Climate Change Baseline Assessment

Funafuti Atoll
Tuvalu

July-August 2011

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ACRONYMS

ANOVA	Analysis of Variance
AusAID	Australian Agency for International Development
COTS	Crown-of-thorns starfish
CPC	Coral Point Count
D-UVC	Distance-sampling Underwater Visual Census
EEZ	Exclusive Economic Zone
GDP	Gross Domestic Product
GPS	Global Positioning System
GR	Government Revenue
ha	hectare
ICCAI	International Climate Change Adaptation Initiative (Australia)
IPCC	Intergovernmental Panel on Climate Change
IRD	Institut de Recherche pour le Développement
MCRMP	Millennium Coral Reef Mapping Project
MPA	Marine Protected Area
NASA	National Aeronautics and Space Administration
NGO	Non-Government Organisation
PCA	Principle Component Analysis
PCCSP	Pacific Climate Change Science Program
PICT	Pacific Island Countries and Territories
PROCFish	Pacific Regional Oceanic and Coastal Fisheries Development Programme
RBT	Reef-benthos transect
SCUBA	Self-Contained Underwater Breathing Apparatus
SEAFRAME	Sea Level Fine Resolution Acoustic Measuring Equipment
SOPAC	Applied Geoscience and Technology Division of SPC
SPC	Secretariat of the Pacific Community
SE	Standard Error
SST	Sea-surface temperature
TL	Total length
USD	United States dollar(s)
USP	University of the South Pacific

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Introduction
Considering the concerns of climate change and its impacts on coastal fisheries resources, SPC is implementing the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project with funding assistance from the Government's International Climate Change Adaptation Initiative (ICCAI). This initiative aims to assist Pacific Islands Countries and Territories (PICTs) to determine whether changes are occurring in the productivity of coastal fisheries and, if changes are found, to identify the extent to which such changes are due to climate change, as opposed to other causative factors. This report presents the results of baseline field surveys for the project conducted in Funafuti Atoll, Tuvalu, in July and August 2011.

Survey Design
Survey work at Funafuti Atoll covered four disciplines (water temperature monitoring, benthic habitat assessments and assessments of finfish and invertebrate resources), and was conducted by a team from SPCs Coastal Fisheries Science and Management Section, staff from Fisheries Department of Tuvalu, and a student from the University of the South Pacific. The fieldwork included capacity development of local counterparts by providing training in survey design and methodologies, data collection and entry, and data analysis.

Two survey sites were established in Funafuti Atoll: Fongafale and Funafuti Conservation Area (FCA). Fongafale is open to fishing while the FCA site is closed, thus allowing direct de-coupling of the effects of fishing from other factors (e.g. climatic effects). For purposes of this baseline report, comparisons were made among the MPA and Open sites, to explore functioning of the protected area. The data collected provides a quantitative baseline that will be analysed after future monitoring events to examine changes in coastal habitat and fishery resources over time.

Water Temperature
Water temperature loggers were deployed at two sites within Funafuti Atoll in August 2011: one at an outer-reef site and one at a back-reef site. The loggers were retrieved in May 2012. Data retrieved from the two loggers shows a frequent change in sea temperature every month. Water temperatures on both the outer and back -reefs increased over October 2011 to reach a peak in November 2011. Water temperatures were generally slightly higher on the back-reef than on the outer-reef, particularly from October to mid November. The logger deployed on the outer-reef recorded data from August to February 2012, while the logger deployed on the back reef recorded data from August 2011 to November 2011 before batteries on both loggers failed. These loggers have subsequently been replaced.

