	1.4	7	6.3	1.3	4
Holothuria atra	16.3	8.3	57	185.8	56.8	5	21.4	12.7	7	49.9	20.2	3
Holothuria edulis	3.5	2.1	57	67.4	12.3	3	4.8	4.8	7	33.7		1
Holothuria nobilis	1.2	0.7	57	23.7	5.3	3	1.7	1.1	7	5.9	0.2	2
Lambis crocata	1.4	0.8	57	27.5	4.5	3	1.5	1.0	7	5.1	2.0	2
Lambis lambis	2.3	1.0	57	26.4	3.9	5	2.9	1.8	7	6.9	2.8	3
Latirolagena smaragdula	0.6	0.6	57	34.3		1	0.8	0.8	7	5.7		1
Linckia laevigata	1.8	1.1	57	34.2	10.9	3	2.2	1.7	7	7.7	4.5	2
Pinctada margaritifera	0.3	0.3	57	18.4		1	0.4	0.4	7	3.1		1
Stichodactyla spp.	1.4	1.0	57	39.3	8.6	2	1.2	0.8	7	4.4	1.0	2
Stichopus chloronotus	16.2	7.7	57	132.3	44.5	7	20.7	12.1	7	36.2	18.1	4
Tectus pyramis	5.9	2.1	57	37.4	7.4	9	6.8	3.5	7	11.9	4.7	4
Thais aculeata	0.6	0.6	57	34.3		1	0.8	0.8	7	5.7		1
Thelenota ananas	0.6	0.6	57	34.3		1	0.8	0.8	7	5.7		1
Tridacna derasa	0.6	0.6	57	34.3		1	0.8	0.8	7	5.7		1
Tridacna maxima	2.1	1.1	57	30.0	4.1	4	2.6	1.4	7	6.1	1.7	3
Trochus niloticus	229.0	43.8	57	310.7	54.2	42	207.1	105.2	7	290.0	131.3	5
Turbo argyrostomus	0.6	0.5	57	18.4	0.0	2	0.9	0.9	7	6.1		1
Turbo crassus	1.6	1.2	57	46.7	14.7	2	1.5	1.0	7	5.2	1.6	2
Turbo setosus	1.1	0.8	57	30.7	0.0	2	1.0	1.0	7	6.8		1
Vasum ceramicum	1.1	0.8	57	30.5	1.5	2	1.0	0.6	7	3.4	0.2	2

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.1.8 Ha'atafu mother-of-pearl search (MOPs) assessment data review

Station: Six 5-min search periods.

Species	Search period			Search period _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Acanthaster planci	18.9	7.7	24	75.8	15.2	6	16.8	16.8	3	50.5		1
Bohadschia argus	70.1	22.4	24	129.4	33.7	13	62.3	33.8	3	93.4	22.7	2
Conus spp.	3.8	2.6	24	45.5	0.0	2	4.2	2.2	3	6.3	1.3	2
Conus vexillum	1.9	1.9	24	45.5		1	1.7	1.7	3	5.1		1
Culcita novaeguineae	1.9	1.9	24	45.5		1	1.7	1.7	3	5.1		1
Diadema spp.	3.8	2.6	24	45.5	0.0	2	3.4	1.7	3	5.1	0.0	2
Echinometra mathaei	53.0	21.7	24	159.1	47.0	8	62.3	37.2	3	62.3	37.2	3
Echinothrix diadema	1.9	1.9	24	45.5		1	1.7	1.7	3	5.1		1
Heterocentrotus mammillatus	37.9	17.7	24	151.5	47.9	6	34.5	25.7	3	34.5	25.7	3
Holothuria atra	128.8	29.9	24	181.8	34.9	17	114.5	60.8	3	171.7	35.4	2
Holothuria edulis	3.8	3.8	24	90.9		1	3.4	3.4	3	10.1		1
Holothuria leucospilota	3.8	2.6	24	45.5	0.0	2	3.4	3.4	3	10.1		1
Holothuria nobilis	1.9	1.9	24	45.5		1	1.7	1.7	3	5.1		1
Lambis truncata	1.9	1.9	24	45.5		1	1.7	1.7	3	5.1		1
Linckia laevigata	1.9	1.9	24	45.5		1	1.7	1.7	3	5.1		1
Pleuroploca filamentosa	1.9	1.9	24	45.5		1	2.5	2.5	3	7.6		1
Stichopus chloronotus	54.9	14.7	24	101.4	19.4	13	50.5	32.9	3	50.5	32.9	3
Tectus pyramis	26.5	13.1	24	106.1	38.3	6	25.3	18.2	3	37.9	22.7	2
Tridacna maxima	15.2	5.2	24	51.9	6.5	7	15.2	0.0	3	15.2	0.0	3
Trochus niloticus	7.6	4.5	24	60.6	15.2	3	6.7	6.7	3	20.2		1
Turbo argyrostomus	7.6	4.5	24	60.6	15.2	3	8.4	4.5	3	12.6	2.5	2
Turbo crassus	5.7	3.1	24	45.5	0.0	3	5.9	3.0	3	8.8	1.3	2
Turbo setosus	1.9	1.9	24	45.5		1	1.7	1.7	3	5.1		1
Vasum ceramicum	3.8	3.8	24	90.9		1	3.4	3.4	3	10.1		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.1.9 Ha'atafu mother-of-pearl transect (MOPt) assessment data review

Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Actinopyga lecanora	2.2	2.2	57	125.0		1	2.6	2.6	8	20.8		1
Bohadschia argus	2.2	2.2	57	125.0		1	2.6	2.6	8	20.8		1
Charonia tritonis	2.2	2.2	57	125.0		1	2.6	2.6	8	20.8		1
Heterocentrotus mammillatus	6.6	4.9	57	187.5	62.5	2	6.9	5.2	8	27.8	13.9	2
Holothuria atra	4.4	4.4	57	250.0		1	5.2	5.2	8	41.7		1
Holothuria edulis	8.8	5.3	57	166.7	41.7	3	10.4	10.4	8	83.3		1
Stichodactyla spp.	6.6	4.9	57	187.5	62.5	2	7.8	7.8	8	62.5		1
Stichopus chloronotus	15.4	8.3	57	218.8	59.8	4	16.5	13.0	8	66.0	38.2	2
Tridacna maxima	8.8	6.9	57	250.0	125.0	2	6.9	6.9	8	55.6		1
Trochus niloticus	804.8	111.8	57	834.1	113.9	55	772.6	177.1	8	772.6	177.1	8
Turbo crassus	2.2	2.2	57	125.0		1	2.6	2.6	8	20.8		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.1.10 Ha'atafu species size review – all survey methods

Species	Mean length (cm)	SE	n measured	n total
Trochus niloticus	9.3	0.1	482	799
Turbo setosus	5.7	0.1	36	78
Turbo chrysostomus	4.5	0.1	36	36
Holothuria atra	26.9	1.7	30	3172
Turbo argyrostomus	6.1	0.1	27	31
Bohadschia argus	34.5	1.7	20	204
Turbo crassus	6.8	0.3	18	30
Tridacna maxima	11.0	1.1	16	46
Thelenota anax	39.1	2.2	16	25
Tectus pyramis	7.7	0.3	15	47
Thelenota ananas	37.3	2.8	13	19
Tripneustes gratilla	8.5	0.5	12	33
Actinopyga miliaris	31.2	0.7	11	16
Stichopus chloronotus	16.3	1.6	6	204
Stichopus hermanni	34.8	1.7	6	44
Conus spp.	9.9	1.1	5	36
Holothuria nobilis	35.4	4.6	5	11
Anadara antiquata	5.7	0.3	5	8
Holothuria fuscopunctata	29.0	4.7	4	20
Tridacna squamosa	18.0	6.7	4	4
Actinopyga echinites	35.0	2.9	3	5
Actinopyga mauritiana	22.0	1.0	3	5
Pleuroploca filamentosa	11.8	1.0	3	4
Vasum ceramicum	10.0	0.0	2	4
Vasum turbinellum	5.5	0.1	2	3
Holothuria fuscogilva	45	0	2	2
Trochus maculata	3.8		1	21
Lambis lambis	17.5		1	20
Stichodactyla spp.	40		1	15
Astralium spp.	4.2		1	12
Conus vexillum	7		1	5
Tutufa rubeta	23		1	1
Trochus spp.	2.7		1	1
Panulirus spp.	5		1	1
Holothuria edulis				3401
Holothuria coluber				2196
Heterocentrotus mammillatus				847
Echinometra mathaei				564
Strombus gibberulus gibbosus				387
Linckia laevigata				218
Bohadschia vitiensis				157
Holothuria leucospilota				130
Strombus spp.				87
Dolabella auricularia				86
Culcita novaeguineae				76
Echinothrix diadema				52
Diadema spp.				42
Latirolagena smaragdula				37
Choriaster granulatus				30
Acanthaster planci				27

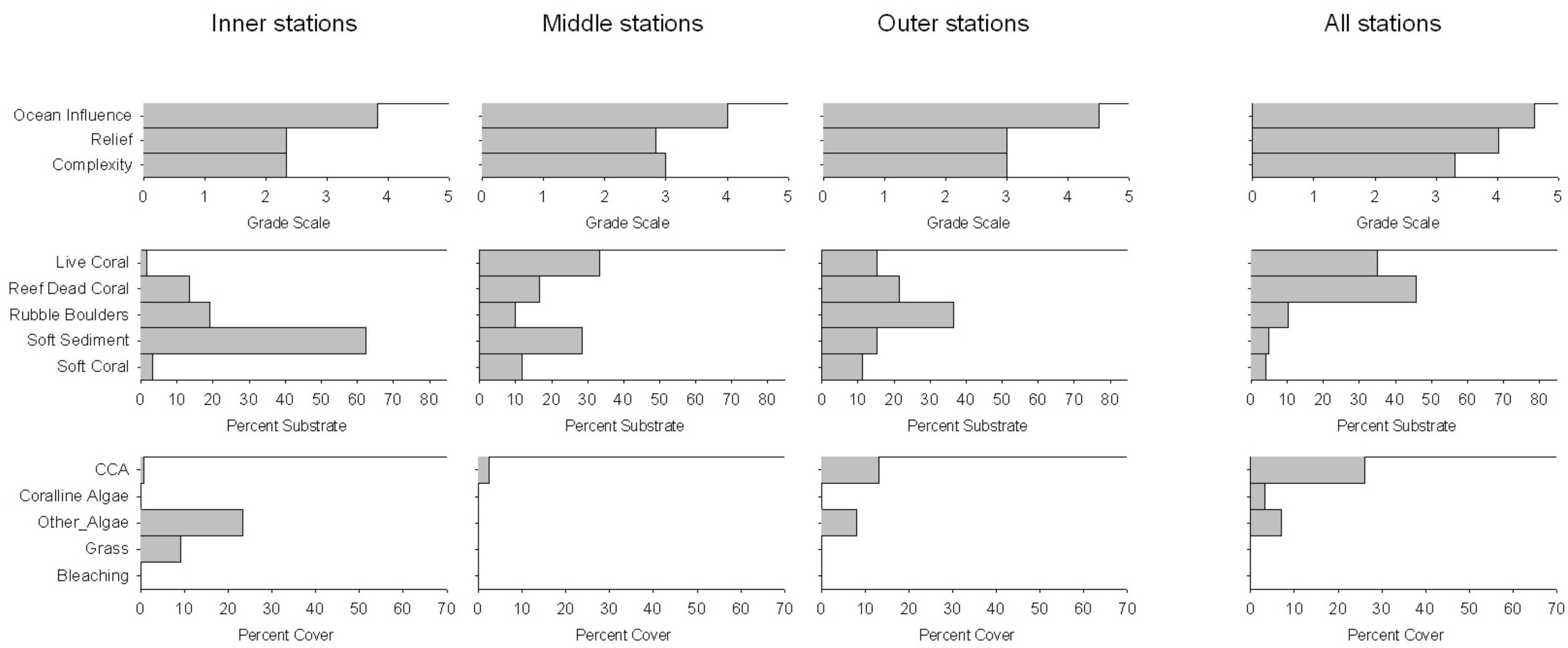
4.1.10 Ha'atafu species size review – all survey methods (continued)

Species	Mean length (cm)	SE	n measured	n total
Synapta spp.				27
Strombus mutabilis				23
Pinctada margaritifera				13
Cypraea caputserpensis				13
Echinothrix calamaris				11
Bohadschia similis				10
Drupa morum				7
Actinopyga lecanora				6
Stichopus hermanni-horrens				5
Spondylus spp.				4
Cypraea annulus				4
Lambis crocata				3
Calappa hepatica				3
Protoreaster nodosus				3
Holothuria scabra versicolor				3
Cypraea moneta				3
Atrina spp.				3
Mammilla melanostoma				2
Nassarius spp.				2
Pinna spp.				2
Cypraea tigris				2
Thais aculeata				1
Chama spp.				1
Cassiopea spp.				1
Cypraea arabica				1
Fragum fragum				1
Charonia tritonis				1
Cypraea argus				1
Cryptoplax spp.				1
Thais spp.				1
Lambis truncata				1
Cassiopea andromeda				1

