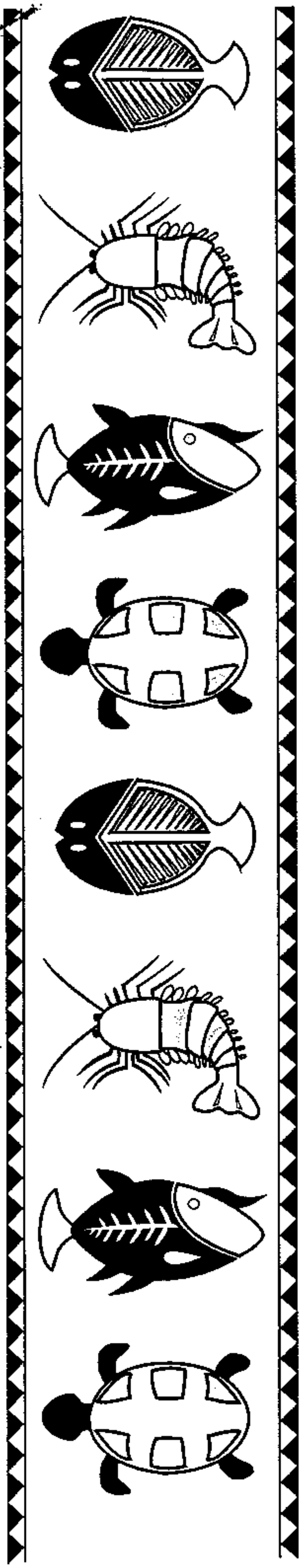

Integrated Coastal Fisheries
Management Project
Country Assignment Report

THE AQUARIUM-FISH FISHERY IN TONGATAPU, TONGA. STATUS AND RECOMMENDATIONS FOR MANAGEMENT

South Pacific Commission
Noumea, New Caledonia

**The aquarium-fish fishery in Tongatapu, Tonga.
Status and recommendations for management**

by

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Introduction

The world trade in aquarium fishes is currently estimated to be about 350 million fish annually, of which about 10 percent are of marine origin (Pyle 1993). Over 20 years ago, Conroy (1975) stated that marine fish accounted for only 1 percent of the world trade, and the increase reflects a dramatic expansion of interest in keeping tropical aquarium fishes, and particularly small, brightly coloured tropical reef fishes.

Commercial fisheries for reef fish species for the aquarium trade have been established in many of the countries and territories of the insular tropical Pacific, including Tonga. Exporting of aquarium fish and other marine organisms from Tonga commenced in 1989 and has continued for the last seven years. Apart from fish, exporters have also harvested live coral, coral rocks encrusted with algae, soft corals, anemones, sea urchins and crustaceans. Exporters have also taken advantage of the culture of giant clams on Tonga to export limited amounts of juvenile giant clams (*Tridacna*) spp for marine aquaria.

There are a total of five licenses available for aquarium exporters in Tonga and, but only two companies are currently active in consistently exporting fish and other organisms for the aquarium trade. The aquarium trade in Tonga is currently limited to Tongatapu and of the two companies, one is relatively large in scale, employing sophisticated techniques for keeping specimens prior to export, while the other is more modest using simpler techniques but employing the same principles of hygiene and care for fish prior to shipment overseas.

The activities of the aquarium exporters have promoted some concern based on the removal of fish and on the collection of live corals and of 'live rock', ie dead coral rock encrusted with colourful algae. A review of the aquarium trade in Tonga, conducted by the South Pacific Regional Environmental programme (SPREP) (Oliver & Smith 1994), generally gave a clean bill of health to the export trade in Tonga but was cautious about the harvest of live corals, noting that while this was likely to be sustainable, further study would be prudent to ensure that it was indeed a sustainable activity at the harvest rates requested by aquarium exporters.

The relative success of the two companies presently operating in Tongatapu has prompted enquiries from other individuals in Tonga about the possibilities of obtaining a license for export. One of the remaining three license holders has never made any shipments overseas, while the other two license holders have made small numbers of shipments and then discontinued their activities. This means that three licenses are being held by individuals who are essentially inactive in the aquarium trade because of various management problems. Nevertheless, the interest in the trade and the potential expansion of export activity encouraged by the Tongan Ministry of Fisheries to develop a management plan for the aquarium trade in Tonga. Recognizing that in spite of the previous review by SPREP, there were still several many unresolved issues for management, the Ministry requested the assistance of the Commission's Integrated Coastal Fisheries Management Project (ICFMaP) in developing management initiatives.

One of the main concerns for the aquarium trade was the banning of the use of underwater breathing apparatus as a result of several deaths and injuries in the beche-de-mer fishery. Untrained divers were using hookah gear to descend to collect sea-cucumbers, without proper training and information about decompression. The Tongan Government had imposed a blanket restriction on the use of hookah and SCUBA gear for all fishing activities and this was clearly a problem for the aquarium trade as it prohibited collection of fish in all but the shallowest reef areas. There were also concerns about the species taken for the aquarium trade and the effect of removals of soft coral, live rock and live coral. The Tongan Government had imposed a ban in 1994 on all coral and rock exports but in early 1995 relaxed the ban on soft corals and live rock.

During this survey it was decided that simple shore based observations would only be a repetition of previous observations conducted on aquarium fisheries in Tonga. It was felt that a better approach would be to determine the biomass or standing stock of shallow reef fishes on the Tongatapu reefs. This included not only aquarium fish but also fishes caught for food, so this approach would also be an additional benefit to the Tonga Government. To this end, the Commission's Fisheries Programme sought and obtained the cooperation of the French scientific organisation, ORSTOM, which has staff with expertise in the visual enumeration of reef fishes through dive census techniques. An ORSTOM technical officer was attached to the ICFMaP team to conduct the censusing of reef fish on the Tongatapu reefs, with the financial assistance of the French Government.

This survey comprised principally a series of dive transects across the reefs to the north of Tongatapu to determine the standing stock of shallow reef species. As well as the species counts on the transects, a reconnaissance was made of the various bottom substrates in the path of the transects, including hard and soft corals. Additional information was obtained from the Ministry of Fisheries on exports of fishes and from the aquarium exporters on their establishments and their operations. Together these various data sources have been used to look at the annual harvest of aquarium fishes in relation to the standing stock. Further, although the observations on substrate type were very general, they permit an estimate of the probable impact of live coral harvesting if permission were once again given to the aquarium trade to re-commence exports.

Study site

Tongatapu is the main island of the Tonga archipelago and is an upraised atoll, with a total land area of 259 km^2. Most of the island is only a few metres above sea level but part of the east coast has tilted raising it to an elevation of 65 m above sea level at Nakolo Township in the southeast.

Tongatapu has a bifurcated shallow lagoon (Fanga'uta Lagoon) with an average depth of about 1.2 m and a total area of 2788 ha. To the north of the island are a series of fringing reefs, barrier reefs and coral islands. About 90 per cent of the coral reef around Tongatapu lies along the north coast and on the shelf that extends about 60 km offshore. Coral reefs around the other coasts are limited mainly to narrow fringing reefs. An approximate estimate of 100 km^2 coral reef area was made from a navigational chart by planimetery for the reefs around Tongatapu. This is almost certainly an underestimate as areas of coral are found throughout the shallow northern shelf and only the major reef complexes are marked on charts. Corals are found in the mouth of the lagoon but absent from most of the interior due to low salinity.

Temperatures on Tongatapu range between 11 and 32 °C, with a mean of 23 °C. The prevailing winds are the Southeast Trades which blow for about nine months of the year. There is a distinct wet season from November to April, but rainfall is generally moderate by Pacific standards, with a long term average between 1950 and 1989 of 1,775 mm/yr.

Most fishing activity on Tongatapu takes place along the northern leeward coast on the extensive reefs and shelf area. In this study, we conducted most of the underwater visual census (UVC) transects in this area and only two elsewhere, on the fringing reef of the west coast.

Methods

Dive census

A total of 45 underwater visual census (UVC) counts were conducted on reef to the north and west of Tongatapu (Figure 1). Fish counts were made by a single diver who swam along a 50 m transect, identifying and counting all fish observed, and estimating the distance of fish from the transect line. Fish size was also estimated, to the nearest 1.0 cm for small fish (< 20 cm) and 5.0 cm for larger fish. Fish were recorded to the species level when possible, otherwise at the genus or family level. A second diver swam along the same transect line to record the depth at 10 m intervals along the transect, the type of substrate (e.g. sand, gravel, rock etc) and the degree of cover by live soft and hermatypic corals, seaweeds and blue-green algae.

Description of the Tonga Aquarium Export Industry

The aquarium fish export industry in Tonga mainly comprises two companies, Walt Smith International (WSI) and Dateline Aquariums (DA) (Other companies were exporting up to December 1995 and one was still exporting until February-March 1996). Both the companies currently active send fish and other marine organisms by air exclusively to dealers in the aquarium trade in the USA.

Walt Smith International

WSI has been operating in Tonga since 1991. The company employs a total of 30 people , including up to seven fishermen who collect the fish and other marine life. Of the fishermen, working for WSI, three are regarded as full time fishermen, while the others work on a part-time basis. Fishing is conducted all year round and WSI provides the fishermen with a powered vessel, fuel, wetsuits, nets, buckets and in the past hookah gear before this was banned. The fishermen were all trained in the fishing techniques for aquarium fish and in using SCUBA and hookah gear safely to avoid decompression problems.