Benthic Habitat Assessments

Benthic habitats of the Fongafale and FCA sites were assessed via photoquadrat analysis. Thirty-five 50 m benthic habitat assessment transects were completed across the reef flat, back-reef and outer-reef habitats of Funafuti Atoll, with 18 transects completed at Fongafale and 17 completed within the FCA. Up to 50 photographs of the benthos were taken per transect (with one photo taken approximately every metre) using a housed underwater camera and a quadrat frame measuring an area of 0.25 m^2. Photographs were analysed using SPC software. In general, both the reef flat and back-reef habitats of the Fongafale site were characterised by a high cover of turf, while the reef flat and back-reefs of the FCA were largely characterised by a high cover of sand. Hard coral diversity was low (≤ seven genera) at the reef flat and back-reef habitats of both Fongafale and the FCA. In contrast, outer-reef habitats of both the Fongafale and FCA monitoring stations had a relatively high percent cover of hard coral, with hard corals constituting approximately 50% of overall cover at Fongafale stations and 40% of overall cover within the FCA stations. Coral diversity was similarly high, with thirteen types of hard coral recorded on the outer-reefs of the Fongafale monitoring stations, and 23 types recorded on the outer-reefs of the FCA stations. *Acropora* was the most common genera in terms of cover within the outer-reefs of the Fongafale stations, while *Favia*, *Acropora*, *Montipora* and *Pocillopora* were the most common coral genera on the outer-reefs of stations within the FCA. The cover of bleached and recently dead corals was low (typically < 2%) across all habitats at both the Fongafale and FCA sites.

Finfish Surveys

Finfish resources and their supporting habitats were surveyed using distance-sampling underwater visual census (D-UVC) methodology. Thirty-five 50 m D-UVC transects were completed across the reef flat, back-reef and outer-reef habitats of Funafuti Atoll, with 17 transects completed in the Fongafale site and 18 transects completed in the FCA. Habitats supporting finfish at both the Fongafale and FCA sites were largely similar to those recorded during the benthic habitat assessments.

A total of 23 families, 69 genera, 197 species and 11,319 individual fish were recorded from the 35 transects, with 18 families, 54 genera, 144 species and 7,004 individual fish recorded from the Fongafale monitoring stations, and 22 families, 59 genera, 144 species and 4,315 individual fish recorded from the FCA monitoring stations. Finfish diversity (no. of species per transect) was largely similar between the Fongafale and FCA sites. Overall mean density and biomass of fish on reef flat habitats were higher at Fongafale than the FCA, while no difference in overall mean density or biomass was observed between sites for back-reef or outer-reef habitats. At Fongafale, no difference was observed in overall mean density among the three habitats, while overall mean density was lower within reef flat habitats compared to back- or outer-reef habitats within the FCA. Little difference was evident in mean density or biomass among habitats at Fongafale, while mean density and biomass were lower at reef flat habitats than back- or outer-reefs at the FCA stations.

The mean densities and biomass of several finfish families were lower than those observed during the PROCFish suvrveys conducted on Funafuti Atoll by SPC in 2004–2005. It should be noted that these surveys were generally conducted at different locations, thus these results may be at least partially influenced by spatial differences in habitat cover or depth among surveys. Further monitoring is warranted to assess the status of fish populations on Funafuti over time.

Invertebrate Surveys

Invertebrate resources and their supporting habitats were surveyed using two complementary approaches. Manta tows were used to assess invertebrate populations at broad spatial scales. A total of 12 manta tow stations (6 x 300 m transects) were established within Funafuti Atoll, with 6 manta tow stations established in each of the Fongafale and FCA monitoring sites. Fifteen invertebrate species were recorded during the manta tow surveys. Species diversity was higher within the FCA than the Fongafale site. Mean density of individual species observed during manta tow in both the Fongafale and FCA sites was low, with no individual species observed in densities greater than 35 individuals/ha. Mean densities of sea cucumber species were particularly low, with no species observed in densities greater than 6 individuals/ha at either site. The mean densities of *Lambis* sp., *Tridacna maxima* and *Tridacna squamosa* were significantly higher within the FCA than the Fongafale site. No crown-of-thorns starfish (*Acanthaster planci*) were recorded during manta tow surveys at either site.

To assess invertebrate resources associated at finer-spatial scales, reef-benthos transects (RBT) were used. A total of 10 RBT stations (6 x 40 m transects) were established within the Fongafale site, while six were established within the FCA. Forty-eight invertebrate species were recorded during the reef-benthos surveys. As with the manta tow surveys, species diversity was slightly higher within the FCA than the Fongafale site. The invertebrate species observed in the highest mean densities during the RBT surveys within the FCA site included the sea urchins *Diadema savignyi* (2354.17±1391.47 individuals/ha) and *Echinometra mathaei* (513.89±364.78 individuals/ha), the gastropod *Lambis truncata* (145.83±145.83 individuals/ha) and the bivalve *Tridacna maxima* (125.00±90.01 individuals/ha) (Appendix 14). The mean densities of *Diadema savignyi* and *Echinometra mathaei* were significantly higher within the FCA than the Fongafale site. A single individual of the crown-of-thorns starfish was observed in the Fongafale stations, while no individuals were observed within the FCA stations. No differences in mean size were apparent for species common to both Fongafale and FCA monitoring sites.