4.1.11 Habitat descriptors for independent assessment – Ha'atafu

Broad-scale stations

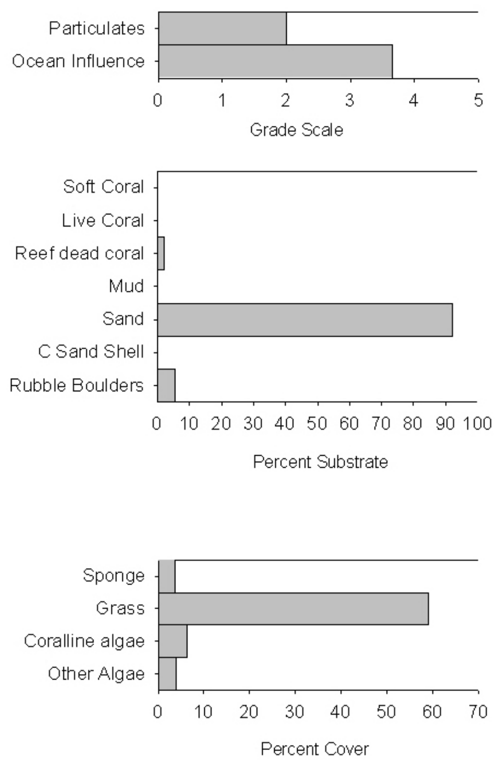
Reef-benthos transect stations



4.1.11 Habitat descriptors for independent assessment – Ha'atafu (continued)

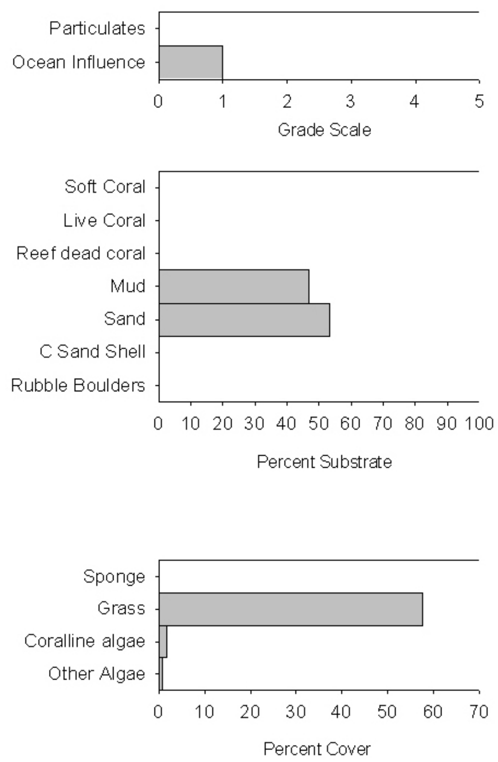
Soft-benthos transect stations

All stations



Soft-infaunal quadrat stations

All stations



4.1.12 Ha'atafu catch assessment - creel survey - data review

Species	CPUE (individuals/hour) ($\bar{x}$, SE, n)	Length (mm) ($\bar{x}$, SE, n)	Comments
Fragum spp.	0.1, 0.1, 4	62	*F. unedo* and *F. fragum*
Calappa spp.	0.1, 0.1, 4		Carapace width
Eel	0.5, 0.5, 4		Length range

4.2 Manuka invertebrate survey data

4.2.1 *Invertebrate species recorded in different assessments in Manuka*

Group	Species	Broad scale	Reef benthos	Soft benthos	Others
Bêche-de-mer	*Actinopyga echinites*	+			+
Bêche-de-mer	*Actinopyga lecanora*	+	+		+
Bêche-de-mer	*Actinopyga mauritiana*		+		+
Bêche-de-mer	*Actinopyga miliaris*	+		+	+
Bêche-de-mer	*Bohadschia argus*	+	+		+
Bêche-de-mer	*Bohadschia similis*	+	+	+	+
Bêche-de-mer	*Bohadschia vitiensis*			+	
Bêche-de-mer	*Bohadschia vitiensis*	+	+		+
Bêche-de-mer	*Holothuria atra*	+	+	+	+
Bêche-de-mer	*Holothuria coluber*	+	+		+
Bêche-de-mer	*Holothuria edulis*	+	+		+
Bêche-de-mer	*Holothuria fuscopunctata*	+			+
Bêche-de-mer	*Holothuria leucospilota*	+	+	+	+
Bêche-de-mer	*Holothuria nobilis*	+	+		+
Bêche-de-mer	*Holothuria scabra versicolor*	+			+
Bêche-de-mer	*Stichopus chloronotus*	+	+		+
Bêche-de-mer	*Stichopus hermanni*	+			+
Bêche-de-mer	*Stichopus horrens*				+
Bêche-de-mer	*Synapta* spp.	+		+	+
Bêche-de-mer	*Thelenota ananas*	+			+
Bêche-de-mer	*Thelenota anax*	+			+
Bivalve	*Anadara antiquata*		+	+	
Bivalve	*Anadara* spp.	+			+
Bivalve	*Atrina* spp.	+			+
Bivalve	*Fragum fragum*			+	
Bivalve	*Hyotissa* spp.	+	+		+
Bivalve	*Modiolus* spp.			+	
Bivalve	*Periglypta reticulata*			+	
Bivalve	*Pinctada margaritifera*	+	+		+
Bivalve	*Pinna bicolor*			+	
Bivalve	*Pinna* spp.			+	
Bivalve	*Pitar* spp.			+	
Bivalve	*Spondylus* spp.	+			
Bivalve	*Spondylus* spp.	+			+
Bivalve	*Tellina palatum*			+	
Bivalve	*Tellina scobinata*			+	
Bivalve	*Tridacna maxima*	+	+		+
Bivalve	*Tridacna squamosa*	+			+
Cnidarian	*Stichodactyla* spp.	+	+		+
Gastropod	*Astralium* spp.		+		+
Gastropod	*Bulla ampulla*			+	
Gastropod	*Cerithium nodulosum*		+	+	
Gastropod	*Charonia tritonis*				+
Gastropod	*Chicoreus ramosus*	+			+
Gastropod	*Conus leopardus*		+		
Gastropod	*Conus quercinus*			+	

+ = presence of the species.

4.2.1 Invertebrate species recorded in different assessments in Manuka (continued)

Group	Species	Broad scale	Reef benthos	Soft benthos	Others
Gastropod	*Conus* spp.	+	+	+	+
Gastropod	*Conus textile*		+		
Gastropod	*Conus vexillum*		+		+
Gastropod	*Cymatium* spp.			+	
Gastropod	*Cypraea caputserpensis*		+		+
Gastropod	*Cypraea* spp.	+		+	+
Gastropod	*Cypraea tigris*	+	+	+	+
Gastropod	*Dolabella auricularia*	+		+	+
Gastropod	*Drupella* spp.		+		+
Gastropod	*Lambis crocata*			+	+
Gastropod	*Lambis lambis*	+		+	+
Gastropod	*Lambis truncata*	+			+
Gastropod	*Latirolagena smaragdula*		+		
Gastropod	*Mitra mitra*			+	
Gastropod	*Ovula ovum*		+		+
Gastropod	*Pleuroploca filamentosa*		+		
Gastropod	*Pleuroploca trapezium*		+		
Gastropod	*Polinices* spp.			+	
Gastropod	*Strombus gibberulus gibbosus*			+	
Gastropod	*Strombus luhuanus*		+	+	
Gastropod	*Strombus mutabilis*			+	
Gastropod	*Strombus* spp.			+	
Gastropod	*Tectus pyramis*	+	+		+
Gastropod	*Thais aculeata*		+		+
Gastropod	*Thais* spp.		+		
Gastropod	*Trochus niloticus*		+		+
Gastropod	*Trochus* spp.		+		
Gastropod	*Turbo argyrostomus*		+		+
Gastropod	*Turbo chrysostomus*		+	+	
Gastropod	*Turbo crassus*		+		+
Gastropod	*Turbo marmoratus*				+
Gastropod	*Turbo setosus*		+		+
Gastropod	*Tutufa rubeta*				+
Gastropod	*Vasum ceramicum*		+		+
Star	*Acanthaster planci*	+			+
Star	*Archaster typicus*			+	
Star	*Choriaster granulatus*	+			+
Star	*Culcita novaeguineae*	+	+	+	+
Star	*Linckia laevigata*	+	+	+	+
Star	*Protoreaster nodosus*	+			+
Urchin	*Diadema* spp.	+	+		+
Urchin	*Echinometra mathaei*	+	+	+	+
Urchin	*Echinothrix calamaris*				+
Urchin	*Echinothrix diadema*	+	+		+
Urchin	*Heterocentrotus mammillatus*	+	+		+
Urchin	*Toxopneustes pileolus*	+			+
Urchin	*Tripneustes gratilla*	+	+	+	+

+ = presence of the species.

4.2.2 Manuka broad-scale assessment data review

Station: Six 2 m x 300 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Acanthaster planci	0.7	0.4	70	16.1	0.3	3	0.7	0.5	12	4.0	1.2	2
Actinopyga echinites	0.2	0.2	70	16.7		1	0.2	0.2	12	2.8		1
Actinopyga lecanora	1.9	0.7	70	19.0	2.4	7	1.9	1.1	12	7.4	2.4	3
Actinopyga miliaris	0.7	0.4	70	16.7	0.0	3	0.7	0.4	12	2.8	0.0	3
Anadara spp.	1.0	0.7	70	33.3	16.7	2	0.9	0.9	12	11.1		1
Atrina spp.	3.1	1.1	70	27.1	4.4	8	3.0	2.1	12	12.0	6.7	3
Bohadschia argus	53.7	6.4	70	73.8	7.0	51	53.2	10.2	12	58.0	9.8	11
Bohadschia similis	2.1	1.7	70	50.0	33.3	3	2.1	2.1	12	25.0		1
Bohadschia vitiensis	141.4	37.4	70	202.0	51.2	49	146.6	57.6	12	146.6	57.6	12
Chicoreus ramosus	0.5	0.3	70	16.7	0.0	2	0.5	0.3	12	2.8	0.0	2
Choriaster granulatus	0.5	0.5	70	33.3		1	0.5	0.5	12	5.6		1
Conus spp.	0.5	0.3	70	16.7	0.0	2	0.5	0.3	12	2.8	0.0	2
Culcita novaeguineae	10.1	2.5	70	35.3	5.9	20	10.1	5.2	12	20.2	8.8	6
Cypraea spp.	1.2	0.6	70	20.8	4.2	4	1.2	0.7	12	4.6	1.9	3
Cypraea tigris	0.7	0.5	70	25.0	8.3	2	0.7	0.5	12	4.2	1.4	2
Diadema spp.	6.7	3.1	70	77.8	20.0	6	6.5	6.0	12	38.9	33.3	2
Dolabella auricularia	1.7	1.2	70	38.9	22.2	3	1.6	1.2	12	9.7	4.2	2
Echinometra mathaei	412.9	118.0	70	1700.0	332.6	17	401.4	183.5	12	1204.2	219.2	4
Echinothrix diadema	32.6	13.3	70	228.3	67.8	10	31.7	26.0	12	126.9	94.0	3
Heterocentrotus mammillatus	9.4	5.3	70	94.1	43.3	7	9.1	7.0	12	21.9	16.0	5
Holothuria atra	329.7	78.6	70	398.0	92.5	58	322.7	139.3	12	322.7	139.3	12
Holothuria coluber	1393.5	285.6	70	2268.5	413.4	43	1391.6	612.7	12	1855.4	762.0	9
Holothuria edulis	111.8	24.4	70	195.6	37.7	40	108.8	50.4	12	145.1	63.2	9
Holothuria fuscopunctata	4.7	1.4	70	23.6	4.3	14	4.7	2.2	12	8.0	3.3	7
Holothuria leucospilota	49.6	16.4	70	216.8	55.0	16	52.3	31.2	12	156.9	72.4	4
Holothuria nobilis	0.2	0.2	70	16.7		1	0.2	0.2	12	2.8		1
Holothuria scabra versicolor	5.2	2.9	70	61.1	25.7	6	5.1	3.9	12	20.4	13.6	3
Hyotissa spp.	1.6	0.9	70	28.4	8.4	4	1.7	1.2	12	6.8	3.6	3

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.2.2 Manuka broad-scale assessment data review (continued)

Station: Six 2 m x 300 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Lambis lambis	6.2	2.0	70	33.3	7.1	13	6.0	2.6	12	14.4	3.6	5
Lambis truncata	0.7	0.5	70	25.0	8.3	2	0.7	0.5	12	4.2	1.4	2
Linckia laevigata	51.1	19.1	70	188.1	60.9	19	62.9	49.4	12	151.0	113.2	5
Pinctada margaritifera	3.4	1.8	70	34.2	13.5	7	4.0	3.0	12	12.0	8.1	4
Protoreaster nodosus	29.5	14.9	70	206.7	88.5	10	28.7	25.8	12	114.8	98.3	3
Spondylus spp.	13.0	5.7	70	75.9	27.5	12	14.9	13.2	12	35.9	31.1	5
Stichodactyla spp.	3.6	0.9	70	17.9	1.2	14	3.5	1.1	12	6.0	1.3	7
Stichopus chloronotus	10.4	2.4	70	36.5	4.5	20	10.1	2.9	12	15.1	2.9	8
Stichopus hermanni	5.5	1.6	70	29.5	5.0	13	5.5	2.3	12	9.4	3.3	7
Synapta spp.	3.6	1.9	70	41.7	16.0	6	3.5	3.0	12	20.8	15.3	2
Tectus pyramis	1.8	0.8	70	24.6	4.7	5	1.7	1.0	12	6.6	1.9	3
Thelenota ananas	0.8	0.4	70	17.8	1.0	3	0.7	0.4	12	2.9	0.2	3
Thelenota anax	2.6	1.8	70	91.7	8.3	2	2.5	2.5	12	30.6		1
Toxopneustes pileolus	0.5	0.3	70	16.7	0.0	2	0.5	0.5	12	5.6		1
Tridacna maxima	12.2	4.5	70	61.2	17.6	14	11.7	6.9	12	20.1	11.0	7
Tridacna squamosa	0.7	0.4	70	16.7	0.0	3	0.7	0.5	12	4.2	1.4	2
Tripneustes gratilla	0.2	0.2	70	16.7		1	0.2	0.2	12	2.8		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.2.3 Manuka reef-benthos transect (RBt) assessment data review

Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Actinopyga lecanora	2.1	2.1	117	250.0		1	2.2	2.2	19	41.7		1
Actinopyga mauritiana	27.8	9.5	117	325.0	53.4	10	27.8	13.5	19	88.0	32.0	6
Anadara antiquata	4.9	3.4	117	285.7	0.0	2	5.0	5.0	19	95.2		1
Astralium spp.	15.0	7.6	117	350.0	100.0	5	15.4	9.1	19	72.9	31.3	4
Bohadschia argus	96.5	23.5	117	490.7	77.6	23	98.3	38.7	19	133.4	49.5	14
Bohadschia similis	2.4	2.4	117	285.7		1	2.5	2.5	19	47.6		1
Bohadschia vitiensis	15.3	7.1	117	357.1	58.7	5	14.9	7.9	19	70.9	21.4	4
Cerithium nodulosum	4.9	4.9	117	571.4		1	5.0	5.0	19	95.2		1
Conus leopardus	2.4	2.4	117	285.7		1	2.5	2.5	19	47.6		1
Conus spp.	34.8	10.1	117	339.3	34.5	12	35.7	13.8	19	113.1	20.2	6
Conus textile	2.1	2.1	117	250.0		1	2.2	2.2	19	41.7		1
Conus vexillum	2.1	2.1	117	250.0		1	2.2	2.2	19	41.7		1
Culcita novaeguineae	13.1	6.1	117	307.1	48.7	5	13.5	9.1	19	85.3	40.7	3
Cypraea caputserpensis	2.1	2.1	117	250.0		1	2.2	2.2	19	41.7		1
Cypraea tigris	11.0	4.8	117	257.1	7.1	5	11.3	4.5	19	42.9	1.2	5
Diadema spp.	32.1	18.3	117	1250.0	0.0	3	32.9	32.9	19	625.0		1
Drupella spp.	2.1	2.1	117	250.0		1	2.2	2.2	19	41.7		1
Echinometra mathaei	721.9	225.2	117	3519.3	904.7	24	739.5	498.0	19	1756.2	1122.4	8
Echinothrix diadema	44.9	15.4	117	437.5	93.0	12	46.1	24.9	19	218.8	70.9	4
Heterocentrotus mammillatus	203.0	41.3	117	659.7	98.7	36	189.3	64.0	19	327.0	90.8	11
Holothuria atra	482.0	65.4	117	909.6	94.7	62	453.7	102.0	19	478.9	104.4	18
Holothuria coluber	149.0	64.5	117	2904.8	529.0	6	152.9	152.9	19	2904.8		1
Holothuria edulis	11.9	6.3	117	348.2	74.9	4	12.2	10.1	19	116.1	74.4	2
Holothuria leucospilota	69.9	22.6	117	629.1	123.1	13	71.7	43.2	19	272.6	134.9	5
Holothuria nobilis	6.4	4.8	117	375.0	125.0	2	6.6	6.6	19	125.0		1
Hyotissa spp.	4.9	3.4	117	285.7	0.0	2	5.0	5.0	19	95.2		1
Latirolagena smaragdula	4.3	3.0	117	250.0	0.0	2	4.4	3.0	19	41.7	0.0	2
Linckia laevigata	17.7	6.8	117	295.9	34.6	7	18.2	7.7	19	69.0	11.4	5

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.2.3 Manuka reef-benthos transect (RBt) assessment data review (continued)

Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Ovula ovum	6.4	4.8	117	375.0	125.0	2	6.6	4.8	19	62.5	20.8	2
Pinctada margaritifera	6.7	3.9	117	261.9	11.9	3	6.9	4.9	19	65.5	17.9	2
Pleuroploca filamentosa	4.3	4.3	117	500.0		1	4.4	4.4	19	83.3		1
Pleuroploca trapezium	6.4	6.4	117	750.0		1	4.4	4.4	19	83.3		1
Stichodactyla spp.	10.7	5.6	117	312.5	62.5	4	11.0	5.4	19	52.1	10.4	4
Stichopus chloronotus	232.9	54.8	117	825.8	152.5	33	213.5	85.2	19	338.0	122.4	12
Strombus luhuanus	7.3	4.2	117	285.7	0.0	3	7.5	7.5	19	142.9		1
Tectus pyramis	40.6	10.0	117	296.9	25.2	16	39.5	11.7	19	83.3	13.9	9
Thais aculeata	2.1	2.1	117	250.0		1	1.5	1.5	19	27.8		1
Thais spp.	4.3	4.3	117	500.0		1	4.4	4.4	19	83.3		1
Tridacna maxima	27.8	8.5	117	295.5	30.5	11	28.5	10.1	19	67.7	15.6	8
Tripneustes gratilla	6.4	3.7	117	250.0	0.0	3	6.6	3.6	19	41.7	0.0	3
Trochus niloticus	145.3	32.3	117	566.7	89.6	30	149.1	48.7	19	236.1	65.3	12
Trochus spp.	2.1	2.1	117	250.0		1	2.2	2.2	19	41.7		1
Turbo argyrostomus	6.4	3.7	117	250.0	0.0	3	5.1	3.6	19	48.6	6.9	2
Turbo chrysostomus	16.8	9.3	117	491.1	141.6	4	17.2	15.1	19	163.7	122.0	2
Turbo crassus	6.4	4.8	117	375.0	125.0	2	6.6	4.8	19	62.5	20.8	2
Turbo setosus	12.8	6.7	117	375.0	72.2	4	11.7	9.1	19	111.1	55.6	2
Vasum ceramicum	6.4	4.8	117	375.0	125.0	2	6.6	6.6	19	125.0		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.2.4 Manuka soft-benthos transect (SBt) assessment data review

Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Actinopyga miliaris	5.7	5.7	50	285.7		1	6.5	6.5	11	71.4		1
Anadara antiquata	17.1	9.7	50	285.7	0.0	3	13.0	9.3	11	71.4	23.8	2
Archaster typicus	131.4	44.9	50	730.2	117.7	9	149.4	74.3	11	328.6	124.9	5
Bohadschia similis	182.9	88.6	50	831.2	347.7	11	197.0	145.9	11	361.1	257.3	6
Bulla ampulla	40.0	24.5	50	666.7	190.5	3	45.5	30.9	11	250.0	35.7	2
Cerithium nodulosum	22.9	13.8	50	381.0	95.2	3	19.5	10.6	11	71.4	13.7	3
Conus quercinus	5.7	5.7	50	285.7		1	6.5	6.5	11	71.4		1
Conus spp.	40.0	20.0	50	400.0	114.3	5	41.1	26.5	11	150.8	67.8	3
Culcita novaeguineae	11.4	8.0	50	285.7	0.0	2	13.0	8.7	11	71.4	0.0	2
Cymatium spp.	80.0	27.1	50	400.0	76.2	10	86.6	28.6	11	136.1	31.9	7
Cypraea tigris	5.7	5.7	50	285.7		1	4.3	4.3	11	47.6		1
Dolabella auricularia	28.6	12.2	50	285.7	0.0	5	23.8	10.6	11	65.5	11.4	4
Echinometra mathaei	680.0	415.2	50	2428.6	1412.1	14	761.9	451.3	11	1047.6	597.8	8
Fragum fragum	11.4	8.0	50	285.7	0.0	2	10.8	7.4	11	59.5	11.9	2
Holothuria atra	1068.6	309.0	50	2323.0	574.3	23	930.7	515.1	11	1023.8	560.0	10
Holothuria leucospilota	5.7	5.7	50	285.7		1	6.5	6.5	11	71.4		1
Lambis lambis	62.9	16.9	50	285.7	0.0	11	60.6	23.5	11	133.3	24.5	5
Modiolus spp.	7034.3	2645.4	50	35,171.4	8974.6	10	5329.0	5183.1	11	29,309.5	27,833.3	2
Periglypta reticulata	5.7	5.7	50	285.7		1	6.5	6.5	11	71.4		1
Pinna bicolor	360.0	109.8	50	1000.0	242.5	18	285.7	185.9	11	523.8	319.0	6
Polinices spp.	5.7	5.7	50	285.7		1	6.5	6.5	11	71.4		1
Strombus gibberulus gibbosus	537.1	215.5	50	1918.4	648.9	14	610.4	313.6	11	1119.0	496.8	6
Strombus luhuanus	51.4	29.1	50	642.9	214.3	4	39.0	39.0	11	428.6		1
Strombus spp.	560.0	290.1	50	2000.0	954.7	14	629.9	363.6	11	866.1	480.0	8
Synapta spp.	17.1	9.7	50	285.7	0.0	3	17.3	13.3	11	95.2	47.6	2
Tellina palatum	5.7	5.7	50	285.7		1	6.5	6.5	11	71.4		1
Tellina scobinata	45.7	18.9	50	381.0	60.2	6	51.9	16.9	11	95.2	15.1	6
Tripneustes gratilla	34.3	19.4	50	428.6	142.9	4	30.3	18.2	11	111.1	39.7	3
Turbo chrysostomus	17.1	12.7	50	428.6	142.9	2	19.5	13.9	11	107.1	35.7	2

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.2.5 Manuka soft-benthos quadrat (SBq) assessment data review

Station: 8 quadrat groups (4 quadrats/group).

Species	Quadrat groups			Quadrat groups _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Anadara antiquata	0.1	0.1	48	4.0		1	0.1	0.1	6	0.5		1
Bohadschia similis	0.3	0.2	48	4.0	0.0	4	0.3	0.2	6	0.7	0.2	3
Bohadschia vitiensis	0.8	0.3	48	4.4	0.4	9	0.8	0.6	6	2.5	1.0	2
Conus spp.	0.2	0.1	48	4.0	0.0	2	0.2	0.1	6	0.5	0.0	2
Cypraea spp.	0.1	0.1	48	4.0		1	0.1	0.1	6	0.5		1
Lambis crocata	0.1	0.1	48	4.0		1	0.1	0.1	6	0.5		1
Linckia laevigata	0.2	0.1	48	4.0	0.0	2	0.2	0.2	6	1.0		1
Mitra mitra	0.4	0.3	48	10.0	2.0	2	0.4	0.4	6	2.5		1
Pinna spp.	0.1	0.1	48	4.0		1	0.1	0.1	6	0.5		1
Pitar spp.	6.8	2.3	48	21.6	5.7	15	6.8	5.1	6	20.3	10.8	2
Strombus mutabilis	0.2	0.1	48	4.0	0.0	2	0.2	0.1	6	0.5	0.0	2
Tellina scobinata	0.2	0.1	48	4.0	0.0	2	0.2	0.2	6	1.0		1
Tripneustes gratilla	0.1	0.1	48	4.0		1	0.1	0.1	6	0.5		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.2.6 Manuka reef-front search (RFs) assessment data review

Station: Six 5-min search periods.

Species	Search period			Search period _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Acanthaster planci	0.9	0.5	102	23.8	2.7	4	1.1	0.7	13	4.9	1.6	3
Actinopyga lecanora	0.4	0.4	102	37.3		1	0.5	0.5	13	6.2		1
Actinopyga mauritiana	2.1	0.7	102	23.8	2.7	9	1.9	0.7	13	4.1	0.7	6
Bohadschia argus	8.4	2.7	102	61.4	12.8	14	8.1	4.2	13	17.6	7.8	6
Bohadschia vitiensis	0.4	0.3	102	19.8	0.1	2	0.4	0.3	13	2.7	0.6	2
Charonia tritonis	0.4	0.3	102	18.2	0.0	2	0.3	0.2	13	2.0	0.0	2
Conus spp.	3.6	1.6	102	41.1	13.6	9	3.5	1.8	13	7.5	3.3	6
Conus vexillum	0.3	0.2	102	16.6	3.3	2	0.6	0.4	13	3.9	0.5	2
Culcita novaeguineae	3.0	1.3	102	38.6	11.0	8	3.5	2.0	13	9.0	4.2	5
Cypraea caputserpensis	0.3	0.3	102	25.7		1	0.2	0.2	13	2.9		1
Cypraea spp.	0.2	0.2	102	19.9		1	0.3	0.3	13	3.3		1
Cypraea tigris	0.4	0.2	102	18.0	1.7	2	0.3	0.2	13	2.0	0.2	2
Diadema spp.	7.4	3.1	102	58.1	19.3	13	7.1	3.0	13	15.4	4.6	6
Echinometra mathaei	4.0	1.7	102	58.3	14.6	7	4.4	3.0	13	14.4	8.1	4
Echinothrix diadema	6.9	2.1	102	58.3	8.8	12	7.0	3.0	13	18.1	4.4	5
Heterocentrotus mammillatus	45.1	12.4	102	107.0	26.7	43	39.0	23.4	13	63.3	36.2	8
Holothuria atra	25.9	4.5	102	67.7	8.1	39	25.6	9.7	13	27.8	10.3	12
Holothuria edulis	1.3	0.6	102	22.8	3.0	6	1.7	0.9	13	5.5	1.7	4
Holothuria fuscopunctata	0.4	0.4	102	37.3		1	0.5	0.5	13	6.2		1
Holothuria leucospilota	2.6	1.6	102	87.0	24.8	3	3.3	3.3	13	43.5		1
Holothuria nobilis	1.0	0.5	102	25.3	5.9	4	0.7	0.4	13	3.2	1.1	3
Lambis crocata	0.4	0.4	102	39.3		1	0.3	0.3	13	4.4		1
Lambis lambis	0.8	0.7	102	41.5	22.8	2	0.6	0.4	13	3.7	1.6	2
Linckia laevigata	1.5	0.7	102	30.4	6.2	5	1.5	0.8	13	4.7	1.6	4
Ovula ovum	2.3	0.9	102	29.1	6.8	8	2.1	1.4	13	9.2	4.5	3
Pinctada margaritifera	0.5	0.4	102	27.8	9.5	2	0.6	0.5	13	4.1	2.1	2
Stichodactyla spp.	17.7	13.0	102	301.3	201.5	6	23.0	21.8	13	74.8	70.0	4

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.2.6 Manuka reef-front search (RFs) assessment data review (continued)

Station: Six 5-min search periods.