Catching aquarium fish is relatively simple but involves a great deal of skill and patience. A small barrier net of mesh sizes between 5/8 inches and ¾ inches (1.6-1.9 cm) is used to trap the aquarium fish, which are driven from holes in the coral with plastic rods. When the fish swim into the barrier net they are stopped and in their confusion can be quickly caught in a hand held scoop net. The captured fish is then transferred to a bucket covered with mosquito netting, but with a zip fastener to permit placing the captured fish from the scoop net to the bucket. After the diver has caught sufficient fish, these are transferred to a larger container on the vessel where the water is changed regularly to avoid ammonia build up in the water which is injurious to the fish and causes red marks on the skin and scales. By-catch of low value species are occasionally taken by during fishing operations. These are kept at the WSI facility for few days before being released in the lagoon during subsequent fishing operations

On return from the sea the fish are taken to the WSI warehouse and each fish is placed in its own small plastic cube or tank. The fish are not fed for the period they are kept in the warehouse to avoid them fouling the water in which they are transported overseas. The seawater in which the fish are kept prior to sending overseas is chilled to between 13 and 18 °C, filtered and purified with ultraviolet light. For transporting fish by air, fish are first placed individually in polythene bags. Each shipping bag is composed of a four separate polythene bags with layers of newspaper in between each layer. (The preparation of the shipping bags is not done by WSI but has become a small 'cottage industry' contracted out to Tongan families on Tongatapu). The four bags and paper are to prevent any leakage of seawater through accidental punctures by fish spines. The paper also acts as a screen to prevent the fish seeing their neighbours as they are packed and thus becoming aggressive and possibly injuring themselves and puncturing the bags.

The bags containing the fish are then placed in cardboard containers lined with styrofoam. WSI usually pack a minimum of 25 fish per box, but more often it is possible to pack 30 fish per box. Anemones and soft corals are also shipped in a similar manner to the fish with numbers per box depending on the size of the corals and anemones. WSI ships all its fish and marine organisms mainly on Royal Tongan airline flights to Auckland where they connect with a United Airline flight to Los Angeles (although Air New Zealand flights may be used from time to time). WSI have not encountered too many problems using this route and even when a mix up resulted in fish staying in Auckland overnight but there was no significant mortality on arrival at their final destination in Los Angeles.

Live rock, ie dead coral rock covered with live algae is shipped wet with newspaper around it to keep it moist in one large plastic bag inside a cardboard container. Shipments of 'live rock' is not a major part of WSI business, however, WSI currently ships slightly more anemones and soft corals than fish. Yellow leather coral is much in demand and appears to be found nowhere except Tonga, where it is very abundant. Export of live coral is still prohibited, but there continues to be a strong demand for Tongan live coral from the USA in preference to traditional suppliers in SE Asia.

According to WSI the ban on breathing apparatus which was in force at the time of this study (but subsequently modified to permit the use of SCUBA for aquarium-fish fishing) had caused a reduction in fishermen earnings during 1996. WSI made their weekly wage dockets for their dive fishermen available for the period January to April 1995 and January to April 1996 so that we could make a comparison and verify this assertion. Unlike the shore based staff whom receive a salary, the fishermen are paid a basic wage which is augmented by a bonus based on the volume and value of the fish they catch. A summary of the results is given in Table 1. Based on the wages data there is about 21 per cent difference in the wages overall between the two six month periods, although the confidence limits about the means are very wide and only significant at the 70 per cent level of confidence interval.

Table 1. Summary of average weekly wages earned by dive fishermen working for WSI between January and April 1995 and 1996

Time period	Year	Average weekly wage	95 % CL
Jan-Apr	1995	156.10	33.30
Jan-Apr	1996	122.90	33.40

Dateline Aquariums

Dateline Aquariums is a more modest establishment and is based in the back yard of two of the owners of the company, Mr David Gilbert and his wife who live in the village of Manuka. Dateline has been in operation since 1994 and employs 5 Tongan divers to catch fish and collect invertebrates of which 3 work on a regular basis. The divers fish 4-5 days per week, spending 2 days collecting soft corals and 3 days collecting fish, a similar regime to that of WSI. Dateline's facilities comprise four concrete block tanks at the rear of the Gilbert's property in which fish and invertebrates are kept prior to shipping overseas. Filtered aerated sea water is circulated through the tanks but the water is not processed through a protein skimmer, UV sterilised or chilled as in the WSI facility. Like WSI Dateline do not export much 'live rock' but do export quantities of 'yellow leather' soft coral. Dateline have constructed a storage area for their soft coral stock in the lagoon, about 100 m from the Gilbert's property.

The techniques to capture and transport the fish from the reefs to the tanks are similar to those employed by WSI. Small mesh gillnets (5/8- ¾") are used to trap the fish after driving them out from the coral, where they can be caught in scoop nets. The larger ¾" nets are used primarily for butterflyfishes and wrasses, while the smaller 5/8" mesh is employed mainly for damsel and angel fishes. The fish are kept by divers in a gallon bucket when they are catching fish and later transferred to a 32 gallon tank on the fishing vessel. As with the WSI Operation, the water in the 32 gallon tank is changed regularly to avoid ammonia build up and burn marks on the fish skin and scales. According to the Dateline, their divers rarely work past 50 ft and normally work at depths of 30 feet or less.

Dateline exports a wider variety of species than WSI, particularly wrasses, which are not a major part of WSI's trade as well as species such as coral beauties, lemon peel angels and lemon gobies. Dateline also exports a greater range of invertebrates than WSI including shame-face crabs, fiddler crabs, hermit crabs as well as anemones and soft coral. Dateline send their fish to a dealer in the USA using the weekly Air New Zealand flight from Tonga to Auckland and a connecting Air New Zealand flight to Los Angeles. Dateline try to send a weekly shipment to the USA and average about 50 shipments per year. On average they ship about 500 fish per week or in a year about 25 per cent of their allocated quota. As with WSI, the emphasis is keeping mortality rates to a minimum ie to no more than 5-10 per cent (A phrase that basically sums up the risks in the aquarium trade is; 'your reputation is only as good as your last shipment).

When airfreighting fish to the USA, Dateline uses a polythene shipping bag is composed of a two separate polythene bags with a layer of newspaper in between each layer. As with WSI the preparation of the shipping bags for Dateline has become a small 'cottage industry' contracted out to Tongan families on Tongatapu. Dateline also employ 9 people at each shipment to work through the night to pack the fish and invertebrates for shipping. The company uses less sophisticated techniques than WSI but employ the same principles for packaging their products by chilling the seawater (Accomplished by placing ice blocks sealed in plastic bags into a seawater tank) and filling the air-space above the water in the bag with oxygen.

Historical data on aquarium-fish exports

Export records of the two companies operating in Tongatapu, for the period March 1995 to April 1996, were available in computer files at The Ministry of Fisheries office, and these have been summarised here in Table 2. The exports of fish and invertebrates are given in numbers or pieces, whilst the volume of 'live rock' is recorded by weight in kilograms. The various fishes exported are reported as angelfish (Pomacentridae), butterflyfish (Chaetodontidae), clownfish (Pomacentridae), damselfish (Pomacentridae), hawkfish (Cirrhitidae), Triggerfish (Balistidae), lionfish (Scorpaenidae), pufferfish (Tetrodontidae) tangs (Acanthuridae) and wrasses (Labridae).

The total value of aquarium trade exports for the 14 months between 1995 and 1996 was 568485.82 T$, making this an industry with an annual export value of about half a million dollars. The total and monthly averages for the different export categories are given in Table 2. About 50,000 aquarium-fish were exported to the USA over this period with a value of about 154,000 T$, however, the largest single revenue earner was 54.5 t of 'live rock' with a gross value of nearly 170,000 T$. The monthly exports for the aquarium trade reflect the seasonal demand from the US market (Figure 2). The busiest time for the two companies in Tongatapu is during the northern winter, leading up Xmas and in the months immediately after the festive season.

The percentage breakdown of the various categories of fish exported over this between 1995 and 1996 is shown in Figure 3. Over half the exports in numbers comprise damselfish, followed by angelfish, wrasses and clownfish. As a family, the Pomacentridae account for nearly 80 per cent of all exports. The breakdown of the fish exports by value are shown in Figure 4. The Pomacentridae only account for about two thirds of the total export value of the aquarium-fish, with rarer species such as hawkfish having greater value than the more common genera.

Table 2: Summary of the volume and value of exports by the aquarium fishery traders in Tongatapu between 1995 and 1996

Month	**'Live rock' (kg)**	**Miscellaneous (no)**	**Giant clams (no)**	**Invertebrates (no)**	**Soft coral (no)**	Fish (no)
MAR 1995	5,408.80	245	0	1,561	3,616	3,173
APR	3,846.60	255	0	1,505	5,180	4,102
MAY	777.00	571	0	2,020	4,870	5,202
JUN	319.00	0	0	221	542	.342
JUL	2,168.40	320	131	1,808	2,866	2,933
AUG	3,493.20	350	798	2,380	3,902	3,308
SEP	3,273.30	185	443	1,662	3,594	2,694
OCT	3,104.20	595	708	3,154	4,754	4,235
NOV	3,732.70	395	552	2,683	3,876	6,516
DEC	4,079.00	178	190	1,269	2,733	2,471
JAN 1996	8,773.00	285	121	1,964	6,092	4,962
FEB	4,848.00	620	451	3,614	5,200	4,128
MAR	7,434.00	521	449	3,914	4,232	3,828
APR	3,219.00	329	638	2,242	2,301	1,824
Total	54,476.20	4,849.00	4,481.00	29,997.00	53,758.00	49,718.00
Average	3,891.16	346.36	320.07	2,142.64	3,839.86	3,551.29

Month	**'Live rock' (S)**	**Miscellaneous (S)**	**Giant clams (S)**	**Invertebrates (S)**	**Soft coral ($)**	**Fish (S)**
MAR 1995	41,536.11	857.50	0.00	5,463.50	12,656.00	11,517.50
APR	5,363.81	892.25	0.00	5,264.00	18,130.00	14,422.50
MAY	1,934.35	1,998.50	0.00	7,070.00	17,045.00	23,095.00
JUN	805.75	0.00	0.00	773.50	1,897.00	1,197.00
JUL	5,428.01	797.00	655.00	4,994.00	2,405.35	9,266.75
AUG	8,925.79	2,502.50	3,432.00	6,227.50	3,439.90	8,696.25
SEP	8,004.43	484.00	1,329.00	4,654.50	3,155.50	6,496.50
OCT	8,060.25	1,307.25	2,077.00	8,157.25	4,351.15	11,160.50
NOV	9,806.07	872.75	1,656.00	7,206.50	5,807.45	14,688.25
DEC	9,622.80	477.50	570.00	2,938.90	2,727.90	5,690.75
JAN 1996	22,077.00	784.50	375.00	5,498.00	8,893.50	12,215.50
FEB	15,026.55	2,178.50	1,826.00	12,649.00	18,049.50	16,208.50
MAR	23,088.00	1,823.00	2,661.00	11,990.00	14,812.00	13,207.75
APR	9,753.50	1,151.50	1,914.00	7,847.00	8,053.50	6,411.50
Total	169,432.42	16,126.75	16,495.00	90,733.65	121,423.75	154,274.25
Average	12,102.32	1,151.91	1,178.21	6,480.98	8,673.13	11,019.59