Recommendations for Future Monitoring

The following recommendations are proposed for future monitoring events:

- The decreases in densities and biomass evident for several finfish families between the PROCFish surveys in 2004–2005 and the current (2011) survey is of concern, as it suggests a significant reduction in finfish populations at Funafuti Atoll over a short-term period. Further monitoring of the locations surveyed in this baseline assessment is required to determine whether these differences are consistent over time. In addition, to ensure that these results, and results of future surveys, were not a result of differences in observer skill or experience, the use of non-observer based monitoring techniques, such as videography, in conjunction with the D-UVC surveys are recommended.

- Many of the reef flat monitoring stations established during the baseline survey were established in shallow (< 1 m deep) water. Accordingly, these habitats will likely only support transient finfish communities due to tidal effects. For future surveys it is recommended that deeper water lagoon-reef monitoring sites, situated at the same sites as those examined during the PROCFish study, be established, where possible.

- Due to strong currents and poor weather at the time of survey, one reef flat benthic habitat and finfish transect at the FCA site could not be completed. To balance the survey design, this transect should be established during the re-survey event.

- For this baseline study, manta tow surveys were conducted on back-and lagoon-reef habitats only. As various reef habitats, and the organisms they support, differ greatly in their vulnerability to climate change, it is recommended that manta tow monitoring stations be established on the outer reef of both the Fongafale and FCA sites, where conditions permit.

- During the baseline assessment, 10 RBT stations were established at Fongafale, while six stations were established in the FCA. To balance the sampling design, additional RBT stations should be established within the FCA.

1. Introduction

Project Background

Considering the concerns of climate change and its impacts on coastal fisheries resources, SPC is implementing the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project with funding assistance from Australia's International Climate Change Adaptation Initiative (ICCAI). This project aims to assist Pacific Islands Countries and Territories (PICTs) to design and field-test monitoring pilot projects to determine whether changes are occurring in the productivity of coastal fisheries and, if changes are found, to identify the extent to which such changes are due to climate change, as opposed to other causative factors.

The purpose of this project is to assist PICTs to:

1. Recognise the need for monitoring the productivity of their coastal fisheries and commit to allocating the resources to implement monitoring measures.

2. Design and field-test the monitoring systems and tools needed to:

   i. Determine whether changes to the productivity of coastal fisheries are occurring, and identify the extent to which such changes are due to climate, as opposed to other pressures on these resources, particularly overfishing and habitat degradation from poor management of catchments;

   ii. Identify the pace at which changes due to climate are occurring to 'ground truth' projections; and

   iii. Assess the effects of adaptive management to maintain the productivity of fisheries and reduce the vulnerability of coastal communities.

The Approach

Monitoring impacts of climate change on coastal fisheries is a complex challenge. To facilitate this task, a set of monitoring methods was selected from the SPC expert workshop 'Vulnerability and Adaptation of Coastal Fisheries to Climate Change: Monitoring Indicators and Survey Design for Implementation in the Pacific' (Noumea, 19–22 April 2010) of scientists and representatives of many PICTs. These methods include monitoring of water temperature using temperature loggers, finfish and invertebrate resources using SPC resource assessment protocols, and photo quadrats for assessing benthic habitats supporting coastal fisheries. The methods were prioritized as they were considered indicators for the oceanic environment, habitats supporting coastal fisheries and finfish and invertebrate resources. In parallel, SPC is currently implementing database backend and software to facilitate data entry, analysis and sharing between national stakeholders and the scientific community as well as providing long-term storage of monitoring data.

Five pilot sites were selected for monitoring: Federated States of Micronesia (Pohnpei), Kiribati (Abemama Atoll), Marshall Islands (Majuro Atoll), Papua New Guinea (Manus Province) and Tuvalu (Funafuti Atoll). Their selection was based on existing available data such as fish, invertebrate and socio-economic survey data from the Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish), multi-temporal images (aerial photographs and satellite images) from the Applied Geosciences and Technology Division of SPC (SOPAC), the presence of Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME), as well as their geographical location.