Species	Search period			Search period _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Stichopus chloronotus	31.0	7.5	102	108.9	20.3	29	27.8	15.5	13	40.2	21.4	9
Stichopus horrens	0.3	0.3	102	25.7		1	0.2	0.2	13	2.9		1
Tectus pyramis	12.0	3.1	102	42.2	8.6	29	13.8	5.5	13	18.0	6.6	10
Thais aculeata	0.2	0.2	102	19.7		1	0.2	0.2	13	2.2		1
Thelenota ananas	0.4	0.3	102	18.2	0.0	2	0.3	0.2	13	2.0	0.0	2
Tridacna maxima	6.4	1.2	102	26.0	2.3	25	5.9	1.0	13	6.9	0.8	11
Tridacna squamosa	0.2	0.2	102	19.7		1	0.2	0.2	13	2.2		1
Trochus niloticus	21.9	3.6	102	54.5	6.1	41	26.5	7.3	13	31.3	7.8	11
Turbo argyrostomus	1.0	0.5	102	20.4	4.3	5	1.3	0.6	13	3.3	0.9	5
Turbo setosus	1.9	0.9	102	31.8	7.6	6	2.2	1.2	13	7.0	2.9	4
Tutufa rubeta	1.5	0.9	102	51.8	10.4	3	2.0	2.0	13	25.9		1
Vasum ceramicum	0.4	0.3	102	22.2	3.5	2	0.4	0.3	13	2.5	0.4	2

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.2.7 Manuka mother-of-pearl search (MOPs) assessment data review

Station: Six 5-min search periods.

Species	Search period			Search period _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Actinopyga lecanora	3.8	3.8	12	45.5		1	3.8	3.8	2	7.6		1
Bohadschia argus	34.1	20.3	12	136.4	45.5	3	34.1	34.1	2	68.2		1
Culcita novaeguineae	11.4	8.2	12	68.2	22.7	2	11.4	11.4	2	22.7		1
Diadema spp.	56.8	33.2	12	227.3	69.4	3	56.8	56.8	2	113.6		1
Holothuria atra	41.7	23.4	12	125.0	50.4	4	41.7	34.1	2	41.7	34.1	2
Holothuria edulis	18.9	11.8	12	75.8	30.3	3	18.9	18.9	2	37.9		1
Holothuria fuscopunctata	26.5	13.1	12	79.5	21.8	4	26.5	18.9	2	26.5	18.9	2
Holothuria nobilis	3.8	3.8	12	45.5		1	3.8	3.8	2	7.6		1
Pinctada margaritifera	11.4	5.9	12	45.5	0.0	3	11.4	11.4	2	22.7		1
Tridacna maxima	22.7	8.8	12	54.5	9.1	5	22.7	7.6	2	22.7	7.6	2
Tripneustes gratilla	7.6	7.6	12	90.9		1	7.6	7.6	2	15.2		1
Trochus niloticus	30.3	19.6	12	121.2	54.6	3	30.3	30.3	2	60.6		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.2.8 Manuka mother-of-pearl transect (MOPt) assessment data review

Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Actinopyga lecanora	2.3	2.3	54	125.0		1	2.6	2.6	8	20.8		1
Actinopyga mauritiana	16.2	9.4	54	291.7	41.7	3	18.2	18.2	8	145.8		1
Actinopyga miliaris	4.6	3.2	54	125.0	0.0	2	5.2	3.4	8	20.8	0.0	2
Astralium spp.	2.3	2.3	54	125.0		1	2.6	2.6	8	20.8		1
Charonia tritonis	2.3	2.3	54	125.0		1	2.6	2.6	8	20.8		1
Conus spp.	2.3	2.3	54	125.0		1	2.6	2.6	8	20.8		1
Diadema spp.	41.7	16.5	54	321.4	60.1	7	42.5	25.9	8	113.4	47.5	3
Drupella spp.	4.6	3.2	54	125.0	0.0	2	3.5	3.5	8	27.8		1
Echinothrix calamaris	2.3	2.3	54	125.0		1	1.7	1.7	8	13.9		1
Echinothrix diadema	55.6	20.0	54	272.7	67.0	11	53.0	22.3	8	105.9	21.5	4
Heterocentrotus mammillatus	71.8	31.1	54	645.8	134.7	6	80.7	57.1	8	322.9	114.6	2
Lambis lambis	6.9	5.1	54	187.5	62.5	2	7.8	5.5	8	31.3	10.4	2
Ovula ovum	13.9	9.7	54	250.0	125.0	3	11.3	6.9	8	30.1	12.9	3
Pinctada margaritifera	2.3	2.3	54	125.0		1	2.6	2.6	8	20.8		1
Thelenota ananas	2.3	2.3	54	125.0		1	2.6	2.6	8	20.8		1
Tridacna maxima	6.9	5.1	54	187.5	62.5	2	6.9	5.2	8	27.8	13.9	2
Trochus niloticus	328.7	41.2	54	422.6	43.0	42	301.2	69.3	8	301.2	69.3	8
Turbo crassus	4.6	4.6	54	250.0		1	3.5	3.5	8	27.8		1
Turbo marmoratus	2.3	2.3	54	125.0		1	2.6	2.6	8	20.8		1
Turbo setosus	9.3	7.3	54	250.0	125.0	2	6.9	6.9	8	55.6		1
Tutufa rubeta	2.3	2.3	54	125.0		1	1.7	1.7	8	13.9		1
Vasum ceramicum	2.3	2.3	54	125.0		1	2.6	2.6	8	20.8		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

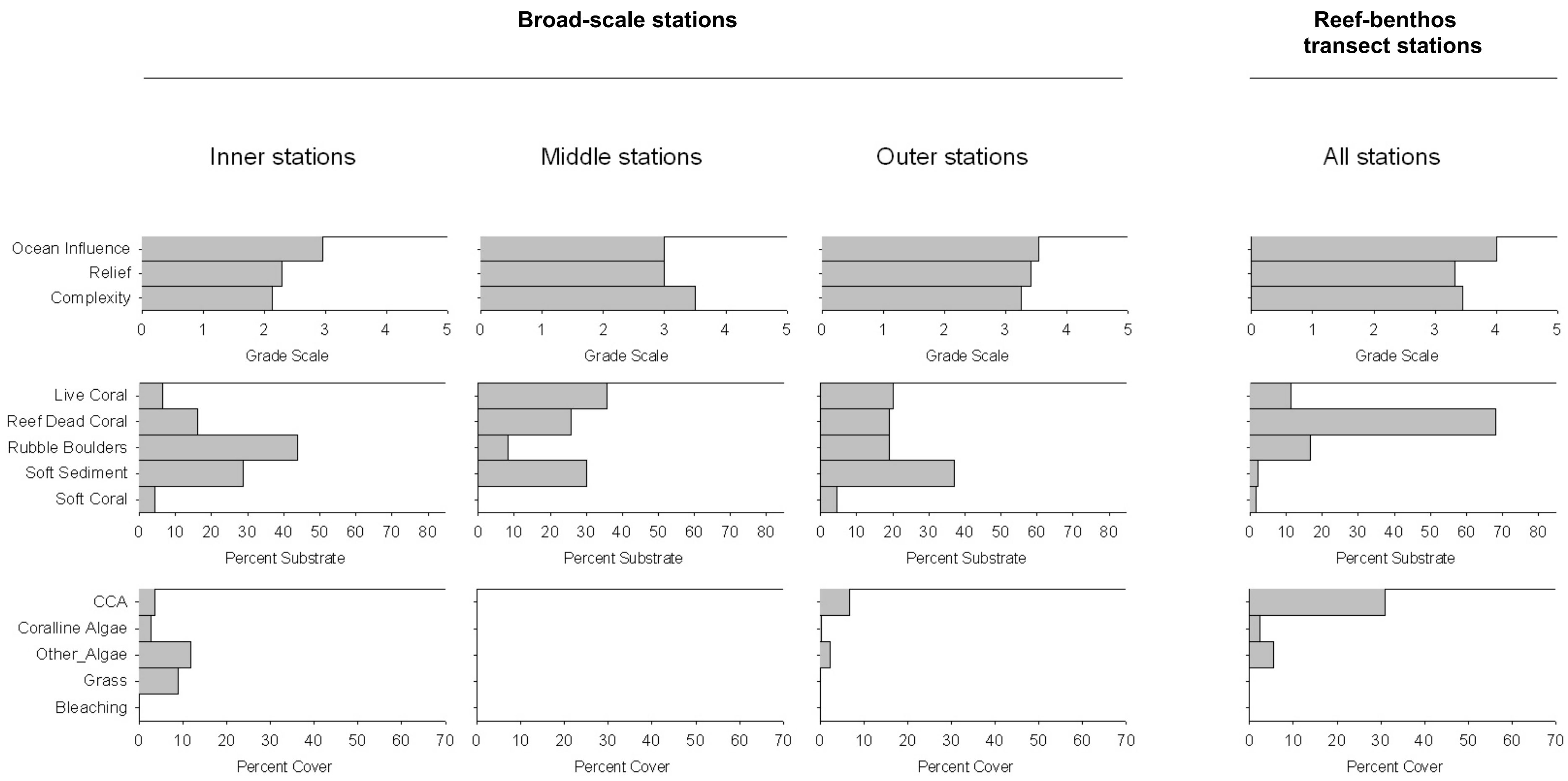
4.2.9 Manuka species size review – all survey methods

Species	Mean length (cm)	SE	n measured	n total
Trochus niloticus	9.9	0.1	216	328
Bohadschia argus	27.2	2.2	21	325
Actinopyga mauritiana	18.5	0.9	21	30
Tridacna maxima	14.7	1.9	18	105
Holothuria fuscopunctata	37.7	2.4	15	30
Holothuria atra	21.9	2.1	14	1945
Tectus pyramis	8.1	0.3	12	77
Holothuria scabra versicolor	16.9	3.5	8	23
Stichopus hermanni	34.2	1.2	5	41
Cypraea tigris	8.1	0.4	4	11
Holothuria nobilis	23.8	2.8	4	10
Vasum ceramicum	9.7	0.7	4	6
Pinctada margaritifera	12.3	2.2	3	23
Thelenota anax	54.7	3.1	3	18
Tridacna squamosa	17.7	5.9	3	4
Conus spp.	11.0	0.0	2	47
Bohadschia vitiensis	25.0		1	671
Stichopus chloronotus	18.0		1	334
Ovula ovum	9.7		1	21
Turbo setosus	4.8		1	18
Actinopyga lecanora	20.0		1	12
Turbo argyrostomus	5.1		1	8
Thelenota ananas	45.0		1	6
Anadara antiquata	7.4		1	6
Actinopyga miliaris	14.0		1	6
Lambis crocata	14.0		1	3
Turbo marmoratus	14.0		1	1
Holothuria coluber				6053
Echinometra mathaei				2178
Modiolus spp.				1231
Holothuria edulis				517
Heterocentrotus mammillatus				377
Linckia laevigata				295
Holothuria leucospilota				264
Echinothrix diadema				213
Protoreaster nodosus				208
Diadema spp.				111
Strombus spp.				98
Strombus gibberulus gibbosus				94
Pitar spp.				81
Stichodactyla spp.				79
Culcita novaeguineae				64
Pinna bicolor				63
Spondylus spp.				47
Bohadschia similis				46
Lambis lambis				44
Archaster typicus				23
Synapta spp.				18

4.2.9 Manuka species size review – all survey methods (continued)

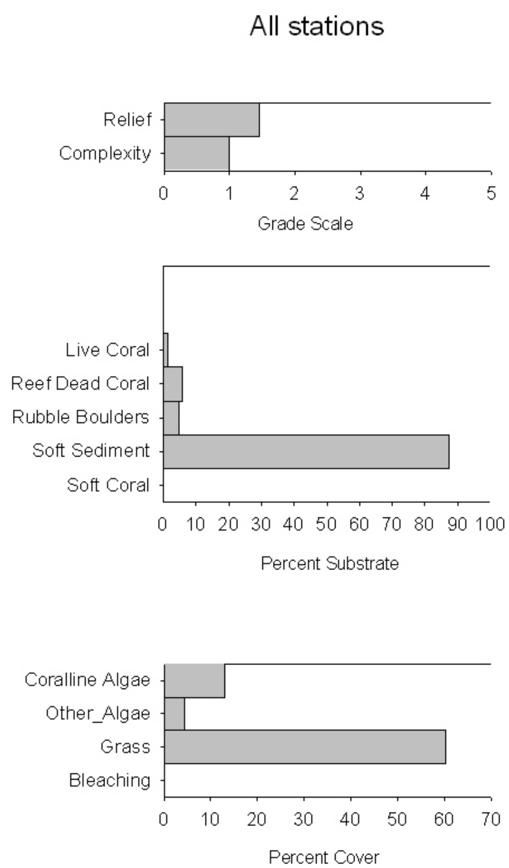
Species	Mean length (cm)	SE	n measured	n total
Cymatium spp.				14
Tripneustes gratilla				13
Atrina spp.				13
Hyotissa spp.				12
Dolabella auricularia				12
Strombus luhuanus				12
Turbo chrysostomus				10
Tellina scobinata				10
Astralium spp.				8
Choriaster granulatus				8
Acanthaster planci				7
Bulla ampulla				7
Cypraea spp.				7
Cerithium nodulosum				6
Tutufa rubeta				6
Mitra mitra				5
Turbo crassus				5
Anadara spp.				4
Pleuroploca trapezium				3
Lambis truncata				3
Drupella spp.				3
Charonia tritonis				3
Conus vexillum				3
Latirolagena smaragdula				2
Thais spp.				2
Strombus mutabilis				2
Chicoreus ramosus				2
Pleuroploca filamentosa				2
Toxopneustes pileolus				2
Thais aculeata				2
Cypraea caputserpensis				2
Fragum fragum				2
Conus leopardus				1
Conus quercinus				1
Trochus spp.				1
Polinices spp.				1
Tellina palatum				1
Pinna spp.				1
Periglypta reticulata				1
Actinopyga echinites				1
Stichopus horrens				1
Echinothrix calamaris				1
Conus textile				1