Reef fish biomass and density estimates

A complete summary of the biomass and density estimate of all the species observed in the 45 UVC transects conducted on the reefs at Tongatapu is given in Appendix I. In all, a total of 282 species were observed during this survey in depths ranging from 2 to 15 m. The same data is shown in Table 3 summarised by family. Four species have been omitted from the family summary, namely, *Spratelloides* spp (sprats), *Euthynus affinis* (mackerel tuna), one unidentified centropomid species and the large parrotfish, *Bolbometapon muricatum.* The small sprats and mackerel tuna are small and medium sized schooling pelagic species which are commonly found near reefs but are not part of the reef biota. Several large schools of sprat and mackerel tunas were observed during this study and their inclusion would create bias in the computation of the mean estimates of biomass and density. Similarly, the centropomids are more typically associated with estuarine environments than with reefs and lagoons and it is the one specimen observed here can be omitted. The large parrotfish *B. muricatum* is a typical component of the reef biota, but because these fish typically can grow to over a meter in length and weigh up to 50 kg they can also introduce bias in the biomass computations, especially since this study is concerned with the smaller specimens in the reef ichthyofauna.

The overall density and biomass of shallow reef fish from the UVC data were 2.8 fish/m^2 and 118.9 g/m^2. The top five families in terms of density were the Pomacentridae (damselfishes, angelfish, anemonefish), Acanthuridae (tangs and unicornfish), Scaridae (parrotfish), Labridae (wrasses) and Chaetodontidae (butterflyfish), which represented about 85 per cent of the total fish density in the transect sites. Parrotfish comprised the single greatest biomass on the reefs followed by Pomacentridae, Acanthuridae, Kyphosidae (drummers) and Labridae, which together formed about 75 per cent of the total observed in this study.

An estimate was made by planimetery of the total reef area around Tongatapu from navigational charts. This estimate of reef area refers mostly to major coral formations marked on the charts which were found to cover an area of about 100 km^2. It was clear from observations made during this study, however, that coral formations, especially patch reefs, were distributed extensively along the large shelf area to the north of Tongatapu, and thus the estimated reef area determined here is acknowledged to only an approximation. However, the density and biomass figures can be extrapolated to standing stock of shallow reef fish in both numbers and weight using an approximate reef area of 100 km^2 which gave estimates of 276 million fish or a total biomass of 11,890 t. The standing stock in numbers of the various families is shown in Table 3 along with the total exports of aquarium fish between 1995 and 1996. Although some of the aquarium fish exports are substantial, particularly the pomacentrids, they represent in total only 0.018 per cent of the shallow reef fish standing stock.

The methods employed in this study have also been applied to reef fish populations in French Polynesia and locations within New Caledonia and are summarised from Kulbicki et al (1994) in Table 4. Although ranked rather low in this grouping, the estimates of reef fish biomass in Tonga are not greatly different from those in New Caledonia, French Polynesia and the Chesterfield Islands, with only much greater biomass and densities found at Ouvea in the Loyalty islands. Comparison of the estimates of density and biomass obtained here, with other locations in the Pacific may be confounded by differences in the estimates used to determine abundance. However, density and biomass estimates from the Pacific were summarised from the literature by Kulbicki et al (1994) and Dalzell et al (1996) and are shown in Table 5, along with the values determined through the UVC methodology in New Caledonia, French Polynesia and Tonga. The biomass and density estimates for Tonga lie in about the middle of the range of values from these different Pacific islands, although it should be emphasised that differences in methods employed to generate biomass and density means that these estimates can only be compared at a superficial level. Nonetheless, they are indicative that the reef fish populations on Tongatapu reefs do not appear to be seriously depleted and the activities of the aquarium fish industry is negligible.

Management of the aquarium industry

The aquarium trade is an attractive industry for Tonga. It is labour intensive with the two companies currently operating employing at present up to 40 individuals between them. Further, it focuses on a natural resource that is not directly used to any great extent by the indigenous people, except for tourism purposes. The value of aquarium fish in comparison with other reef fish or deep slope species is excellent, and the fishermen do not have to venture far from land or work in dangerous conditions to achieve a reasonable catch. The aquarium trade is also a significant user of service industries and utilities in Tonga.

The two operations, Walt Smith International & Dateline Aquariums are good examples of two different scales of operation. Walt Smith International (WSI) is a high-tech capital intensive operation that is based on a selective market for relatively few species in the wholesale aquarium trade. Dateline Aquariums is a smaller operation that is based on a wider variety of species based on demand from retail traders. Both operations export all their fish to the USA, which is the center of the world aquarium industry and both operators also currently export invertebrates such as anemones, and pieces of dead coral rock with a covering of live algae ('live rock'). These items are also in much demand by the aquarium trade for attractive tank displays and to give fish the semblance of the original reef environment.

Currently there are 5 licenses available for the aquarium trade in Tonga. It is suggested that license holders who do not commence exporting fish within 12 months of obtaining their license should have their permit withdrawn. The cancelled license(s) can then be made available to other persons interested in the aquarium trade. However, we believe it is important to stress the need for the Ministry of Fisheries to have an in-house capability to understand the aquarium trade so that new license applications can be vetted without the need for assistance from external agencies. One of the biggest danger to the survival of the aquarium trade in Tonga is the entry of untrained and unexperienced operators into the industry.

Vetting procedures need to be established to review license applications that establish how much money an applicant is willing to invest in starting an aquarium export fishery, where and who are the applicant's overseas markets, which species will be targeted, what fishing methods will be used and what volume of fish etc does the new applicant expect to export each week? Most importantly, what experience does the new applicant have with the aquarium fish trade? At least one fisheries officer/biologist should regularly work with the fishermen to record catch rates and catch composition and liaise with the two companies to learn more about the industry in terms of marketing and infrastructure. Kailola (1995) made similar recommendations in her review of fisheries development and management in Tonga and suggests guidelines for monitoring and management of the Tongatapu aquarium fishery.

Table 3. Summary of the results of UVC estimates of density and biomass for shallow water reef fish on reefs at Tongatapu. Density and biomass estimates have been transformed to standing stocks in numbers and weight using an estimate of 100 km^2 for coral reef area around Tongatapu.

Families	**Number of species**	**Density** fish/m^2	**Biomass** g/m^2	**Standing** stock (n)	**Standing** stock (t)	**Aquarium catch (n)**	% **Standing stock**
Acanthuridae	**17**	0.3188	14.33	31,880,000	1,433.14	1,042	0.0045
Apogonidae	**5**	0.0120	0.08	1,200,000	8.48		
Aulostomidae	**1**	0.0051	1.14	510,000	114.29		
Balistidae	**12**	0.0259	0.62	2,590,000	61.89	45	0.0024
Blenniidae	**13**	0.0331	0.18	3,310,000	18.30		
Caesionidae	**2**	0.0763	8.44	7,630,000	844.04		
Carangidae	**1**	0.0001	0.16	10,000	16.03		
Chaetodontidae	**24**	0.0978	2.40	9,780,000	240.19	1,043	0.0025
Cirrhitidae	**4**	0.0034	0.07	340,000	7.47	2,956	0.0022
Fistulariidae	**2**	0.0009	0.17	90,000	17.17		
Gobiidae	**8**	0.0073	0.05	730,000	5.46		
Grammistidae	**1**	0.0002	0.00	20,000	0.12		
Haemulidae	**1**	0.0003	0.21	30,000	20.94		
Hemiramphidae	**1**	0.0001	0.12	10,000	12.09		
Holocentridae	**7**	0.0168	1.06	1,680,000	105.81		
Kyphosidae	**1**	0.0201	13.73	2,010,000	1,373.23		
Labridae	50	0.2246	9.37	22,460,000	937.28	5,223	0.0042
Lethrinidae	**6**	0.0043	1.82	430,000	181.98		
Lutjanidae	**7**	0.0077	1.31	770,000	131.36		
Mugiloididae	**3**	0.0097	0.42	970,000	41.61		
Mullidae	**9**	0.0348	5.54	3,480,000	554.47		
Nemipteridae	**3**	0.0055	0.29	550,000	28.87		
Ostraciidae	2	0.0014	0.16	140,000	15.82		
Pempheridae	1	0.0009	0.04	90,000	4.34		
Plotosidae	1	0.0039	0.02	390,000	1.60		
Pomacanthidae	5	0.0402	0.51	4,020,000	51.29		
Pomacentridae	40	1.4641	16.08	146,410,000	1,607.92	39,217	0.0011
Priacanthidae	1	0.0002	0.02	20,000	2.23		
Pseudochromidae	2	0.0041	0.01	410,000	0.87		
Scaridae	22	0.2516	37.17	25,160,000	3,716.85		
Scorpaenidae	1	0.0009	0.01	90,000	0.85	66	0.0009
Serranidae	10	0.0370	1.20	3,700,000	119.99		
Siganidae	3	0.0186	0.66	1,860,000	65.81		
Synodontidae	6	0.0070	0.28	700,000	28.26		
Tetraodontidae	5	0.0192	0.97	1,920,000	96.95	126	0.0050
Zanclidae	1	0.0092	0.24	920,000	23.83		
Total	278	2.7631	118.91	276,310,000	11.890.83	48,676	0.0228

Table 4. Density and biomass estimates of reef fish at sites in French Polynesia, New Caledonia and Tonga made using the same UVC methods

Location	Density (fish/m^2)	Biomass (g/m^2)
Ouvea	3.70	259
Moorea	2.54	172
NC SW lagoon intermediate reef	4.00	150
Chesterfields	2.25	145
NC SW lagoon barrier reef	2.40	120
Tonga	2.76	119
NC SW lagoon coast	4.00	108

Table 5. Density and biomass estimates of shallow water reef fish in the tropical Pacific. Estimates summarised from Kulbicki et al (1994) and Dalzell et al (1996). nd = no data.