This report presents the results of baseline field surveys for the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project conducted in Funafuti Atoll, Tuvalu, between July and August 2011, by a team from SPCs Coastal Fisheries Science and Management Section, staff from Tuvalu's Department of Fisheries and a student from the University of the South Pacific (USP).

Tuvalu

Background

Tuvalu is located in the western South Pacific Ocean between the equator and 11° S, stretching from 176° E - 180° E (Figure 1). The country consists of five true atolls: Nanumea, Nui, Nukufetau, Funafuti and Nukulaelae, and four raised limestone reef islands: Nanumaga, Niutao, Vaitupu and Niulakita, listed in sequence from North to South. The total land area of Tuvalu is approximately 26 km^2, while the Exclusive Economic Zone (EEZ) totals approximately 900,000 km^2 (Gillet 2009). In 2010, the estimated population of Tuvalu was 11,149. The capital is Funafuti which is located on an atoll of the same name.

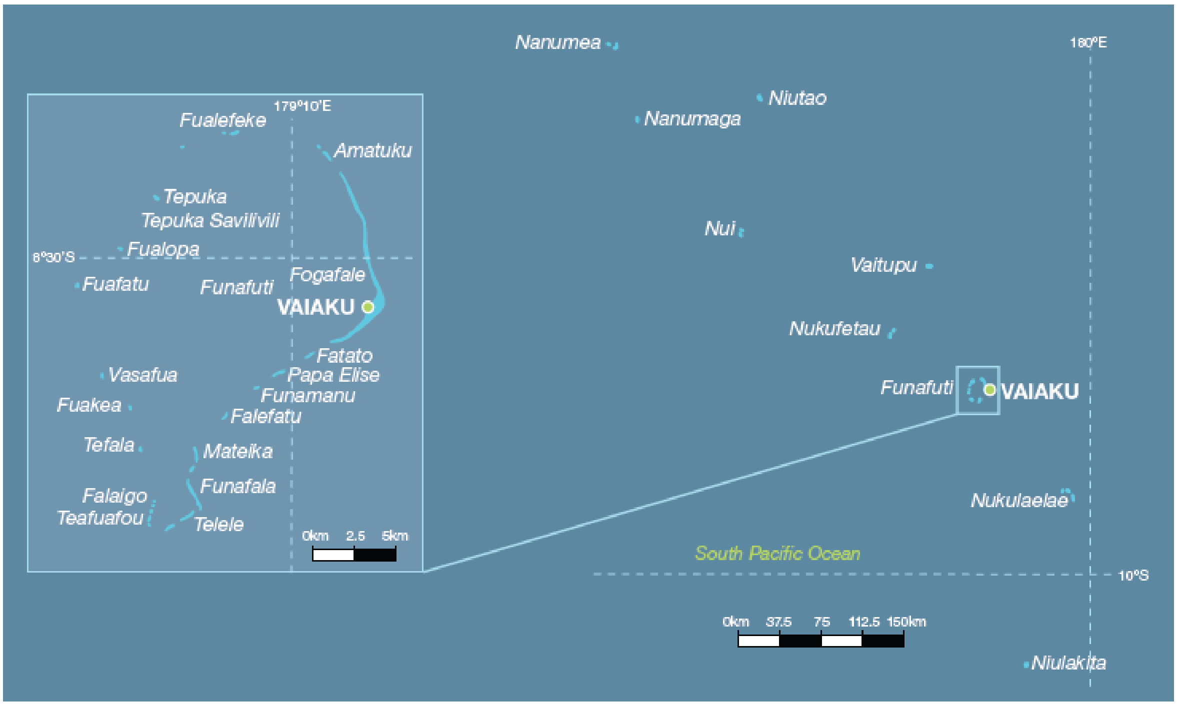

Figure 1 **Tuvalu (from PCCSP 2011).**

Fisheries of Tuvalu

Oceanic fisheries

Tuvalu has a very small local fishery for tuna within its EEZ. Recent (2004–2008) average annual catches were approximately 16 tonnes, worth > USD 36,000. Tuvalu also licenses foreign vessels to fish for tuna within its EEZ. Between 1999 and 2008, foreign fleets made an average total annual catches of 26,380 tonnes, worth USD 22.6 million (Gillet 2009). Licence fees from foreign vessels contributed approximately 11% to government revenue (GR). The small locally-based tuna fishery does not contribute to the gross domestic product (GDP) of Tuvalu (Bell et al. 2011).