4.2.10 Habitat descriptors for independent assessment – Manuka

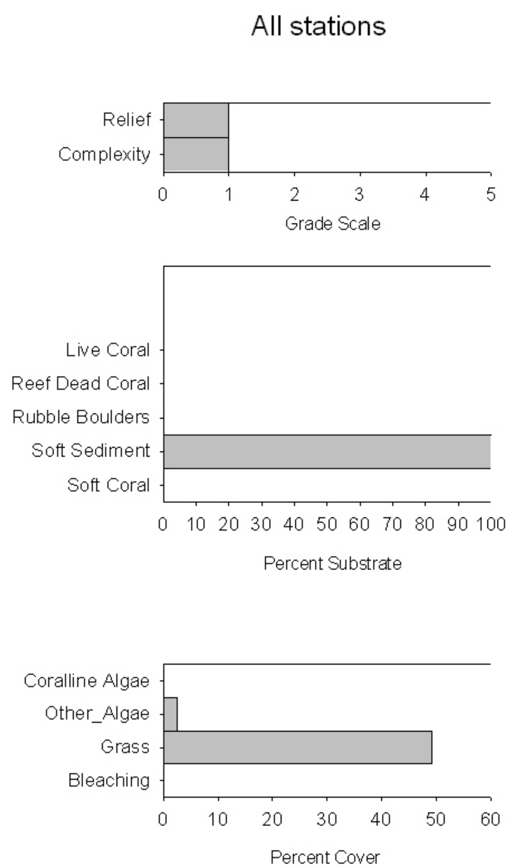


4.2.10 Habitat descriptors for independent assessment – Manuka (continued)

Soft-benthos transect stations



Soft-infaunal quadrat stations



4.3 Koulo invertebrate survey data

4.3.1 Invertebrate species recorded in different assessments in Koulo

Group	Species	Broad scale	Reef benthos	Soft benthos	Others
Bêche-de-mer	*Actinopyga lecanora*	+			
Bêche-de-mer	*Actinopyga mauritiana*	+	+		+
Bêche-de-mer	*Actinopyga miliaris*	+			+
Bêche-de-mer	*Actinopyga palauensis*	+			
Bêche-de-mer	*Actinopyga* spp.	+			
Bêche-de-mer	*Bohadschia argus*	+	+		
Bêche-de-mer	*Bohadschia vitiensis*	+	+		
Bêche-de-mer	*Holothuria atra*	+	+		+
Bêche-de-mer	*Holothuria edulis*	+			
Bêche-de-mer	*Holothuria fuscopunctata*	+			
Bêche-de-mer	*Holothuria leucospilota*				+
Bêche-de-mer	*Holothuria nobilis*	+			+
Bêche-de-mer	*Stichopus chloronotus*	+	+		+
Bêche-de-mer	*Stichopus hermanni*	+			
Bêche-de-mer	*Synapta* spp.	+			
Bêche-de-mer	*Thelenota ananas*	+	+		
Bêche-de-mer	*Thelenota anax*	+			
Bivalve	*Atrina* spp.	+			
Bivalve	*Atrina vexillum*	+			
Bivalve	*Chama* spp.	+			
Bivalve	*Hyotissa* spp.	+			
Bivalve	*Pinctada margaritifera*	+	+		
Bivalve	*Spondylus squamosus*	+	+		
Bivalve	*Tridacna derasa*	+			
Bivalve	*Tridacna maxima*	+	+		+
Bivalve	*Tridacna squamosa*	+	+		
Cnidarian	*Stichodactyla gigantea*	+	+		
Cnidarian	*Stichodactyla* spp.	+	+		+
Crustacean	*Panulirus* spp.				+
Crustacean	*Panulirus versicolor*	+			
Gastropod	*Cerithium nodulosum*				+
Gastropod	*Conus miles*		+		
Gastropod	*Conus* spp.		+		
Gastropod	*Cypraea caputserpensis*		+		
Gastropod	*Cypraea isabella*		+		
Gastropod	*Cypraea tigris*	+	+		+
Gastropod	*Lambis lambis*	+	+		
Gastropod	*Lambis truncata*	+			+
Gastropod	*Latirolagena smaragdula*		+		
Gastropod	*Ovula ovum*		+		
Gastropod	*Pleuroploca* spp.		+		
Gastropod	*Strombus* spp.		+		
Gastropod	*Tectus pyramis*	+	+		+
Gastropod	*Thais armigera*		+		
Gastropod	*Thais* spp.		+		+
Gastropod	*Trochus maculata*		+		

+ = presence of the species.

4.3.1 Invertebrate species recorded in different assessments in Koulo (continued)

Group	Species	Broad scale	Reef benthos	Soft benthos	Others
Gastropod	*Trochus niloticus*	+	+		+
Gastropod	*Trochus* spp.				+
Gastropod	*Turbo argyrostomus*		+		
Gastropod	*Turbo chrysostomus*	+	+		
Gastropod	*Turbo marmoratus*				+
Gastropod	*Turbo setosus*				+
Gastropod	*Turbo* spp.	+	+		
Octopus	*Octopus cyanea*	+			+
Star	*Acanthaster planci*	+	+		
Star	*Choriaster granulatus*	+	+		
Star	*Culcita novaeguineae*	+	+		+
Star	*Linckia laevigata*	+	+		+
Star	*Protoreaster nodosus*	+			
Urchin	*Diadema* spp.	+	+		
Urchin	*Echinometra mathaei*	+	+		
Urchin	*Echinothrix diadema*	+	+		+
Urchin	*Echinothrix* spp.		+		
Urchin	*Heterocentrotus mammillatus*	+	+		+
Urchin	*Tripneustes gratilla*	+			

+ = presence of the species.

4.3.2 Koulo broad-scale assessment data review

Station: Six 2 m x 300 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Acanthaster planci	0.5	0.4	66	16.7	0.0	2	0.5	0.3	11	2.8	0.0	2
Actinopyga lecanora	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1
Actinopyga mauritiana	1.8	0.8	66	23.3	4.1	5	1.8	1.1	11	6.5	2.4	3
Actinopyga miliaris	1.0	0.5	66	16.7	0.0	4	1.0	0.6	11	3.7	0.9	3
Actinopyga palauensis	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1
Actinopyga spp.	0.8	0.4	66	16.7	0.0	3	0.8	0.5	11	4.2	1.4	2
Atrina spp.	3.3	2.0	66	54.2	21.9	4	3.3	3.3	11	36.1		1
Atrina vexillum	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1
Bohadschia argus	18.9	2.6	66	31.2	3.0	40	18.9	3.8	11	18.9	3.8	11
Bohadschia vitiensis	7.1	2.9	66	51.9	14.0	9	7.1	5.5	11	25.9	17.6	3
Chama spp.	2.5	1.2	66	33.2	7.5	5	2.5	1.2	11	6.9	1.8	4
Choriaster granulatus	1.0	0.6	66	22.2	5.6	3	1.0	0.6	11	3.7	0.9	3
Culcita novaeguineae	10.4	3.5	66	40.2	11.1	17	10.4	5.0	11	16.3	7.1	7
Cypraea tigris	1.0	0.5	66	16.7	0.0	4	1.0	0.6	11	3.7	0.9	3
Diadema spp.	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1
Echinometra mathaei	4.7	3.4	66	153.6	36.9	2	4.7	3.2	11	25.6	6.2	2
Echinothrix diadema	1.3	0.7	66	20.7	4.2	4	1.3	0.7	11	4.6	0.9	3
Heterocentrotus mammillatus	1.5	0.7	66	19.8	3.4	5	1.5	0.7	11	4.1	0.8	4
Holothuria atra	12.4	4.5	66	58.3	16.5	14	12.4	5.8	11	19.4	8.1	7
Holothuria edulis	1.5	0.9	66	25.0	8.3	4	1.5	1.5	11	16.7		1
Holothuria fuscopunctata	1.8	0.6	66	16.7	0.0	7	1.8	0.8	11	3.9	1.1	5
Holothuria nobilis	1.5	0.7	66	20.0	3.3	5	1.5	0.8	11	4.2	1.4	4
Hyotissa spp.	2.3	2.0	66	75.0	58.3	2	2.3	2.3	11	25.0		1
Lambis lambis	3.8	1.4	66	27.8	5.6	9	3.8	1.3	11	6.9	1.2	6
Lambis truncata	0.8	0.4	66	16.7	0.0	3	0.8	0.4	11	2.8	0.0	3
Linckia laevigata	17.1	5.2	66	59.5	14.1	19	17.1	8.2	11	31.4	12.5	6
Octopus cyanea	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1
Panulirus versicolor	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.3.2 Koulo broad-scale assessment data review (continued)
Station: Six 2 m x 300 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Pinctada margaritifera	1.5	0.6	66	16.7	0.0	6	1.5	1.0	11	5.6	2.8	3
Protoreaster nodosus	5.8	5.8	66	383.3		1	5.8	5.8	11	63.9		1
Spondylus squamosus	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1
Stichodactyla gigantea	3.8	1.5	66	27.7	7.3	9	3.8	1.5	11	6.9	2.0	6
Stichodactyla spp.	1.5	0.7	66	20.0	3.3	5	1.5	0.7	11	4.2	0.8	4
Stichopus chloronotus	5.3	2.5	66	35.0	13.3	10	5.3	3.5	11	11.7	6.9	5
Stichopus hermanni	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1
Synapta spp.	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1
Tectus pyramis	2.3	0.8	66	18.7	2.1	8	2.3	1.2	11	6.2	2.1	4
Thelenota ananas	7.3	1.8	66	28.3	3.7	17	7.3	2.8	11	13.4	3.4	6
Thelenota anax	8.1	1.9	66	28.1	4.0	19	8.1	2.7	11	11.1	3.1	8
Tridacna derasa	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1
Tridacna maxima	42.8	7.3	66	64.2	9.4	44	42.8	9.3	11	42.8	9.3	11
Tridacna squamosa	1.8	0.7	66	19.4	2.8	6	1.8	0.6	11	3.2	0.5	6
Tripneustes gratilla	1.0	0.6	66	22.2	5.6	3	1.0	0.6	11	3.7	0.9	3
Trochus niloticus	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1
Turbo chrysostomus	0.5	0.4	66	16.7	0.0	2	0.5	0.5	11	5.6		1
Turbo spp.	0.3	0.3	66	16.7		1	0.3	0.3	11	2.8		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.3.3 All Ha'apai medium- and deep-water broad-scale assessment data review

Station: Twelve 4 m x 100 m transects on SCUBA towed by broad-scale board in mid-to-deep waters.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Acanthaster planci	0.2	0.1	480	25.0	0.0	3	0.2	0.1	40	3.1	1.0	2
Actinopyga lecanora	0.1	0.1	480	25.0	0.0	2	0.1	0.1	40	4.2		1
Actinopyga miliaris	1.9	0.4	480	33.3	3.2	28	1.9	0.5	40	5.2	0.9	15
Atrina spp.	0.1	0.1	480	25.0		1	0.1	0.1	40	2.1		1
Atrina vexillum	0.1	0.1	480	25.0		1	0.1	0.1	40	2.1		1
Bohadschia argus	6.2	0.7	480	35.4	2.1	84	6.2	1.5	40	10.0	2.0	25
Bohadschia similis	0.1	0.1	480	25.0		1	0.1	0.1	40	2.2		1
Bohadschia vitiensis	4.4	1.0	480	62.5	9.2	34	4.4	2.5	40	25.3	12.4	7
Chicoreus ramosus	0.1	0.1	480	25.0		1	0.1	0.1	40	2.1		1
Choriaster granulatus	18.2	1.5	480	51.2	2.9	171	18.3	3.0	40	24.4	3.3	30
Conus spp.	0.1	0.1	480	25.0		1	0.1	0.1	40	2.1		1
Culcita novaeguineae	3.9	0.5	480	32.3	1.8	58	3.9	0.9	40	6.9	1.2	23
Echinothrix diadema	0.1	0.1	480	25.0	0.0	2	0.1	0.1	40	4.3		1
Holothuria atra	75.7	17.1	480	586.3	113.0	62	75.7	57.8	40	178.1	134.3	17
Holothuria edulis	89.2	17.8	480	528.4	91.1	81	89.2	60.1	40	254.8	166.5	14
Holothuria fuscogilva	6.8	0.7	480	34.1	2.0	95	6.7	1.2	40	10.0	1.4	27
Holothuria fuscopunctata	7.4	1.1	480	44.1	4.8	80	7.4	2.0	40	11.8	2.8	25
Holothuria nobilis	2.2	0.4	480	34.7	3.4	31	2.3	0.6	40	4.7	1.1	19
Hyotissa spp.	0.6	0.2	480	30.0	5.0	10	0.7	0.4	40	5.2	2.0	5
Lambis lambis	0.5	0.2	480	31.3	6.3	8	0.5	0.2	40	3.5	1.0	6
Lambis spp.	0.2	0.1	480	25.0	0.0	3	0.2	0.1	40	3.1	1.0	2
Lambis truncata	1.4	0.4	480	37.5	4.2	18	1.4	0.4	40	4.3	0.7	13
Linckia laevigata	8.1	1.1	480	56.2	4.7	69	8.1	3.1	40	21.5	7.1	15
Ovula ovum	0.1	0.1	480	29.2	4.2	2	0.1	0.1	40	2.1	0.0	2
Panulirus spp.	0.1	0.1	480	25.0	0.0	2	0.1	0.1	40	2.2	0.1	2
Pinctada margaritifera	0.3	0.1	480	31.3	6.3	4	0.3	0.1	40	2.6	0.5	4
Spondylus spp.	0.4	0.2	480	40.0	10.0	5	0.4	0.2	40	3.3	0.8	5
Stichodactyla gigantea	5.5	1.0	480	62.6	7.1	42	5.4	1.3	40	10.9	2.0	20

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.3.3 All Ha'apai medium- and deep-water broad-scale assessment data review (continued)
Station: Twelve 4 m x 100 m transects on SCUBA towed by broad-scale board in mid-to-deep waters.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Stichodactyla spp.	0.5	0.2	480	45.0	14.6	5	0.5	0.4	40	6.3	4.1	3
Stichopus chloronotus	0.4	0.1	480	25.0	0.0	7	0.4	0.3	40	7.3	1.0	2
Stichopus hermanni	2.6	0.6	480	43.8	7.5	28	2.6	1.3	40	11.3	5.0	9
Thelenota ananas	1.9	0.4	480	32.1	2.2	28	1.9	0.5	40	4.5	0.8	17
Thelenota anax	14.6	1.0	480	37.3	1.5	188	14.7	1.5	40	15.9	1.5	37
Tridacna derasa	1.5	0.3	480	25.9	0.9	28	1.5	0.3	40	3.5	0.4	17
Tridacna maxima	3.0	0.8	480	44.8	8.9	32	2.7	0.9	40	7.2	2.1	15
Tridacna squamosa	2.0	0.4	480	31.7	3.1	31	1.9	0.5	40	5.2	0.9	15
Tridacna tevoroa	0.1	0.1	480	25.0	0.0	2	0.1	0.1	40	2.1	0.0	2