Location	Density (fish/m^2)	Biomass (g/m^2)
Moorea (French Polynesia)	3.6	nd
Mataiva (French Polynesia)	0.5	nd
Fangataufa (French Polynesia)	1.64	nd
Muroroa (French Polynesia)	1.88	nd
Midway (North West Hawaiian Islands)	5.85	nd
Papua New Guinea	3.3	nd
Ouvea	3.7	259
Moorea	1.45	240
Great Barrier Reef (GBR) intermediate reef	8.4	237
GBR islet	1.7	195
Moorea	2.54	172
GBR outer reef	3.2	156
Tonga	4.8	153
NC SW lagoon intermediate reef	4	149.5
Chesterfields	2.25	145
NC SW lagoon barrier reef	2.4	120
Tikehau	3.65	109
NC SW lagoon coast	4	108
Hawaii	3.1	106
Hawaii	2.6	102
GBR internal reef	7	92
Papua New Guinea (Kavieng)	nd	43.5
Enewetak	nd	42.5
Fiji	nd	25.1

Hookah gears were used in the aquarium trade to fish in deeper waters (10-15 m) to catch valuable species such as the flame hawk (on the outer reef slope) and the bicolor angel fish (in the lagoon). However, the use of hookah gear was proscribed for all fishing activities following several deaths and injuries in the Tonga beche-de-mer fishery. Without hookah gear, fishermen have had to concentrate their fishing effort in shallow waters on the reef and range over a wider area to catch an economic quantity of fish. However, shortly following this survey a recommendation was given to the Ministry of Fisheries that the aquarium trade be exempted from the ban on hookah gear. Instead, a compromise agreement was reached between the the Ministry and the aquarium exporting companies which permitted the aquarium-fish fishermen to use SCUBA gear. The Government was thus able to keep the hookah ban in place to regulate beche-de-mer harvesting, while at the same time freeing up the aquarium trade to be able to fish at depths beyond range of free diving.

The initial study of the aquarium trade in Tongatapu conducted by SPREP did not make any estimate of the abundance or density of the target species, however, a limit of 100,000 fish per exporter was recommended (Oliver & Smith 1994). This study has shown that this would represent a negligible fraction of the target species biomass on the reefs of Tongatapu. Further, 100,000 fish per exporter is higher than the current total export levels of aqaurium fish by both the companies active in Tongatapu at present. There also appear to be no sustainability issues related to the harvest and export of dead coral rock encrusted with algae, nor with the harvest and export of soft corals. The base of lagoon reefs around Tongatapu have large accumulations of dead coral rock due to wave action and storms. SPREP recommended a limit of 100 t per exporter in their report (Oliver & Smith) and this is a sensible limit and significantly higher than the amount currently being exported by both companies in Tongatapu. There is an abundance of soft coral on the Tongatapu reefs, particularly the 'yellow leather' species which is in demand for the aquarium trade. The trade requires small new growths of this species and these are removed carefully from the reefs with minimal damage.

The harvesting of living corals is clearly a sensitive issue and the bans on harvesting of live corals from decorative purposes or for medical purposes should remain in place. The aqurium trade exporters, however, wish to harvest small pieces of new-growth coral which is also in demand by US aquarium hobbyists. We note, however, that the report by SPREP had no serious objections to this form of live coral harvesting (Oliver & Smith 1994), and that the concerns about this form of coral harvesting expressed in the SPREP report concerned the abundance and distribution of the target coral species, the ability of the Ministry of Fisheries to monitor this activity and the potential expansion of this form of coral harvesting if more than two operators become active in this industry. The SPREP report also stated that neither of the current aquarium trade exporters are heavily reliant on live coral exports for financial success.

However, the aquarium traders in Tongatapu suggest that the ability to supply live coral gives the Tonga aquarium trade a competitive edge with other exporting countries. The aquarium trade in Tonga has a good reputation for high quality net-caught fish with minimal mortality rates on delivery. However, the industry in Tonga has to compete with other suppliers, notably in Southeast Asia, who can supply at lower prices a greater range of reef fish and invertebrate species, including those found in Tonga,. According to the aquarium traders, the export of small pieces of living hard coral will attract buyers in the USA to focus on Tonga, and improve the marketing of the fish and invertebrates currently sold by the two exporters in Tongatapu. It would be useful to check on the accuracy of this statement, perhaps by contacting other aquarium exporters in the Pacific who operate without collecting corals and by checking with importers in the US aquarium trade.

Interviews with the aquarium exporters in Tongatapu suggested that they would like to export between 200 to 300 pieces of live coral per week, with the pieces ranging in size from between 5 to 15 cm. In our initial recommendations to the Ministry of Fisheries we suggested that the scale of coral harvesting for the aquarium trade would amount to a tiny fraction of the total coral cover at Tongatapu. We recommended an initial export maximum of up to 200 pieces of live coral per week per company, with the possibility of a limited increases of between 10 and 20 per cent of this maximum after a one year period, subject to review by the Ministry of Fisheries. We further recommend that the coral pieces be no larger than 12 cm in width or maximum diameter. To put the live coral harvest in perspective, the total reef area around Tongatapu is at least 100 km^2 in extent. If both export companies harvested the maximum 200 pieces of coral per week, than this would represent an area of around 0.002 km^2/yr or 0.0043 km^2 if all five export licenses were currently active.

Our information on reef composition at the 45 stations where transects were conducted is restricted to observations on the percentage of coral cover over the underlying substrate and will be reported on in detail in a supplementary report. According to a conservative estimate from preliminary figures extracted from the data, live coral cover ranged from 0 to 75 per cent with an overall mean of 13 per cent (Appendix II). We do not have any information on the composition of the coral species forming the reefs at Tongatapu, not or the densities, abundance and distribution of these component species. This is important as the extensive reef areas to the north of Tongatapu are used not only by the aquarium industry but by fishermen and by tourists who come to dive and snorkel among the coral formations. As this level of detail on the reef structures at Tongatapu is lacking it is understandable if the Ministry of Fisheries may be reluctant to permit live coral harvesting, without having information available to respond to any concerns about live coral removal and to manage the harvesting of live coral.

We would therefore strongly recommend that a follow up survey be conducted at or near the sites where transects were conducted in this survey by a coral biologist so that more quantitative information on coral composition, densities and distribution can be obtained. Further, the areas that are used by the tourist industry for diving and snorkeling should be clearly defined so that coral collecting activities, should they be permitted, will be proscribed from those locations. Other guidelines for the harvesting of corals are given in the publication 'Environmental Guidelines for Reef Coral Harvesting Operations' published by SPREP (Wells et al 1994). We recommend that the guidelines listed in this document for safe coral harvesting form the basis for management of aquarium coral harvests on Tongatapu.

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Figures

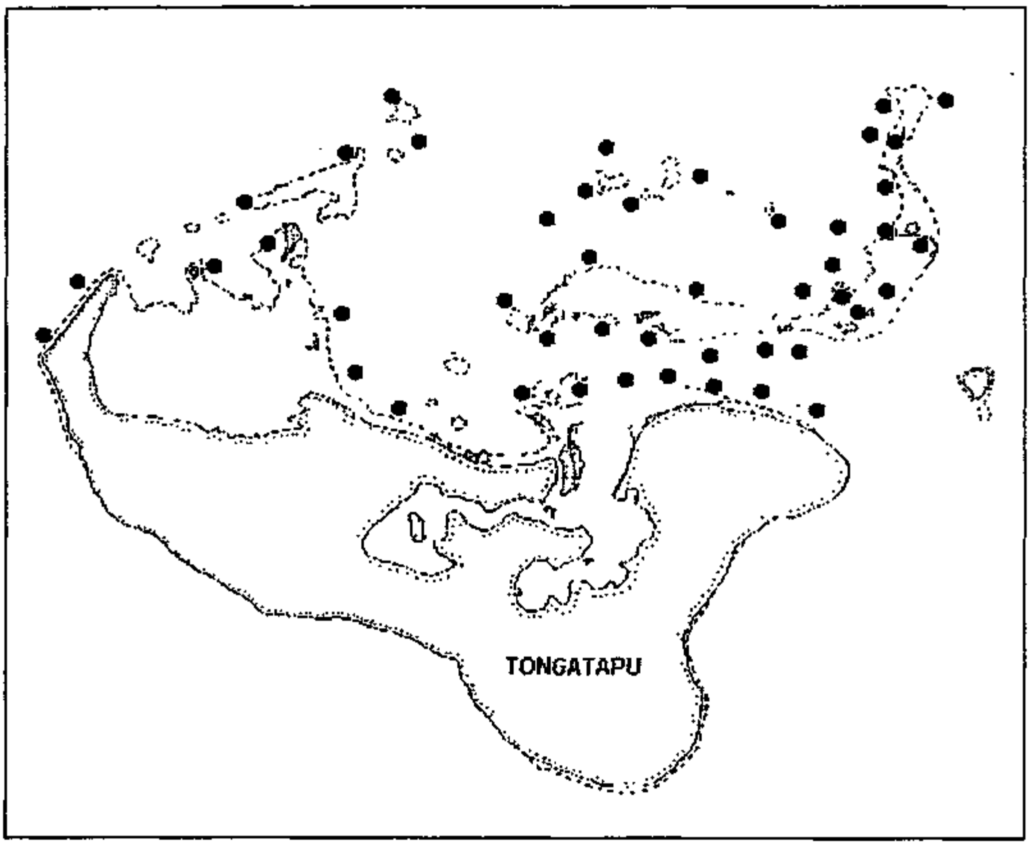

Figure 1. Map of Tongatapu Island and associated reefs showing sampling locations for UVC transects Sampling locations overlap areas most frequented by aquarium-fish fishermen