Table 1 **Annual fisheries and aquaculture harvest in Tuvalu, 2007 (Gillet 2009).**

Harvest sector	Quantity (tonnes)	Value (USD million)
Coastal commercial	226	733,666
Coastal subsistence	989	2,656,896
Offshore locally-based	0	0
Offshore foreign-based	35,541	48,700,000
Freshwater	0	0
Aquaculture	0	0
Total	**36,756**	**52,090,562**

Coastal fisheries

The coastal fisheries of Tuvalu are comprised of three categories; demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahimahi), and invertebrates gleaned from intertidal and subtidal areas (Bell et al. 2011). In 2007, the total annual catch of the coastal sector was estimated to be 1,215 tonnes, worth > USD 2.8 million (Gillet 2009). The commercial catch was 226 tonnes (Gillet 2009).

Table 2 Estimated catch and value of coastal fisheries sectors in Tuvalu, 2007 (Bell et al. 2011).

Coastal fishery category	Quantity (tonnes)	Contribution of catch (%)
Demersal finfish	837	69
Nearshore pelagic finfish	326	27
Targeted invertebrates	0	0
Inter/subtidal invertebrates	52	4
Total	**12,600**	**100**

Climate change projections for Tuvalu

Air temperature

Historical air temperature data records for Tuvalu are available for Funafuti Island only. An increase in average daily temperatures of approximately 0.24°C per decade has been observed since recording began in 1950 (Figure 2). Mean air temperatures are projected to continue to rise, with increases of +0.7, +0.8 and +0.7°C (relative to 1990 values) projected for 2030, under the IPCC B1 (low), A1B (medium) and A2 (high) emissions scenarios, respectively (PCCSP 2011) (Table 3).

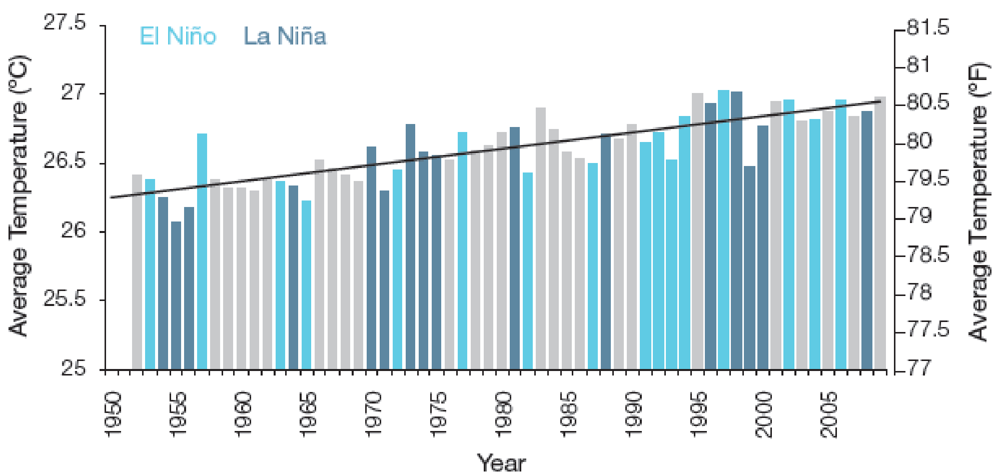

Figure 2 Annual mean air temperature at Funafuti Atoll (1950–2009) (from PCCSP 2011).

Table 3 Projected air temperature increases (in °C) for Tuvalu under various IPCC emission scenarios (from PCCSP 2011).

Emission scenario	2030	2055	2090
B1	+0.7 ± 0.4	+1.1 ± 0.4	+1.5 ± 0.6
A1B	+0.8 ± 0.4	+1.5 ± 0.5	+2.3 ± 0.8
A2	+0.7 ± 0.3	+1.4 ± 0.4	+2.7 ± 0.6

Sea-surface temperature

In accordance with mean air temperatures, sea-surface temperatures are projected to further increase, with increases of +0.6, +0.7, and +0.7°C (relative to 1990) values projected for 2030, under the IPCC B1 (low), A1B (medium) and A2 (high) emissions scenarios, respectively (PCCSP 2011) (Table 4).

Table 4 Projected sea-surface temperature increases (in °C) for Tuvalu under various IPCC emission scenarios (from PCCSP 2011).