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.3.4 Koulo reef-benthos transect (RBt) assessment data review
Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Acanthaster planci	2.8	2.8	88	250.0		1	3.0	3.0	14	41.7		1
Actinopyga mauritiana	48.3	12.7	88	283.3	33.3	15	50.6	15.2	14	88.5	16.6	8
Bohadschia argus	34.1	10.0	88	272.7	22.7	11	27.4	13.3	14	76.7	25.9	5
Bohadschia vitiensis	11.4	6.9	88	333.3	83.3	3	11.9	9.2	14	83.3	41.7	2
Choriaster granulatus	8.5	4.9	88	250.0	0.0	3	7.7	4.2	14	36.1	5.6	3
Conus miles	19.9	12.3	88	583.3	166.7	3	20.8	14.3	14	145.8	20.8	2
Conus spp.	39.8	13.3	88	388.9	43.9	9	35.7	15.7	14	100.0	25.0	5
Culcita novaeguineae	5.7	4.0	88	250.0	0.0	2	4.8	3.4	14	33.3	8.3	2
Cypraea caputserpensis	17.0	12.0	88	500.0	250.0	3	16.7	14.9	14	116.7	91.7	2
Cypraea isabella	5.7	5.7	88	500.0		1	3.6	3.6	14	50.0		1
Cypraea tigris	5.7	5.7	88	500.0		1	6.0	6.0	14	83.3		1
Diadema spp.	48.3	16.6	88	425.0	75.0	10	48.2	19.0	14	96.4	28.0	7

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.3.4 Koulo reef-benthos transect (RBt) assessment data review (continued)

Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Echinometra mathaei	1855.1	234.1	88	2766.9	281.3	59	1939.9	494.0	14	1939.9	494.0	14
Echinothrix diadema	62.5	26.3	88	550.0	170.0	10	65.5	41.6	14	152.8	88.5	6
Echinothrix spp.	8.5	6.3	88	375.0	125.0	2	8.9	8.9	14	125.0		1
Heterocentrotus mammillatus	65.3	22.3	88	522.7	103.7	11	63.7	29.3	14	148.6	51.8	6
Holothuria atra	187.5	31.9	88	500.0	49.9	33	190.5	66.1	14	296.3	84.3	9
Lambis lambis	2.8	2.8	88	250.0		1	3.0	3.0	14	41.7		1
Latirolagena smaragdula	45.5	35.8	88	2000.0	1000.0	2	28.6	28.6	14	400.0		1
Linckia laevigata	497.2	72.0	88	875.0	97.2	50	491.1	151.9	14	763.9	179.6	9
Ovula ovum	2.8	2.8	88	250.0		1	3.0	3.0	14	41.7		1
Pinctada margaritifera	2.8	2.8	88	250.0		1	3.0	3.0	14	41.7		1
Pleuroploca spp.	2.8	2.8	88	250.0		1	3.0	3.0	14	41.7		1
Spondylus squamosus	2.8	2.8	88	250.0		1	1.8	1.8	14	25.0		1
Stichodactyla gigantea	8.5	4.9	88	250.0	0.0	3	8.9	6.4	14	62.5	20.8	2
Stichodactyla spp.	2.8	2.8	88	250.0		1	3.0	3.0	14	41.7		1
Stichopus chloronotus	28.4	9.4	88	277.8	27.8	9	26.2	11.0	14	73.3	15.5	5
Strombus spp.	2.8	2.8	88	250.0		1	3.0	3.0	14	41.7		1
Tectus pyramis	73.9	16.7	88	342.1	34.3	19	77.4	17.9	14	108.3	16.7	10
Thais armigera	2.8	2.8	88	250.0		1	1.8	1.8	14	25.0		1
Thais spp.	54.0	18.7	88	527.8	77.3	9	51.8	25.3	14	181.3	43.5	4
Thelenota ananas	2.8	2.8	88	250.0		1	3.0	3.0	14	41.7		1
Tridacna maxima	127.8	23.2	88	387.9	38.4	29	132.7	34.2	14	154.9	36.0	12
Tridacna squamosa	2.8	2.8	88	250.0		1	3.0	3.0	14	41.7		1
Trochus maculata	2.8	2.8	88	250.0		1	1.8	1.8	14	25.0		1
Trochus niloticus	8.5	6.3	88	375.0	125.0	2	8.9	6.4	14	62.5	20.8	2
Turbo argyrostomus	19.9	9.2	88	350.0	61.2	5	18.5	10.6	14	86.1	21.7	3
Turbo chrysostomus	5.7	4.0	88	250.0	0.0	2	3.6	3.6	14	50.0		1
Turbo spp.	45.5	22.7	88	571.4	209.3	7	46.4	24.3	14	130.0	51.6	5

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.3.5 Koulo reef-front search (RFs) assessment data review

Station: Six 5-min search periods.

Species	Search period			Search period _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Actinopyga mauritiana	22.2	5.2	18	36	4.9	11	22.2	2.6	3	22.2	2.6	3
Culcita novaeguineae	3.9	2.1	18	24	0.0	3	3.9	3.9	3	11.8		1
Holothuria atra	6.5	2.6	18	24	0.0	5	6.5	4.7	3	9.8	5.9	2
Lambis truncata	1.3	1.3	18	24		1	1.3	1.3	3	3.9		1
Stichopus chloronotus	2.6	2.6	18	47		1	2.6	2.6	3	7.8		1
Tectus pyramis	32.7	12.5	18	98	17.6	6	32.7	32.7	3	98.0		1
Tridacna maxima	20.9	6.3	18	42	7.6	9	20.9	13.3	3	20.9	13.3	3
Trochus niloticus	3.9	2.9	18	35	11.8	2	3.9	2.3	3	5.9	2.0	2
Trochus spp.	1.3	1.3	18	24		1	1.3	1.3	3	3.9		1
Turbo marmoratus	1.3	1.3	18	23.5		1	1.3	1.3	3	3.9		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.3.6 Koulo reef-front search by walking (RFs_w) assessment data review

Station: Six 5-min search periods.

Species	Search period			Search period _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Actinopyga mauritiana	677.1	49.8	65	677.1	49.8	65	677.1	81.3	13	677.1	81.3	13
Actinopyga miliaris	1.6	0.8	65	21.4	4.2	5	1.6	0.7	13	5.3	0.7	4
Cerithium nodulosum	0.5	0.5	65	31.2		1	0.5	0.5	13	6.2		1
Cypraea tigris	0.2	0.2	65	13.7		1	0.2	0.2	13	2.7		1
Echinothrix diadema	16.4	4.9	65	59.1	13.3	18	16.4	7.9	13	26.6	11.7	8
Heterocentrotus mammillatus	0.3	0.3	65	17.4		1	0.3	0.3	13	3.5		1
Holothuria atra	513.7	62.9	65	618.4	67.3	54	513.7	71.7	13	513.7	71.7	13
Holothuria leucospilota	10.3	5.1	65	83.6	32.0	8	10.3	5.1	13	22.3	9.1	6
Holothuria nobilis	0.5	0.4	65	17.3	0.2	2	0.5	0.4	13	3.5	0.0	2
Linckia laevigata	5.6	2.2	65	52.0	8.3	7	5.6	3.6	13	18.2	9.7	4
Octopus cyanea	0.3	0.3	65	18.0		1	0.3	0.3	13	3.6		1
Panulirus spp.	0.8	0.4	65	17.2	0.3	3	0.8	0.6	13	5.1	1.8	2
Stichodactyla spp.	12.3	3.4	65	47.0	8.9	17	12.3	5.6	13	22.8	8.8	7
Stichopus chloronotus	45.3	15.1	65	128.1	37.4	23	45.3	13.8	13	49.1	14.5	12
Thais spp.	0.5	0.5	65	31.1		1	0.5	0.5	13	6.2		1
Trochus niloticus	0.5	0.3	65	15.6	0.0	2	0.5	0.5	13	6.2		1
Turbo setosus	0.2	0.2	65	14.4		1	0.2	0.2	13	2.9		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.3.7 Koulo species size review – all survey methods

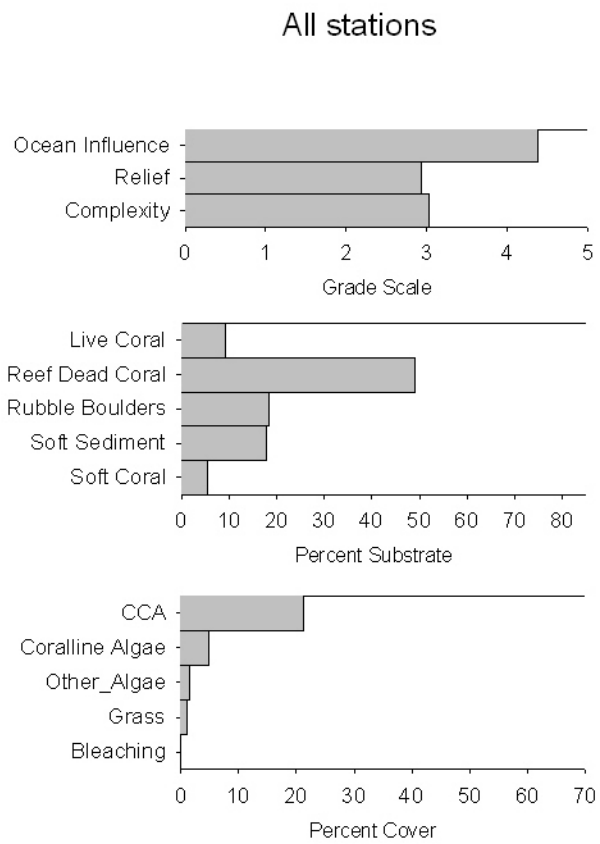
Species	Mean length (cm)	SE	n measured	n total
Tridacna maxima	12.2	0.3	205	231
Bohadschia argus	31.1	0.8	83	87
Holothuria atra	28.2	1.5	53	2317
Actinopyga mauritiana	26.7	0.9	29	2877
Thelenota anax	42.6	1.6	29	32
Thelenota ananas	36.0	1.0	27	30
Stichopus chloronotus	20.2	0.9	22	224
Tectus pyramis	7.9	0.5	10	60
Trochus niloticus	7.1	0.9	8	9
Tridacna squamosa	17.7	1.5	7	8
Holothuria nobilis	31.6	3.1	7	8
Pinctada margaritifera	13.0	0.4	5	7
Holothuria fuscopunctata	38.5	2.2	4	7
Actinopyga miliaris	27.7	1.5	3	11
Lambis truncata	29.0	3.8	3	4
Thais spp.	4.2	0	2	21
Conus spp.	4.4	1.15	2	14
Bohadschia vitiensis	28.0		1	32
Lambis lambis	20.0		1	16
Cypraea caputserpensis	35.0		1	6
Turbo chrysostomus	4.2		1	4
Actinopyga spp.	60.0		1	3
Thais armigera	5.0		1	1
Panulirus versicolor	15.0		1	1
Stichopus hermanni	35.0		1	1
Tridacna derasa	19.0		1	1
Trochus spp.	6.0		1	1
Actinopyga lecanora	26.0		1	1
Echinometra mathaei				672
Linckia laevigata				269
Echinothrix diadema				102
Stichodactyla spp.				59
Culcita novaeguineae				46
Holothuria leucospilota				46
Heterocentrotus mammillatus				30
Protoreaster nodosus				23
Stichodactyla gigantea				18
Diadema spp.				18
Turbo spp.				17
Latirolagena smaragdula				16
Atrina spp.				13
Chama spp.				10
Hyotissa spp.				9
Turbo argyrostomus				7
Cypraea tigris				7
Conus miles				7
Choriaster granulatus				7
Holothuria edulis				6

4.3.7 Koulo species size review – all survey methods (continued)

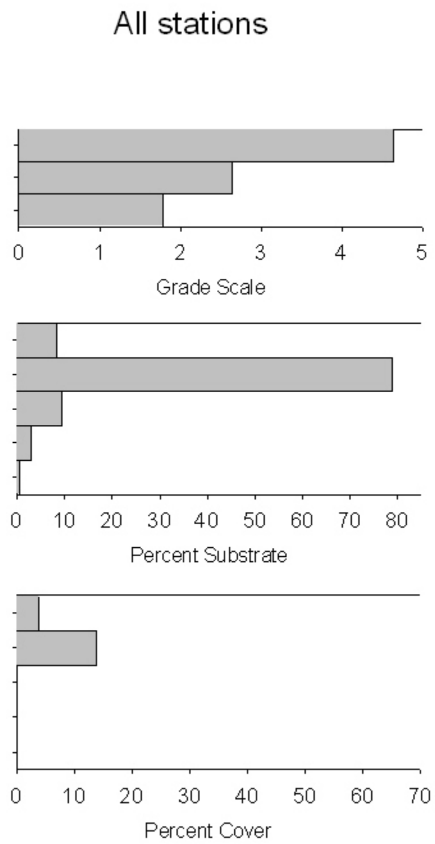
Species	Mean length (cm)	SE	n measured	n total
Tripneustes gratilla				4
Panulirus spp.				3
Acanthaster planci				3
Echinothrix spp.				3
Spondylus squamosus				2
Cerithium nodulosum				2
Octopus cyanea				2
Cypraea isabella				2
Ovula ovum				1
Pleuroploca spp.				1
Synapta spp.				1
Turbo setosus				1
Turbo marmoratus				1
Strombus spp.				1
Trochus maculata				1
Actinopyga palauensis				1
Atrina vexillum				1