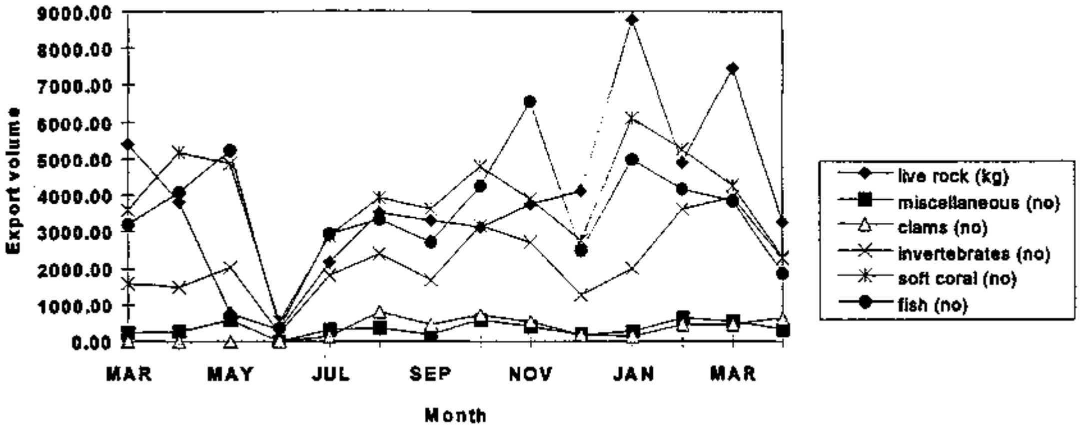

Figure 2. Monthly export volume of fish, invertebrates and 'live rock' by the aquarium trade in Tongatapu

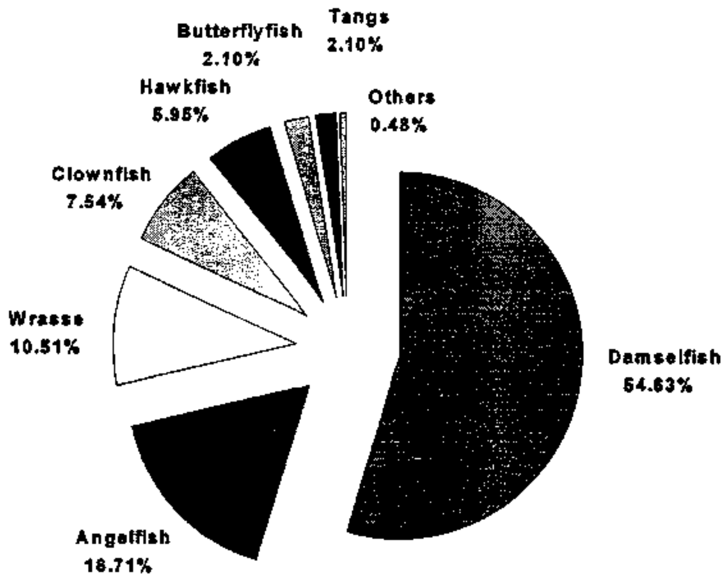

Figure 3. Per cent composition of aquarium-fish exports by number from Tongatapu between 1995 and 1996

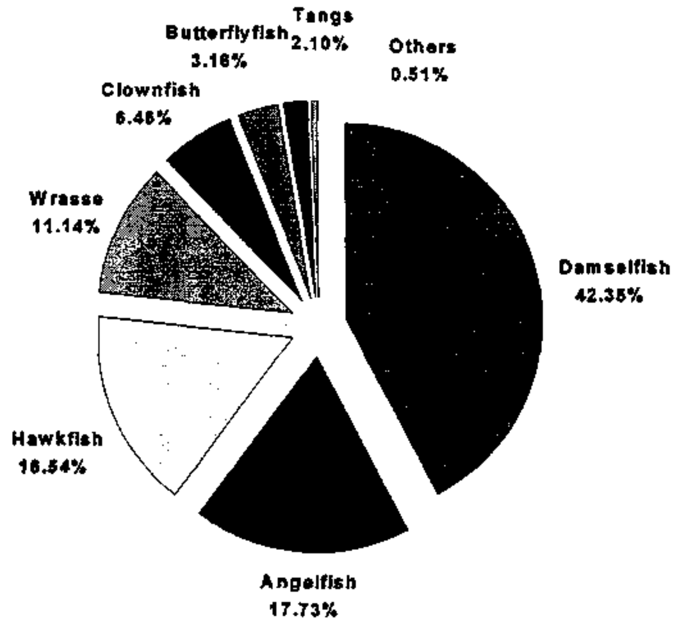

Figure 4. Per cent value of aquarium-fish exports from Tongatapu between 1995 and 1996

Appendix I. Summary of the results of UVC counts of shallow-water reef fishes on Tongatapu reefs

Species	No of transects fish seen	No of sectors fish observed	Total no seen in 45 transects (nb)	No of sightings or occurences (occ)	School size (nb/occ)	Average size (cm)	Distance of fish to transect	Density (no/m²)	Weight (g)	Biomass (g/m²)
Abudebdufspp.	1	3	16	3	5.33	8.75	2.66	0.0027	22	0.0584
Abudefduf saxatilis	1	1	2	1	2.00	12.00	4.50	0.0002	57	0.0114
Abudefduf sexfasciatus	23	53	407	62	6.56	8.79	5.37	0.0337	23	0.7844
Abudefduf sordidus	1	1	1	1	1.00	15.00	5.50	0.0001	118	0.0095
Acanthurus blochii	5	5	6	5	1.20	11.83	3.33	0.0008	45	0.0364
Acanthurus dussumieri	1	1	1	1	1.00	30.00	5.50	0.0001	764	0.0618
Acanthurus gahm	1	1	1	1	1.00	15.00	5.50	0.0001	91	0.0074
Acanthurus lineatus	7	12	157	13	12.08	18.51	7.74	0.0090	181	1.6323
Acanthurus mata	1	1	1	1	1.00	18.00	5.50	0.0001	133	0.0107
Acanthurus nigricans	7	9	11	10	1.10	13.46	4.96	0.0010	83	0.0818
Acanthurus nigrofuscus	12	34	721	59	12.22	11.61	4.99	0.0642	50	3.2201
Acanthurus olivaceus	2	2	2	2	1.00	15.00	4.00	0.0002	91	0.0202
Acanthurus triostegus	10	18	482	23	20.96	9.12	7.43	0.0288	25	0.7292
Acanthurus xanthopterus	4	4	8	4	2.00	20.63	6.19	0.0006	178	0.1022
Amblyglyphidod curacao	1	4	23	5	4.60	8.26	1.39	0.0073	20	0.1480
Amblyglyphidod leucogaster	10	23	364	34	10.71	8.23	3.72	0.0434	20	0.8475
Amblygobius phalaena	2	2	3	2	1.50	10.33	1.83	0.0007	24	0.0178
Amblygobius spp.	1	1	1	1	1.00	6.00	0.50	0.0009	2	0.0022
Amphiprion akindynos	5	6	10	7	1.43	9.10	3.00	0.0015	24	0.0358
Amphiprion clarkii	1	1	1	1	1.00	7.00	2.50	0.0002	10	0.0017
Amphiprion melanopus	11	13	27	20	1.35	7.59	1.70	0.0070	14	0.1011
Amphiprion perideraion	5	6	15	9	1.67	5.73	2.70	0.0025	6	0.0151
Anampses caeruleopunctus	2	3	3	3	1.00	12.33	3.50	0.0004	28	0.0105
Anampses geographicus	23	36	48	38	1.26	8.88	2.96	0.0072	11	0.0829
Anampses meleagrides	5	7	12	8	1.50	8.00	1.75	0.0030	11	0.0321
Anampses neoguinaicus	25	41	57	51	1.12	9.14	3.22	0.0079	13	0.1002
Anampses spp.	13	17	28	19	1.47	8.82	1.95	0.0064	12	0.0763
Anampses twistii	11	13	13	13	1.00	8.92	2.96	0.0020	11	0.0223
Aphareus furca	3	3	3	3	1.00	20.67	3.17	0.0004	146	0.0617
Apogon angustatus	1	1	1	1	1.00	7.00	0.50	0.0009	7	0.0066
Apogon aureus	1	2	18	3	6.00	7.94	4.75	0.0017	9	0.0157
Apogon sp.	1	1	1	1	1.00	7.00	0.50	0.0009	6	0.0057
Apogon spp.	3	5	42	6	7.00	6.74	2.98	0.0063	7	0.0469
Aprion virescens	3	3	4	3	1.33	47.50	7.50	0.0002	1945	0.4610
Arothron meleagris	1	1	1	1	1.00	30.00	0.50	0.0009	872	0.7749
Arothron nigropunctatus	2	2	2	2	1.00	18.50	2.50	0.0004	131	0.0465
Aulostomus chinensis	16	23	28	28	1.00	43.04	2.45	0.0051	225	1.1429
Balislapus undulatus	6	6	6	6	1.00	14.67	4.33	0.0006	76	0.0469
Balistes spp.	1	1	1	1	1.00	15.00	10.50	0.0000	71	0.0030
Balistoides conspicillum	1	1	2	1	2.00	25.00	8.50	0.0001	311	0.0325
Blenniidae spp.	1	1	1	1	1.00	10.00	2.50	0.0002	19	0.0034
Bodianus axillaris	7	8	9	8	1.12	13.22	1.83	0.0022	40	0.0877
Bodianus loxozonus	9	12	12	12	1.00	19.50	4.42	0.0012	166	0.2005
Bodianus sp.	1	1	1	1	1.00	7.00	0.50	0.0009	6	0.0052
Bolbomelopon muricatum	1	2	6	2	3.00	86.67	13.00	0.0002	29871	6.1273
Calotomus spinidens	3	3	4	4	1.00	12.75	0.50	0.0036	43	0.1512
Cantherines dumerili	3	3	4	3	1.33	18.75	4.75	0.0004	135	0.0506
Canthisaster valentini	21	32	43	37	1.16	6.44	2.21	0.0087	8	0.0710