Emission scenario	2030	2055	2090
B1	+0.6 ± 0.4	+1.0 ± 0.3	+1.3 ± 0.5
A1B	+0.7 ± 0.3	+1.3 ± 0.4	+2.1 ± 0.6
A2	+0.7 ± 0.4	+1.3 ± 0.5	+2.5 ± 0.6

Sea level rise

As part of the AusAID-sponsored South Pacific Sea Level and Climate Monitoring Project (‘Pacific Project’) a SEAFRAME (Sea Level Fine Resolution Acoustic Measuring Equipment) gauge was installed in Funafuti Atoll in March 1993. According to the 2010 Pacific country report on sea level and climate for Tuvalu (http://www.bom.gov.au/pacificsealevel/picreports.shtml), the gauge had been returning high resolution, good quality scientific data since installation and as of 2010 the net trend in sea-level rise in Funafuti (accounting for barometric pressure and tidal gauge movement) was calculated at +3.7 mm per year. Based on empirical modeling, mean sea-level is projected to continue to rise during the 21st century, with increases of up to +20 to +30 cm projected for 2035 and +90 to +140 cm projected for 2100 (Bell et al. 2011). Sea level rise may potentially create severe problems for low lying coastal areas, namely through increases in coastal erosion and saltwater intrusion (Mimura 1999). Such processes may result in increased fishing pressure on coastal habitats, as traditional garden crops fail, further exacerbating the effects of climate change on coastal fisheries.

Ocean acidification

Based on the large-scale distribution of coral reefs across the Pacific and seawater chemistry, Guinotte et al. (2003) suggested that aragonite saturation states above 4.0 were optimal for coral growth and for the development of healthy reef ecosystems, with values from 3.5 to 4.0 being adequate for coral growth, and values between 3.0 and 3.5 were marginal. There is strong evidence to suggest that when aragonite saturation levels drop below 3.0 reef organisms cannot precipitate the calcium carbonate that they need to build their skeletons or shells (Langdon and Atkinson 2005).

In Tuvalu, the aragonite saturation state has declined from about 4.5 in the late 18th century to an observed value of about 4.0±0.1 by 2000 (PCCSP 2011). Ocean acidification is projected to increase, and thus aragonite saturation states are projected to decrease, during the 21st century (PCCSP 2011). Climate model results suggested that by 2060 the annual maximum aragonite saturation state for Tuvalu will reach values below 3.5 and continue to decline thereafter (PCCSP 2011). These projections suggest that coral reefs of Tuvalu will be vulnerable to actual dissolution as they will have trouble producing the calcium carbonate needed to build their skeletons. This will impact the ability of coral reefs to have net growth rates that exceed natural bioerosion rates. Increasing acidity and decreasing levels of aragonite saturation are also expected to have negative impacts on ocean life apart from corals; including calcifying invertebrates, non-calcifying invertebrates and fish. High levels of CO_2 in the water are expected to negatively impact the lifecycles of fish and large invertebrates through habitat loss and impacts on reproduction, settlement, sensory systems and respiratory effectiveness (Kurihara 2008, Munday et al. 2009a, Munday et al. 2009b). The impact of acidification change on the health of reef ecosystems is likely to be compounded by other stressors including coral bleaching, storm damage and fishing pressure (PCCSP 2011).

Projected effects of climate change of coastal fisheries of Tuvalu

Tuvalu has extensive (> 3,000 km^2) coral reef areas, and small areas of mangrove habitat (Bell et al. 2011). Climate change is expected to add to the existing local threats to these habitats, resulting in declines in their quality and area (Table 5). Fisheries for demersal fish and intertidal and subtidal invertebrates are projected to show progressive declines in productivity due to both the direct (e.g. increased SST) and indirect (e.g. changes to fish habitats) of climate change (Table 6) (Bell et al. 2011). In contrast, fisheries for nearshore pelagic fish are projected to increase in productivity due to the redistribution of tuna to the east (Table 6) (Bell et al. 2011).

Table 5 Projected changes in coastal fish habitat in Tuvalu under various IPCC emission scenarios (from Bell et al. 2011).

Habitat	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[a]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60

* Approximates A2 in 2050; a = assumes there is strong management of coral reefs.

Table 6 Projected changes to coastal fisheries production in Tuvalu under various IPCC emission scenarios (from Bell et al. 2011).