4.3.8 Habitat descriptors for independent assessment – Koulo

Broad-scale stations



Reef-benthos transect stations



4.4 Lofanga invertebrate survey data

4.4.1 Invertebrate species recorded in different assessments in Lofanga

Group	Species	Broad scale	Reef benthos	Soft benthos	Others
Bêche-de-mer	*Actinopyga mauritiana*	+	+		+
Bêche-de-mer	*Actinopyga miliaris*	+			
Bêche-de-mer	*Bohadschia argus*	+	+		
Bêche-de-mer	*Bohadschia similis*	+			
Bêche-de-mer	*Bohadschia vitiensis*	+	+		
Bêche-de-mer	*Holothuria atra*	+	+		
Bêche-de-mer	*Holothuria coluber*	+			
Bêche-de-mer	*Holothuria edulis*	+			
Bêche-de-mer	*Holothuria fuscopunctata*	+			
Bêche-de-mer	*Holothuria leucospilota*	+			
Bêche-de-mer	*Holothuria nobilis*	+			
Bêche-de-mer	*Holothuria scabra versicolor*	+			
Bêche-de-mer	*Stichopus chloronotus*	+	+		
Bêche-de-mer	*Stichopus hermanni*	+			
Bêche-de-mer	*Stichopus horrens*	+			
Bêche-de-mer	*Synapta* spp.	+			
Bêche-de-mer	*Thelenota ananas*	+			
Bêche-de-mer	*Thelenota anax*	+			
Bivalve	*Atrina* spp.	+			
Bivalve	*Atrina vexillum*	+			
Bivalve	*Chama* spp.		+		
Bivalve	*Pinctada margaritifera*	+			
Bivalve	*Spondylus* spp.	+			
Bivalve	*Spondylus squamosus*	+			
Bivalve	*Tridacna maxima*	+	+		+
Bivalve	*Tridacna squamosa*	+			
Cnidarian	*Stichodactyla gigantea*	+	+		
Cnidarian	*Stichodactyla* spp.		+		
Crustacean	*Panulirus* spp.		+		
Gastropod	*Astralium* spp.		+		
Gastropod	*Conus miles*		+		
Gastropod	*Conus* spp.	+	+		
Gastropod	*Cypraea caputserpensis*		+		
Gastropod	*Cypraea tigris*	+			
Gastropod	*Drupa* spp.		+		
Gastropod	*Lambis lambis*	+			
Gastropod	*Lambis truncata*	+			
Gastropod	*Ovula ovum*	+			
Gastropod	*Tectus pyramis*	+	+		+
Gastropod	*Thais* spp.		+		
Gastropod	*Trochus maculata*		+		
Gastropod	*Trochus niloticus*		+		
Gastropod	*Turbo argyrostomus*		+		+
Gastropod	*Turbo crassus*		+		
Gastropod	*Turbo marmoratus*				+
Gastropod	*Turbo setosus*		+		

+ = presence of the species.

4.4.1 Invertebrate species recorded in different assessments in Lofanga (continued)

Group	Species	Broad scale	Reef benthos	Soft benthos	Others
Gastropod	*Turbo* spp.	+	+		
Gastropod	*Tutufa bubo*	+			
Octopus	*Octopus* spp.	+			
Star	*Acanthaster planci*	+			
Star	*Culcita novaeguineae*	+			
Star	*Linckia laevigata*	+	+		
Urchin	*Diadema* spp.	+	+		
Urchin	*Echinometra mathaei*	+	+		
Urchin	*Echinothrix diadema*	+	+		
Urchin	*Echinothrix* spp.		+		+
Urchin	*Heterocentrotus mammillatus*	+	+		+
Urchin	*Tripneustes gratilla*	+			

+ = presence of the species.

4.4.2 Lofanga broad-scale assessment data review

Station: Six 2 m x 300 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Acanthaster planci	1.9	0.9	61	23.3	4.1	5	1.9	1.4	10	6.5	3.7	3
Actinopyga mauritiana	2.4	1.3	61	29.8	9.8	5	2.5	1.7	10	8.3	4.3	3
Actinopyga miliaris	0.8	0.5	61	16.7	0.0	3	0.8	0.4	10	2.8	0.0	3
Atrina spp.	0.8	0.8	61	50.0		1	0.8	0.8	10	8.3		1
Atrina vexillum	0.5	0.4	61	16.7	0.0	2	0.6	0.4	10	2.8	0.0	2
Bohadschia argus	25.4	6.6	61	53.3	12.0	29	25.8	13.3	10	28.6	14.5	9
Bohadschia similis	0.3	0.3	61	16.7		1	0.2	0.2	10	2.4		1
Bohadschia vitiensis	59.3	18.6	61	180.8	46.8	20	59.6	45.1	10	119.1	85.8	5
Conus spp.	2.7	1.0	61	20.8	2.7	8	2.6	1.1	10	5.2	1.2	5
Culcita novaeguineae	8.2	2.0	61	26.2	4.3	19	8.1	3.2	10	11.5	3.8	7
Cypraea tigris	2.5	0.9	61	21.4	3.1	7	2.5	1.1	10	6.3	1.3	4
Diadema spp.	7.9	4.0	61	69.0	26.1	7	8.1	7.2	10	26.9	22.7	3
Echinometra mathaei	7.1	2.2	61	35.9	6.4	12	6.8	2.6	10	13.6	2.7	5
Echinothrix diadema	9.8	3.3	61	42.9	10.3	14	10.0	6.0	10	25.0	12.2	4
Heterocentrotus mammillatus	2.7	1.1	61	27.8	3.5	6	2.8	1.0	10	5.6	0.9	5
Holothuria atra	3195.6	956.8	61	5907.1	1634.8	33	3002.2	1868.2	10	3335.8	2055.1	9
Holothuria coluber	26.5	11.7	61	101.0	39.7	16	26.7	21.6	10	66.8	50.9	4
Holothuria edulis	488.8	254.6	61	1296.4	649.0	23	482.1	362.6	10	1205.3	834.1	4
Holothuria fuscopunctata	2.4	1.1	61	24.8	5.6	6	2.4	1.3	10	4.9	2.2	5
Holothuria leucospilota	0.3	0.3	61	16.7		1	0.3	0.3	10	2.8		1
Holothuria nobilis	0.8	0.5	61	16.7	0.0	3	0.8	0.6	10	4.2	1.4	2
Holothuria scabra versicolor	2.2	1.3	61	33.3	11.8	4	2.1	1.2	10	7.0	2.4	3
Lambis lambis	5.5	1.8	61	33.3	5.0	10	5.2	2.5	10	13.1	3.6	4
Lambis truncata	2.4	0.8	61	18.5	2.0	8	2.5	1.2	10	6.2	1.7	4
Linckia laevigata	13.1	3.8	61	42.1	9.4	19	13.1	5.6	10	18.8	7.0	7
Octopus spp.	0.3	0.3	61	16.7		1	0.3	0.3	10	2.8		1
Ovula ovum	0.5	0.4	61	16.7	0.0	2	0.6	0.4	10	2.8	0.0	2
Pinctada margaritifera	1.6	0.8	61	25.0	4.8	4	1.7	0.9	10	5.6	1.6	3

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.4.2 Lofanga broad-scale assessment data review (continued)

Station: Six 2 m x 300 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Spondylus spp.	0.5	0.4	61	16.7	0.0	2	0.6	0.4	10	2.8	0.0	2
Spondylus squamosus	0.3	0.3	61	16.7		1	0.3	0.3	10	2.8		1
Stichodactyla gigantea	9.8	2.4	61	33.3	4.9	18	10.0	4.6	10	16.7	6.5	6
Stichopus chloronotus	67.1	16.6	61	132.0	28.2	31	67.0	27.1	10	83.8	31.3	8
Stichopus hermanni	3.8	1.7	61	33.3	8.9	7	3.8	2.0	10	9.5	3.4	4
Stichopus horrens	1.1	0.9	61	33.3	16.7	2	1.0	1.0	10	9.5		1
Synapta spp.	1.1	1.1	61	66.7		1	1.0	1.0	10	9.5		1
Tectus pyramis	5.7	1.8	61	31.6	5.2	11	5.8	2.3	10	11.6	2.8	5
Thelenota ananas	2.4	0.8	61	18.4	1.8	8	2.4	1.3	10	6.1	2.1	4
Thelenota anax	1.6	0.8	61	24.8	4.9	4	1.7	1.1	10	5.5	2.8	3
Tridacna maxima	57.7	8.7	61	80.0	10.3	44	58.5	16.5	10	65.0	17.0	9
Tridacna squamosa	1.4	0.6	61	16.7	0.0	5	1.4	0.7	10	4.6	0.9	3
Tripneustes gratilla	0.3	0.3	61	16.7		1	0.2	0.2	10	2.4		1
Turbo spp.	0.3	0.3	61	16.7		1	0.3	0.3	10	2.8		1
Tutufa bubo	0.3	0.3	61	16.7		1	0.3	0.3	10	2.8		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.4.3 All Ha'apai medium- and deep-water broad-scale assessment data review

Station: Twelve 4 m x 100 m transects on SCUBA towed by broad-scale board in mid-to-deep waters.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Acanthaster planci	0.2	0.1	480	25.0	0.0	3	0.2	0.1	40	3.1	1.0	2
Actinopyga lecanora	0.1	0.1	480	25.0	0.0	2	0.1	0.1	40	4.2		1
Actinopyga miliaris	1.9	0.4	480	33.3	3.2	28	1.9	0.5	40	5.2	0.9	15
Atrina spp.	0.1	0.1	480	25.0		1	0.1	0.1	40	2.1		1
Atrina vexillum	0.1	0.1	480	25.0		1	0.1	0.1	40	2.1		1
Bohadschia argus	6.2	0.7	480	35.4	2.1	84	6.2	1.5	40	10.0	2.0	25
Bohadschia similis	0.1	0.1	480	25.0		1	0.1	0.1	40	2.2		1
Bohadschia vitiensis	4.4	1.0	480	62.5	9.2	34	4.4	2.5	40	25.3	12.4	7
Chicoreus ramosus	0.1	0.1	480	25.0		1	0.1	0.1	40	2.1		1
Choriaster granulatus	18.2	1.5	480	51.2	2.9	171	18.3	3.0	40	24.4	3.3	30
Conus spp.	0.1	0.1	480	25.0		1	0.1	0.1	40	2.1		1
Culcita novaeguineae	3.9	0.5	480	32.3	1.8	58	3.9	0.9	40	6.9	1.2	23
Echinothrix diadema	0.1	0.1	480	25.0	0.0	2	0.1	0.1	40	4.3		1
Holothuria atra	75.7	17.1	480	586.3	113.0	62	75.7	57.8	40	178.1	134.3	17
Holothuria edulis	89.2	17.8	480	528.4	91.1	81	89.2	60.1	40	254.8	166.5	14
Holothuria fuscogilva	6.8	0.7	480	34.1	2.0	95	6.7	1.2	40	10.0	1.4	27
Holothuria fuscopunctata	7.4	1.1	480	44.1	4.8	80	7.4	2.0	40	11.8	2.8	25
Holothuria nobilis	2.2	0.4	480	34.7	3.4	31	2.3	0.6	40	4.7	1.1	19
Hyotissa spp.	0.6	0.2	480	30.0	5.0	10	0.7	0.4	40	5.2	2.0	5
Lambis lambis	0.5	0.2	480	31.3	6.3	8	0.5	0.2	40	3.5	1.0	6
Lambis spp.	0.2	0.1	480	25.0	0.0	3	0.2	0.1	40	3.1	1.0	2
Lambis truncata	1.4	0.4	480	37.5	4.2	18	1.4	0.4	40	4.3	0.7	13
Linckia laevigata	8.1	1.1	480	56.2	4.7	69	8.1	3.1	40	21.5	7.1	15
Ovula ovum	0.1	0.1	480	29.2	4.2	2	0.1	0.1	40	2.1	0.0	2
Panulirus spp.	0.1	0.1	480	25.0	0.0	2	0.1	0.1	40	2.2	0.1	2
Pinctada margaritifera	0.3	0.1	480	31.3	6.3	4	0.3	0.1	40	2.6	0.5	4
Spondylus spp.	0.4	0.2	480	40.0	10.0	5	0.4	0.2	40	3.3	0.8	5
Stichodactyla gigantea	5.5	1.0	480	62.6	7.1	42	5.4	1.3	40	10.9	2.0	20

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.4.3 All Ha'apai medium- and deep-water broad-scale assessment data review (continued)
Station: Twelve 4 m x 100 m transects on SCUBA towed by broad-scale board in mid-to-deep waters.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Stichodactyla spp.	0.5	0.2	480	45.0	14.6	5	0.5	0.4	40	6.3	4.1	3
Stichopus chloronotus	0.4	0.1	480	25.0	0.0	7	0.4	0.3	40	7.3	1.0	2
Stichopus hermanni	2.6	0.6	480	43.8	7.5	28	2.6	1.3	40	11.3	5.0	9
Thelenota ananas	1.9	0.4	480	32.1	2.2	28	1.9	0.5	40	4.5	0.8	17
Thelenota anax	14.6	1.0	480	37.3	1.5	188	14.7	1.5	40	15.9	1.5	37
Tridacna derasa	1.5	0.3	480	25.9	0.9	28	1.5	0.3	40	3.5	0.4	17
Tridacna maxima	3.0	0.8	480	44.8	8.9	32	2.7	0.9	40	7.2	2.1	15
Tridacna squamosa	2.0	0.4	480	31.7	3.1	31	1.9	0.5	40	5.2	0.9	15
Tridacna tevoroa	0.1	0.1	480	25.0	0.0	2	0.1	0.1	40	2.1	0.0	2

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.4.4 Lofanga reef-benthos transect (RBt) assessment data review
Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Actinopyga mauritiana	26.0	11.1	48	250.0	0.0	5	26.0	15.6	8	69.4	27.8	3
Astralium spp.	5.2	5.2	48	250.0		1	5.2	5.2	8	41.7		1
Bohadschia argus	20.8	16.4	48	500.0	250.0	2	20.8	15.7	8	83.3	41.7	2
Bohadschia vitiensis	5.2	5.2	48	250.0		1	5.2	5.2	8	41.7		1
Chama spp.	10.4	7.3	48	250.0	0.0	2	10.4	10.4	8	83.3		1
Conus miles	15.6	8.8	48	250.0	0.0	3	15.6	11.0	8	62.5	20.8	2
Conus spp.	31.3	16.0	48	375.0	72.2	4	31.3	17.2	8	83.3	24.1	3
Cypraea caputserpensis	20.8	16.4	48	500.0	250.0	2	20.8	15.7	8	83.3	41.7	2
Diadema spp.	36.5	26.8	48	583.3	333.3	3	36.5	36.5	8	291.7		1
Drupa spp.	5.2	5.2	48	250.0		1	5.2	5.2	8	41.7		1
Echinometra mathaei	130.2	60.0	48	694.4	252.7	9	130.2	74.1	8	208.3	106.2	5
Echinothrix diadema	10.4	10.4	48	500.0		1	10.4	10.4	8	83.3		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.4.4 Lofanga reef-benthos transect (RBt) assessment data review (continued)

Station: Six 1 m x 40 m transects.