Species	No of transects fish seen	No of sectors fish observed	Total no seen in 45 transects (nb)	No of sightings or occurences (occ)	School size (nb/occ)	Average size (cm)	Distance of fish to transect	Density (no/m^2)	Weight (g)	Biomass (g/m^2)
Carangoides chrysophrys	1	1	100	1	100.00	30.00	5.50	0.0081	518	4.1844
Caranx melampygus	2	2	2	2	1.00	37.50	6.50	0.0001	1172	0.1603
Centropyge bicolor	9	12	20	17	1.18	7.70	3.00	0.0030	15	0.0450
Centropyge bispinosus	25	64	156	109	1.43	6.99	2.33	0.0297	11	0.3317
Centropyge flavissimus	21	40	57	50	1.14	7.23	3.78	0.0067	12	0.0782
Cephalopholis argus	3	3	3	3	1.00	21.67	6.50	0.0002	213	0.0437
Cephalopholis urodeta	10	18	22	21	1.05	15.59	2.14	0.0046	67	0.3077
Cetoscarus bicolor	1	1	4	2	2.00	36.25	6.25	0.0003	1219	0.3469
Chaetodon auriga	26	39	58	42	1.38	11.40	3.88	0.0066	46	0.3033
Chaetodon baronessa	1	1	1	1	1.00	10.00	3.50	0.0001	31	0.0040
Chaetodon bennetti	4	4	5	5	1.00	8.80	2.10	0.0011	23	0.0243
Chaetodon citrinellus	23	60	96	67	1.43	7.47	3.31	0.0129	12	0.1514
Chaetodon ephippium	12	15	18	15	1.20	10.78	3.39	0.0024	42	0.0991
Chaetodon flavirostris	9	11	18	12	1.50	10.78	2.42	0.0033	43	0.1416
Chaetodon lineolatus	5	5	5	5	1.00	12.20	5.50	0.0004	79	0.0317
Chaetodon lunula	3	3	3	3	1.00	11.67	5.17	0.0003	52	0.0135
Chaetodon melannotus	23	34	58	36	1.61	9.05	3.26	0.0079	25	0.1952
Chaetodon mertensii	13	21	30	22	1.36	8.27	2.82	0.0047	14	0.0646
Chaetodon ornatissimus	2	2	2	2	1.00	10.00	2.50	0.0004	35	0.0124
Chaetodon pelewensis	21	35	60	38	1.58	7.70	2.42	0.0110	14	0.1530
Chaetodon plebeius	22	35	47	39	1.21	7.47	3.18	0.0066	13	0.0841
Chaetodon rafflesi	5	6	8	6	1.33	9.00	5.38	0.0007	23	0.0153
Chaetodon reticulatus	5	6	8	6	1.33	10.00	2.75	0.0013	33	0.04??
Chaetodon trifascialis	18	34	56	37	1.51	8.63	3.41	0.0073	20	0.1466
Chaetodon trifasciatus	23	48	102	61	1.67	7.79	2.75	0.0165	15	0.2549
Chaetodon ulietensis	10	12	15	12	1.25	9.87	3.23	0.0021	29	0.0606
Chaetodon unimaculatus	9	10	34	15	2.27	11.29	3.96	0.0038	54	0.2049
Chaetodon vagabundus	7	8	11	8	1.38	9.64	3.14	0.0016	26	0.0404
Cheilinus chlorourus	40	86	115	113	1.02	14.41	2.71	0.0189	75	1.4195
Cheilinus diagrammus	14	15	15	15	1.00	14.27	3.03	0.0022	49	0.1073
Cheilinus spp.	5	6	6	6	1.00	10.50	2.67	0.0010	25	0.0255
Cheilinus trilobatus	1	1	1	1	1.00	35.00	5.50	0.0001	799	0.0646
Cheilio inermis	8	12	44	18	2.44	32.16	3.34	0.0059	222	1.3006
Cheilodipterus quinquelineat	3	5	12	8	1.50	6.42	2.42	0.0022	4	0.0099
Choerodon jordani	2	2	3	2	1.50	15.00	4.83	0.0003	63	0.0173
Chromis atripectorali	20	30	459	36	12.75	6.38	2.94	0.0694	9	0.5925
Chromis chrysura	5	7	99	7	14.14	7.25	3.11	0.0141	14	0.1971
Chromis iomelas	6	10	79	12	6.58	5.81	3.70	0.0095	5	0.0512
Chromis lepidolepis	3	6	63	6	10.50	5.95	2.57	0.0109	6	0.0667
Chromis retrofasciata	1	1	1	1	1.00	7.00	3.50	0.0001	29	0.0037
Chromis spp.	6	9	170	11	15.45	5.90	3.00	0.0252	6	0.1566
Chromis ternatensis	3	5	23	5	4.60	6.26	2.46	0.0042	8	0.0352
Chromis vanderbilti	4	12	655	12	54.58	5.16	3.91	0.0746	4	0.3135
Chromis viridis	17	29	1448	42	34.48	4.35	2.46	0.2615	3	0.8958
Chromis xanthura	10	19	926	25	37.04	6.60	6.43	0.0641	9	0.5740
Chrysiptera rollandi	5	7	27	10	2.70	5.22	1.67	0.0072	4	0.0284
Chrysiptera taupou	44	145	886	190	4.66	5.29	2.18	0.1805	4	0.6772
Cirrhilabrus punctatus	1	1	1	1	1.00	15.00	2.50	0.0002	41	0.0074
Cirrhitichtys falco	2	2	2	2	1.00	8.00	2.00	0.0004	9	0.0039
Cirripectes castaneus	2	3	6	3	2.00	6.67	0.83	0.0032	3	0.0110
Cirripectes sp.	2	2	2	2	1.00	9.00	1.00	0.0009	8	0.0069
Coris aygula	7	8	9	8	1.12	27.00	4.50	0.0009	428	0.3807

Species	No of transects fish seen	No of sectors fish observed	Total no seen in 45 transects (nb)	No of sightings or occurences (occ)	School size (nb/occ)	Average size (cm)	Distance of fish to transect	Density (no/m²)	Weight (g)	Biomass (g/m²)
Coris gaimard	10	12	12	12	1.00	21.25	4.08	0.0013	213	0.2776
Coris sp.	1	1	1	1	1.00	15.00	0.50	0.0009	46	0.0405
Coris variegata	6	7	9	7	1.29	12.44	0.94	0.0042	30	0.1285
Ctenochaetus binotatus	6	11	30	13	2.31	9.87	2.80	0.0048	28	0.1345
Ctenochaetus striatus	38	137	1047	259	4.04	10.03	3.86	0.1205	32	3.8223
Dascyllus aruanus	13	30	1108	85	13.04	5.15	3.10	0.1590	7	1.0554
Dascyllus reticulatus	8	13	132	20	6.60	6.16	2.60	0.0226	10	0.2157
Dascyllus spp.	1	1	26	2	13.00	9.54	2.54	0.0046	35	0.1607
Dascyllus trimaculatus	20	34	174	52	3.35	6.85	2.03	0.0381	17	0.6469
Ecsenius bicolor	1	1	1	1	1.00	7.00	2.50	0.0002	4	0.0007
Ecsenius midas	1	" 1	1	1	1.00	8.00	4.50	0.0001	5	0.0005
Ecsenius sp.	4	4	5	4	1.25	7.20	1.90	0.0012	4	0.0044
Epibulus insidiator	14	17	18	18	1.00	11.50	4.22	0.0019	44	0.0827
Epinephelus fasciatus	1	1	1	1	1.00	12.00	1.50	0.0003	29	0.0085
Epinephelus maculatus	2	2	2	2	1.00	16.50	3.00	0.0003	67	0.0197
Epinephelus merra	17	29	33	32	1.03	17.24	2.74	0.0053	80	0.4304
Epinephelus polyphekadion	4	4	4	4	1.00	23.75	3.00	0.0006	303	0.1795
Not identified	2	2	3	2	1.50	7.33	2.50	0.0005	12	0.0061
Not idenified	1	1	1	1	1.00	15.00	4.50	0.0001	6	0.0006
Euthynnus affinis	1	1	50	1	50.00	40.00	5.50	0.0040	3520	14.2216
Fistularia commersonii	2	2	3	3	1.00	58.33	2.17	0.0006	1	0.0006
Fistularia petimba	1	1	; 2	1	2.00	100.00	3.50	0.0003	674	0.1711
Forcipiger longirostris	11	14	27	14	1.93	10.52	4.32	0.0028	27	0.0758
Genicanthus watanabei	1	1	3	1	3.00	12.00	2.50	0.0005	51	0.0271
Gobiidae spp.	1	1	2	1	2.00	7.00	0.50	0.0018	3	0.0062
Gobiodon citrinus	2	2	3	3	1.00	5.33	1.83	0.0007	3	0.0021
Gomphosus varius	27	40	44	44	1.00	10.93	3.25	0.0060	21	0.1235
Grammistes sexlineatus	1	1	1	1	1.00	8.00	2.50	0.0002	7	0.0012
Gymnocranius euanus	2	2	16	3	5.33.	31.88	8.50	0.0008	746	0.6244
Halichoeres argus	9	11	18	15	1.20	8.06	2.14	0.0037	9	0.0333
Halichoeres hortulanus	19	26	29	28	1.04	12.17	2.85	0.0045	30	0.1377
Halichoeres margaritaceus	3	4	4	4	1.00	10.50	1.50	0.0012	18	0.0216
Halichoeres marginatus	3	3	4	4	1.00	12.00	2.25	0.0008	25	0.0196
Halichoeres nebulosus	7	9	11	10	1.10	8.91	2.55	0.0019	12	0.0238
Halichoeres spp.	3	3	5	3	1.67	7.00	1.10	0.0020	6	0.0124
Halichoeres trimaculatus	16	28	40	35	1.14	9.85	2.25	0.0079	16	0.1284
Hemigymnus fasciatus	10	15	21	19	1.11	16.19	4.79	0.0020	92	0.1791
Hemigymnus melapterus	14	22	27	26	1.04	19.04	4.28	0.0028	188	0.5269
Hemiramphidae spp.	1	1	1	1	1.00	80.00	3.50	0.0001	952	0.1209
Heniochus chrysostomus	17	20	27	21	1.29	12.11	3.91	0.0031	66	0.2012
Heniochus monoceros	2	2	2	2	1.00	12.50	3.00	0.0003	67	0.0197
Heniochus varius	2	5	5	5	1.00	14.40	3.70	0.0006	104	0.0622
Hipposcarus longiceps	1	1	1	1	1.00	40.00	5.50	0.0001	1655	0.1337
Hologymnosus doliatus	2	2	2	2	1.00	25.00	5.00	0.0002	99	0.0176
Kyphosus vaigiensis	4	4	205	5	41.00	29.78	4.54	0.0201	684	13.7323
Labrichthys unilineatus	3	4	4	4	1.00	12.25	3.75	0.0005	21	0.0099
Labridae spp.	4	4	7	4	1.75	8.00	1.14	0.0027	10	0.0260
Labroides bicolor	3	3	3	3	1.00	7.00	1.83	0.0007	3	0.0023
Labroides dimidiatus	19	25	36	28	1.29	7.31	2.56	0.0063	5	0.0292
Labropsis australis	1	1	1	1	1.00	7.00	5.00	0.0001	3	0.0003
Leptoscarus vaigiensis	2	5	6	5	1.20	22.00	4.00	0.0007	307	0.2044
Lethrinus atkinsoni	3	3	9	4	2.25	20.56	5.78	0.0007	277	0.1915