Coastal fisheries category	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Demersal fish	-2 to -5	-20	-20 to -50
Nearshore pelagic fish[1]	+15 to +20	+20	+10
Inter/subtidal invertebrates	0	-5	-10

* Approximates A2 in 2050; a = tuna contribute to the nearshore pelagic fishery.

2. Site and Habitat Selection

Site Selection

Funafuti Atoll was selected as a pilot site for the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project within Tuvalu following consultations with Tuvalu's Department of Fisheries. Funafuti Atoll was selected as it offered a number of advantages as a study site, most notably:

- Funafuti Atoll contains the Funafuti Conservation Area (FCA), a gazetted 'no take' marine park (designed to conserve the terrestrial and marine biodiversity resources of Funafuti Atoll), thereby allowing decoupling of the effects of fishing and pollution against other factors (i.e. climate change);

- A SEAFRAME gauge was installed in Funafuti in 1993 as part of the AusAID-sponsored South Pacific Sea Level and Climate Monitoring project for purposes of recording sea level rise, air temperature, water temperature, wind speed and direction and atmospheric pressure;

- Government offices are located in Funafuti which simplifies logistics;

- Fish, invertebrate and socio-economic data were collected by SPC under the PROCFish/C project in Funafuti Atoll in 2004–2005 (Sauni et al. 2008) and SPC's SOPAC division conducted bathymetric surveys in the region in 2006 and 2010.

Funafuti Atoll is located at approximately 8^{o}31`S latitude and 179$^{o}$13`E longitude, and is comprised of 30 small islets. Funafuti consists of approximately 2.4km^2 of land area and 275km^2 of lagoon. Being an urbanized atoll, Funafuti's reefs are impacted by various anthropogenic stressors including poor waste management systems and increased coastal development causing increased sedimentation and coastal erosion (Sauni et al. 2008).

For the purposes of the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project, monitoring sites were established within and outside of the FCA. The FCA is located in the western side of Funafuti Atoll which encompasses 33km^2 of ocean area including six small islets (motu) that occupy a land area of approximately 8 ha. The FCA was established in 1996 with the aim of conserving the terrestrial and marine biodiversity resources of Funafuti Atoll (Figure 3).