Species	Transect			Transect _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Heterocentrotus mammillatus	52.1	28.8	48	500.0	193.6	5	52.1	27.0	8	104.2	39.9	4
Echinothrix spp.	10.4	10.4	48	500.0		1	10.4	10.4	8	83.3		1
Holothuria atra	151.0	41.9	48	453.1	86.1	16	151.0	62.5	8	172.6	67.7	7
Linckia laevigata	41.7	17.2	48	333.3	52.7	6	41.7	23.6	8	111.1	36.7	3
Panulirus spp.	5.2	5.2	48	250.0		1	5.2	5.2	8	41.7		1
Stichodactyla gigantea	5.2	5.2	48	250.0		1	5.2	5.2	8	41.7		1
Stichodactyla spp.	5.2	5.2	48	250.0		1	5.2	5.2	8	41.7		1
Stichopus chloronotus	156.3	88.3	48	1250.0	559.0	6	156.3	138.8	8	416.7	354.4	3
Tectus pyramis	88.5	24.1	48	354.2	37.2	12	88.5	38.1	8	141.7	46.8	5
Thais spp.	57.3	30.9	48	687.5	187.5	4	57.3	36.0	8	152.8	69.4	3
Tridacna maxima	36.5	14.9	48	291.7	41.7	6	36.5	12.3	8	58.3	10.2	5
Trochus maculata	15.6	15.6	48	750.0		1	15.6	15.6	8	125.0		1
Trochus niloticus	5.2	5.2	48	250.0		1	5.2	5.2	8	41.7		1
Turbo argyrostomus	36.5	12.9	48	250.0	0.0	7	36.5	16.6	8	72.9	19.9	4
Turbo crassus	15.6	8.8	48	250.0	0.0	3	15.6	11.0	8	62.5	20.8	2
Turbo setosus	26.0	17.0	48	416.7	166.7	3	26.0	15.6	8	69.4	27.8	3
Turbo spp.	78.1	41.5	48	937.5	236.6	4	78.1	52.5	8	208.3	110.2	3

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.4.5 Lofanga reef-front search (RFs) assessment data review

Station: Six 5-min search periods.

Species	Search period			Search period _P			Station			Station _P		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Actinopyga mauritiana	19.6	11.2	6	39.2	15.7	3	19.6		1	19.6		1
Echinothrix spp.	39.2	34.7	6	117.6	94.1	2	39.2		1	39.2		1
Heterocentrotus mammillatus	70.6	8.6	6	70.6	8.6	6	70.6		1	70.6		1
Tectus pyramis	19.6	9.4	6	39.2	7.8	3	19.6		1	19.6		1
Tridacna maxima	7.8	5.0	6	23.5	0.0	2	7.8		1	7.8		1
Turbo argyrostomus	11.8	5.3	6	23.5	0.0	3	11.8		1	11.8		1
Turbo marmoratus	3.9	3.9	6	23.5		1	3.9		1	3.9		1

Mean = mean density (numbers/ha); _P = result for transects or stations where the species was located during the survey; n = number; SE = standard error.

4.4.6 Lofanga species size review – all survey methods

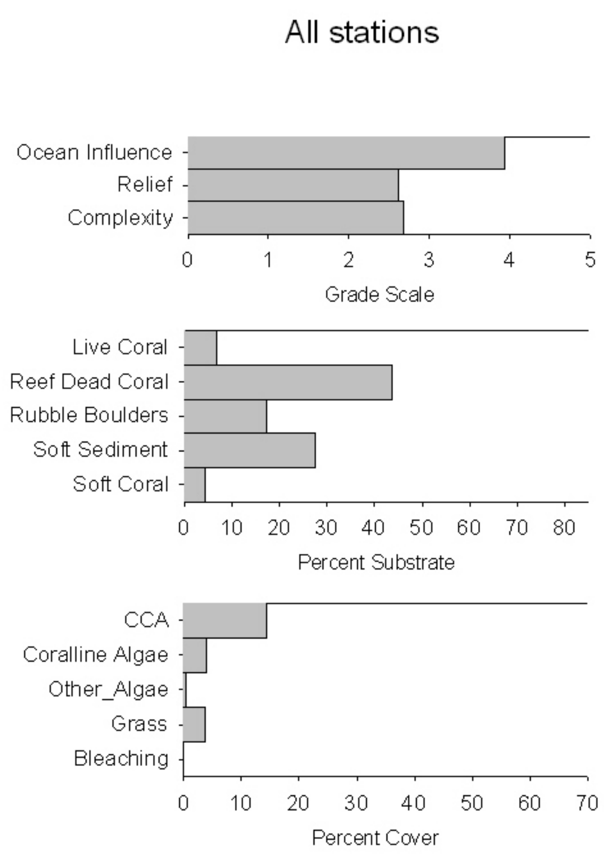
Species	Mean length (cm)	SE	n measured	n total
Tridacna maxima	11.4	0.2	192	221
Bohadschia argus	33.4	0.5	58	97
Holothuria atra	31.0	2.3	19	11,239
Stichopus chloronotus	16.9	1.3	16	276
Stichopus hermanni	35.9	1.1	14	14
Thelenota ananas	35.2	2.9	9	9
Holothuria fuscopunctata	36.2	0.8	9	9
Conus spp.	11.0	0.0	8	16
Lambis truncata	34.0	1.0	7	9
Holothuria scabra versicolor	24.0	2.9	7	8
Tectus pyramis	9.5	0.5	6	43
Thais spp.	5.6	0.4	6	11
Thelenota anax	39.7	4.4	6	6
Actinopyga mauritiana	16.2	2.5	5	19
Turbo argyrostomus	5.7	0.1	5	10
Pinctada margaritifera	14.0	0.5	5	6
Turbo setosus	6.1	0.3	5	5
Tridacna squamosa	23.2	2.7	5	5
Lambis lambis	18.7	0.7	3	18
Turbo crassus	8.9	0.2	3	3
Trochus maculata	3.9	0.3	3	3
Conus miles	4.7	0.1	3	3
Actinopyga miliaris	26.0	4.0	3	3
Holothuria nobilis	31.7	1.7	3	3
Bohadschia vitiensis	32.5	7.5	2	218
Stichopus horrens	12.5	0.5	2	2
Culcita novaeguineae	3.5		1	30
Trochus niloticus	7.5		1	1
Tutufa bubo	38.0		1	1
Drupa spp.	4.3		1	1
Bohadschia similis	35.0		1	1
Astralium spp.	4.2		1	1
Panulirus spp.	15.0		1	1
Holothuria edulis				1789
Holothuria coluber				97
Linckia laevigata				56
Echinometra mathaei				51
Heterocentrotus mammillatus				38
Echinothrix diadema				38
Stichodactyla gigantea				37
Diadema spp.				36
Turbo spp.				16
Echinothrix spp.				12
Cypraea tigris				9
Acanthaster planci				7
Synapta spp.				4
Cypraea caputserpensis				4
Atrina spp.				3

4.4.6 Lofanga species size review – all survey methods (continued)

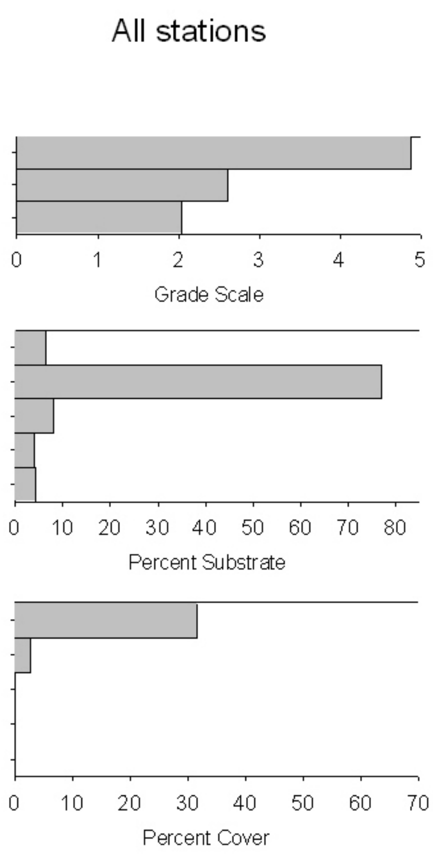
Species	Mean length (cm)	SE	n measured	n total
Ovula ovum				2
Chama spp.				2
Atrina vexillum				2
Spondylus spp.				2
Tripneustes gratilla				1
Turbo marmoratus				1
Spondylus squamosus				1
Stichodactyla spp.				1
Holothuria leucospilota				1
Octopus spp.				1

4.4.7 Habitat descriptors for independent assessment – Lofanga

Broad-scale stations



Reef-benthos transect stations

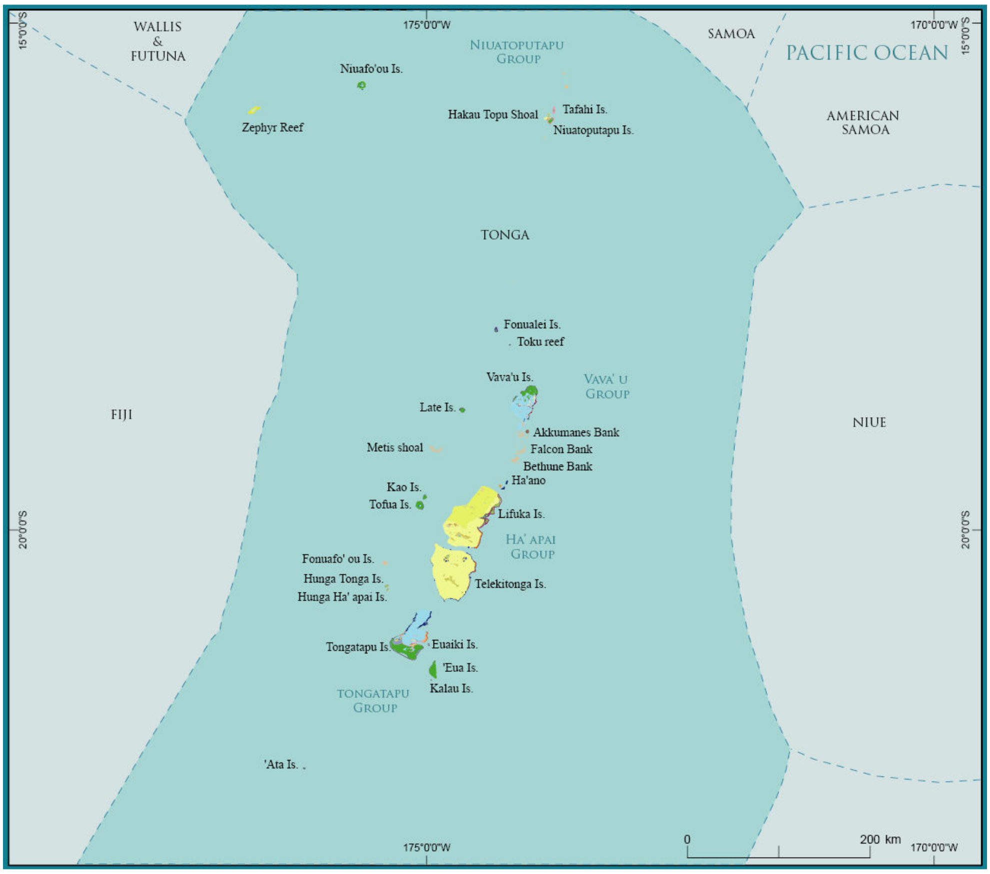


APPENDIX 5: MILLENNIUM CORAL REEF MAPPING PROJECT – TONGA

Institut de Recherche pour le Développement, UR 128 (France)
Institute for Marine Remote Sensing, University of South Florida (USA)
National Aeronautics and Space Administration (USA)

Millennium Coral Reef Mapping Project
Tonga

(May 2009)



The Institute for Marine Remote Sensing (IMaRS) of University of South Florida (USF) was funded in 2002 by the Oceanography Program of the National Aeronautics and Space Administration (NASA) to characterize, map and estimate the extent of shallow coral reef ecosystems worldwide using high-resolution satellite imagery (Landsat 7 images at 30 meters resolution). Since mid-2003, the project is a partnership between Institut de Recherche Pour le Développement (IRD, France) and USF. The program aims to highlight similarities and differences between reef structures at a scale never considered so far by traditional work based on field studies. It provides a reliable, spatially well constrained data set for biogeochemical budgets, biodiversity assessment, coral reef conservation programs and fisheries. The PROCFish/Coastal project has been using Millennium products in the last four years to optimize sampling strategy, access reliable reef maps, and further help in fishery data interpretation for all targeted countries. PROCFish/C is using Millennium maps only for the fishery grounds surveyed for the project.

For further inquiries regarding the status of the coral reef mapping of Tonga and data availability, please contact:

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Reference: Andréfouët S *et al.* (2006), Global assessment of modern coral reef extent and diversity for regional science and management applications: a view from space. Proc 10th Int. Coral Reef Symposium, Okinawa 2004, Japan: pp. 1732-1745.