Species	No of transects fish seen	No of sectors fish observed	Total no seen in 45 transects (nb)	No of sightings or occurences (occ)	School size (nb/occ)	Average size (cm)	Distance of fish to transect	Density (no/m²)	Weight (g)	Biomass (g/m²)
Lethrinus harak	9	9	10	9	1.11	19.00	4.55	0.0010	143	0.1395
Lethrinus nebulosus	1	1	1	1	1.00	60.00	6.50	0.0001	3973	0.2716
Lethrinus obsoletus	4	5	11	6	1.83	15.91	5.23	0.0009	75	0.0699
Lutjanus bohar	1	2	2	2	1.00	25.00	5.50	0.0002	425	0.0687
Lutjanus fulviflammus	9	14	49	15	3.27	16.37	5.01	0.0043	86	0.3757
Lutjanus fulvus	11	12	15	13	1.15	16.80	3.77	0.0018	101	0.1790
Lutjanus monostigma	3	3	7	3	2.33	25.86	5.21	0.0006	217	0.1294
Macolor niger	2	2	2	2	1.00	22.50	5.00	0.0002	214	0.0381
Macropharyngod meleagris	1	1	1	1	1.00	7.00	0.50	0.0009	6	0.0051
Meiacanthus atrodorsalis	28	51	72	58	1.24	7.35	1.79	0.0179	4	0.0704
Meiacanthus ditrema	1	2	16	2	8.00	7.00	2.84	0.0025	3	0.0085
Meiacanthus oualanensis	3	3	3	3	1.00	7.33	1.50	0.0009	4	0.0035
Meiacanthus sp.	5	10	12	11	1.09	7.83	1.25	0.0043	5	0.0205
Melichthys vidua	1	1	2	1	2.00	30.00	6.50	0.0001	528	0.0722
Monotaxis grandoculis	6	8	10	8	1.25	26.50	5.80	0.0008	682	0.5229
Mulloides flavolineatus	4	4	12	5	2.40	16.17	3.67	0.0015	92	0.1331
Mulloides vanicolensis	6	6	116	7	16.57	24.06	6.75	0.0076	438	3.3425
Myripristis kuniee	6	7	7	7	1.00	12.29	1.21	0.0026	66	0.1683
Myripristis spp.	7	13	36	14	2.57	13.42	2.72	0.0059	71	0.4181
Myripristis violacea	1	1	5	1	5.00	15.00	2.00	0.0011	109	0.1211
Naso annulatus	5	5	56	5	11.20	26.29	9.38	0.0027	424	1.1262
Naso lituratus	15	23	50	30	1.67	16.58	5.52	0.0040	127	0.5119
Naso unicornis	13	15	23	16	1.44	22.48	5.37	0.0019	417	0.7946
Nemateleotris decora	1	1	2	1	2.00	7.00	2.50	0.0004	1	0.0004
Neoniphon operationis	2	2	2	2	1.00	12.50	2.00	0.0004	44	0.0196
Neoniphon sammara	9	10	11	11	1.00	12.09	1.59	0.0031	38	0.1155
Neonyphon spp.	2	2	2	2	1.00	10.00	2.75	0.0003	20	0.0064
Novaculichthys taeniourus	3	4	5	4	1.25	10.40	5.90	0.0004	38	0.0143
Ostracion cubicus	6	6	6	6	1.00	13.50	3.25	0.0008	168	0.1376
Ostracion meleagris	4	4	4	4	1.00	8.50	3.00	0.0006	35	0.0206
Oxycirrhites typus	1	1	1	1	1.00	12.00	2.50	0.0002	27	0.0048
Oxymonacanthus longirostris	24	44	102	46	2.22	6.92	2.41	0.0188	5	0.0871
Paracirrhites forsteri	7	8	8	8	1.00	9.75	1.88	0.0019	18	0.0350
Paracirrhites hemistictus	3	4	4	4	1.00	12.50	2.00	0.0009	35	0.0310
Parapercis clathrata	5	5	5	5	1.00	13.40	1.50	0.0015	43	0.0631
Parapercis cylindrica	4	6	6	6	1.00	9.83	0.83	0.0032	16	0.0503
Parapercis polyophtalma	12	17	22	19	1.16	15.27	1.96	0.0050	61	0.3027
Parupeneus barberinoides	7	8	11	8	1.38	12.27	2.68	0.0018	38	0.0686
Parupeneus barberinus	11	13	16	14	1.14	18.00	4.13	0.0017	149	0.2566
Parupeneus bifasciatus	8	8	8	8	1.00	16.63	4.88	0.0007	126	0.0921
Parupeneus cyclostomus	4	4	7	4	1.75	16.14	5.36	0.0006	99	0.0573
Parupeneus dispilurus	12	19	59	21	2.81	15.46	2.44	0.0107	81	0.8755
Parupeneus pleurostigma	7	9	10	9	1.11	15.60	2.00	0.0022	84	0.1864
Parupeneus trifasciatus	27	46	63	53	1.19	13.97	3.49	0.0080	66	0.5326
Pempheris oualensis	3	4	7	4	1.75	13.43	3.64	0.0009	51	0.0434
Pervagor alternans	5	6	6	6	1.00	7.17	2.67	0.0010	4	0.0044
Pervagor sp.	2	2	2	2	1.00	7.50	2.00	0.0004	7	0.0032
Plagiotremus tapeinosoma	1	1	1	1	1.00	8.00	1.50	0.0003	3	0.0009
Plectorhinchus picus	3	3	3	3	1.00	35.00	4.50	0.0003	707	0.2094
Plectroglyphid lacrymatus	17	29	61	30	2.03	7.10	1.41	0.0192	8	0.1574
Plectroglyphid leucozona	1	1	3	2	1.50	6.67	2.50	0.0005	7	0.0035
Plectropglyphi dicki	7	9	23	10	2.30	6.74	3.41	0.0030	7	0.0203

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Plotosus lineatus	1	1	22	1	22.00	8.00	2.50	0.0039	4	0.0160
Pomacentrus amboinensis	11	28	140	40	3.50	6.31	2.08	0.0299	9	0.2660
Pomacentrus bankanensis	10	18	32	19	1.68	5.75	1.47	0.0097	7	0.0661
Pomacentrus popei	5	8	26	12	2.17	6.27	1.54	0.0075	10	0.0766
Pomacentrus sp.	40	101	844	135	6.25	7.00	2.82	0.1332	8	1.1173
Pomacentrus vaiuli	33	87	359	129	2.78	6.59	2.01	0.0794	9	0.7305
Pomacentrus wardi	1	1	2	1	2.00	7.00	0.50	0.0018	11	0.0188
Priacanthus hamrur	1	1	1	1	1.00	20.00	2.50	0.0002	126	0.0223
Pristotis jerdoni	1	1	15	1	15.00	7.00	2.00	0.0033	8	0.0259
Pseudanthias hypselosoma	1	2	21	2	10.50	9.86	4.31	0.0022	19	0.0404
Pseudanthias sp.	1	" 2	57	4	14.25	6.53	2.13	0.0119	5	0.0628
Pseudanthias spp.	1	1	1	1	1.00	10.00	2.50	0.0002	33	0.0059
Pseudanthias squamipinnis	4	6	55	7	7.86	7.16	2.14	0.0114	9	0.1013
Pseudobalistes fuscus	1	1	1	1	1.00	35.00	5.00	0.0001	1381	0.1227
Pseudochromida spp.	2	2	9	2	4.50	5.33	1.00	0.0040	2	0.0081
Pseudochromis purpurascens	1	1	1	1	1.00	8.00	5.00	0.0001	7	0.0006
Ptereleotris evides	9	11	20	11	1.82	10.40	3.55	0.0025	9	0.0237
Ptereleotris hanae	1	1	1	1	1.00	10.00	4.50	0.0001	5	0.0005
Pterocaesio tile	2	2	65	3	21.67	15.00	5.23	0.0055	68	0.3757
Pterocaesio diagramma	10	13	799	14	57.07	17.90	5.02	0.0708	114	8.0647
Pterois zebra	1	1	1	1	1.00	8.00	0.50	0.0009	10	0.0085
Pygoplites diacanthus	1	1	1	1	1.00	15.00	1.50	0.0003	104	0.0309
Rhinecanthus aculeatus	2	2	2	2	1.00	12.00	4.50	0.0002	41	0.0081
Salarias fasciatus	4	5	5	5	1.00	12.60	2.70	0.0008	40	0.0332
Salarias sp.	2	4	4	4	1.00	11.25	3.00	0.0006	32	0.0191
Sargocentron spiniferum	13	17	19	18	1.06	14.00	2.47	0.0034	61	0.2091
Saurida sp.	1	1	1	1	1.00	18.00	0.50	0.0009	62	0.0554
Saurida undosquamis	1	1	2	1	2.00	15.00	0.50	0.0018	30	0.0541
Scarus altipinnis	7	7	67	12	5.58	39.22	6.86	0.0043	1610	6.9892
Scarus chameleon	14	21	37	25	1.48	19.19	3.95	0.0042	180	0.7486
Scarus dimidiatus	1	3	8	4	2.00	31.63	4.88	0.0007	835	0.6093
Scarus frenatus	8	10	17	12	1.42	24.59	6.56	0.0012	450	0.5186
Scarus ghobban	12	18	28	22	1.27	22.57	4.59	0.0027	387	1.0498
Scarus globiceps	6	9	18	9	2.00	27.00	5.83	0.0014	448	0.6150
Scarus longipinnis	2	3	6	4	1.50	19.17	4.50	0.0006	171	0.1014
Scarus microrhinos	8	8	13	9	1.44	35.31	5.42	0.0011	1170	12463
Scarus niger	8	9	10	10	1.00	22.50	4.90	0.0009	305	0.2771
Scarus oviceps	11	18	39	23	1.70	22.95	6.14	0.0028	358	1.0095
Scarus psittacus	11	16	125	19	6.58	16.66	4.80	0.0116	108	1.2456
Scarus rivulatus	33	51	403	71	5.68	16.79	5.08	0.0352	126	4.4350
Scarus schlegeli	30	52	145	75	1.93	19.50	4.11	0.0157	218	3.4250
Scarus sp. "gris"	3	3	28	4	7.00	12.64	3.59	0.0035	41	0.1430
Scarus sp. juvenile	4	5	57	5	11.40	7.60	3.43	0.0074	8	0.0575
Scarus spinus	5	7	8	8	1.00	14.00	4.13	0.0009	102	0.0880
Scarus spp.	19	30	200	34	5.88	11.20	3.29	0.0271	40	1.0954
Scarus sordidus	44	149	1200	288	4.17	15.00	4.25	0.1256	101	12.6780
Scolopsis bilineatus	19	32	35	33	1.06	13.14	3.30	0.0047	54	02547
Scolopsis spp.	1	1	2	1	2.00	12.00	4.50	0.0002	31	0.0061
Scolopsis trilineatus	2	4	5	4	1.25	13.20	4.00	0.0006	50	0.0279
Siganus argenteus	13	18	126	20	6.30	14.11	5.91	0.0095	52	0.4878
Siganus punctatus	1	1	5	1	5.00	15.00	6.50	0.0003	69	0.0236
Siganus spinus	19	31	88	34	2.59	9.66	4.43	0.0088	17	0.1467

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Spratelloides spp.	1	2	10000	2	5000.00	6.00	5.50	0.8081	2	2.0054
Stegastes lividus	2	2	5	2	2.50	8.80	3.20	0.0007	30	0.0207
Stegastes nigricans	24	44	677	89	7.61	10.33	2.84	0.1060	51	5.4130
Stegastes sp.	13	21	73	25	2.92	8.10	2.81	0.0116	24	0.2825
Stethojulis bandanensis	30	54	72	57	1.26	7.25	2.35	0.0136	5	0.0715
Stethojulis sp.	2	2	2	2	1.00	7.50	2.50	0.0004	6	0.0020
Stethojulis strigiventer	3	3	4	3	1.33	7.25	2.75	0.0006	6	0.0036
Stetholulis interrupta	5	6	8	6	1.33	7.50	2.56	0.0014	6	0.0079
Sufflamen bursa	10	18	23	19	1.21	11.39	3.33	0.0031	36	0.1120
Sufflamen chrysopterus	7	10	10	10	1.00	14.10	4.20	0.0011	72	0.0762
Synodus dermatogennis	3	3	3	3	1.00	15.00	1.17	0.0011	41	0.0465
Synodus hoshinonis	5	6	7	6	1.17	16.00	2.64	0.0012	52	0.0614
Synodus spp.	2	2	3	3	1.00	15.00	1.17	0.0011	29	0.0327
Synodus variegatus	2	2	2	2	1.00	14.50	1.00	0.0009	37	0.0325
Thalassoma amblycephalum	4	4	14	5	2.80	8.57	2.14	0.0029	9	0.0269
Thalassoma hardwicke	36	96	194	132	1.47	11.87	3.16	0.0273	25	0.6892
Thalassoma janseni	6	8	10	10	1.00	11.60	2.20	0.0020	22	0.0451
Thalassoma lunare	16	32	62	42	1.48	12.95	2.15	0.0128	31	0.3924
Thalassoma lutescens	38	124	224	174	1.29	13.62	2.11	0.0472	47	2.2187
Thalassoma purpureum	4	7	14	7	2.00	11.14	2.82	0.0022	42	0.0925
Thalassoma quinquevittat	1	1	2	1	2.00	15.00	1.50	0.0006	71	0.0421
Valenciennea strigatus	1	1	; 1	1	1.00	8.00	2.50	0.0002	9	0.0017
Zanclus cornutus	34	57	96	67	1.43	10.89	4.65	0.0092	26	0.2383
Zebrasoma scopas	36	139	603	203	2.97	9.10	3.50	0.0767	25	1.9269
Zebrasoma veliferum	12	17	29	22	1.32	10.72	3.88	0.0033	34	0.1129
Total								3.5608		145.1795

Appendix II. Summary of the substrate data for the 45 transects conducted at Tongatapu

	SUBSTRATE (%.)										MAIN ORGANISMS ON SUBSTRATE (%)				
Station	Mud	Fine sand	Coarse sand	Gravel	Debris	Small blocks	Large blocks	Rock	Beach rock	Coral, substrate	Turf algae	Green algae	Brown algae	Soft coral	Hard coral
1	0	12	0	0	4	34	12	38	0	0	0	0	31	21	0
2	0	0	10	0	0	0	6	82	2	0	0	0	31	3	0
3	0	0	0	0	0	4	36	60	0	0	1	12	65	3	0
4	0	0	0	0	0	0	4	96	0	0	7	4	55	41	8
5	0	0	6	2	2	12	20	54	0	4	0	1	75	4	22
6	0	0	16	4	2	0	34	44	0	0	0	0	75	0	75
7	0	0	0	0	0	0	0	100	0	0	0	4	45	55	3
8	0	0	0	0	0	6	36	58	0	0	0	31	45	47	5
9	0	0	0	0	0	0	0	98	0	2	0	4	55	65	13
10	0	0	0	0	0	0	0	88	0	12	0	4	65	30	8
11	0	0	20	8	8	12	18	28	0	6	0	8	61	3	5
12	0	0	4	2	2	0	6	78	0	8	0	0	75	21	13
13	0	0	16	0	0	10	12	54	0	8	0	0	75	3	55
14	0	0	4	0	0	0	8	68	18	2	0	2	75	0	5
15	0	0	4	0	0	0	0	94	0	2	0	1	75	2	5
16	0	0	2	0	0	0	0	96	0	2	0	4	75	5	5
17	0	0	0	0	0	0	0	100	0	0	5	5	75	5	5
18	0	0	0	0	0	0	0	100	0	0	0	5	75	5	5
19	0	6	0	0	0	0	0	94	0	0	0	1	75	8	4
20	0	14	0	0	0	0	0	78	0	8	0	1	75	3	5
21	0	0	22	10	18	12	0	8	16	14	0	2	20	0	13
22	0	0	4	0	0	0	4	92	0	0	0	2	55	0	4
23	0	0	22	2	0	0	10	6	60	0	1	4	35	0	5
24	0	0	2	6	0	0	0	92	0	0	0	0	40	1	4
25	0	0	10	2	2	0	0	82	0	4	1	4	40	1	5
26	0	0	0	0	0	0	0	98	0	2	0	5	45	0	5
27	0	0	0	0	0	0	0	92	0	8	0	5	17	0	25
28	0	0	0	0	0	0	0	100	0	0	0	4	25	21	9
29	0	0	20	2	0	0	0	76	0	2	0	17	23	5	5
30	0	18	0	0	0	0	0	76	0	6	0	21	4	17	3
31	0	2	2	0	0	0	0	96	0	0	0	13	13	5	5
32	0	0	6	0	0	0	0	94	0	0	0	9	13	55	13
33	0	0	0	0	0	0	0	100	0	0	0	5	17	55	55
34	0	0	0	0	0	0	0	100	0	0	0	5	55	3	45
35	0	0	20	0	0	4	0	40	32	4	0	2	17	21	5
36	0	0	10	8	0	2	4	36	16	24	0	6	3	11	0
37	0	0	0	0	0	0	0	100	0	0	0	0	17	0	35
38	0	0	0	0	0	20	26	50	0	4	0	0	25	13	16
39	0	0	0	0	0	0	0	100	0	0	0	0	15	15	15
40	0	0	0	0	0	0	0	16	84	0	0	0	21	5	25
41	0	0	12	0	0	8	14	66	0	0	8	4	17	13	13
42	0	0	0	0	0	22	22	44	12	0	0	7	25	0	0
43	0	0	0	0	0	0	0	100	0	0	0	0	25	3	5
44	0	0	0	0	0	4	16	70	0	10	1	2	20	12	20
45	0	0	0	0	0	2	8	80	0	10	0	3	25	17	17
Average (%)	0.00	1.16	4.71	1.02	0.84	3.38	6.58	73.82	5.33	3.16	0.53	4.60	42.00	1327	13.07