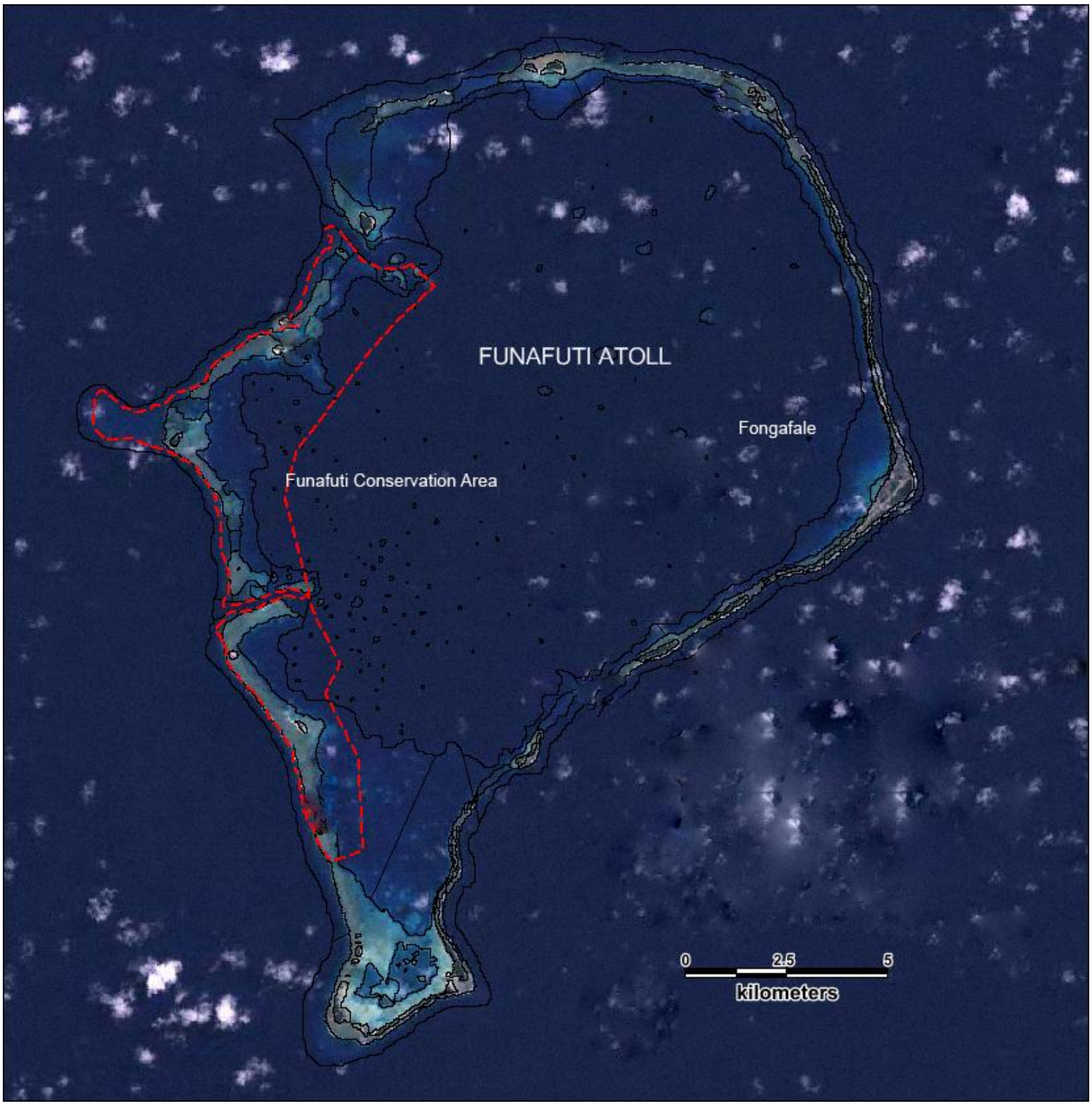

Figure 3 Map of Funafuti Atoll showing the Funafuti Conservation Area.

Fisheries of Funafuti Atoll

Fishing is an important activity for the people of Funafuti. Socio-economic survey work conducted at Funafuti as part of the PROCFish surveys by SPC in 2004–2005 revealed that 100% of households surveyed engage in some form of fishing activity (Sauni et al. 2008). Average per capita consumption of fresh fish was found to be almost 135 kg/person/year, more than four times the regional average of approximately 35 kg/person/year, with fresh fish consumed 5.6 times per week (Sauni et al. 2008). The local demand for fresh fish is high and market supply often falls short of demand. Trolling for pelagic fish is common, using either wooden or aluminium skiffs that are equipped with an outboard engine. Lagoon fishing is mostly performed using gillnets, handlines, rods and fish traps. Spearfishing, rod fishing and handlining are common methods used for reef fishing (Sauni et al 2008). Main finfish families targeted are Carangidae, Kyphosidae, Lethrinidae, Acanthuridae, Lutjanidae and Serranidae (Sauni et al. 2008). The fishing roles on Tuvalu, like many other Pacific Islands, are divided by gender, with women mainly reef gleaning at low tide, and processing, and men fishing both inshore and offshore (Sauni et al. 2008).

Relative to fresh fish, invertebrate fishing and consumption is less frequent, with invertebrates consumed approximately 0.7 times per week (Sauni et al. 2008). Most invertebrates are typically caught by gleaning on soft-benthos habitats, while small dive fisheries exist for lobsters (*Panulirus penicillatus*), and, to a lesser extent, giant clams (*Tridacna* spp.) and the spider conch (*Lambis truncata*). Although 14 species of sea cucumber have been recorded from Tuvalu waters, sea cucumbers are not a traditional dietary component of Tuvalu islanders (Kinch et al. 2008). An export industry for sea cucumbers existed in Funafuti. In 2010, this venture was abandoned due to unprofitability in harvesting a diminishing resource.

Habitat Definition and Selection

Coral reefs are highly complex and diverse ecosystems. 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 purposes of the baseline field surveys in Funafuti Atoll, three general reef types were categorised:

1) reef flat;
2) back-reef: inner/lagoon side of outer reef/main reef body; and
3) outer-reef: ocean-side of fringing or barrier reefs.

A Comparative Approach Only

The data collected provides a quantitative baseline that will be analysed after future monitoring events to examine temporal changes in coastal habitat and fishery resources. It should be stressed that due to the comparative design of the project, the methodologies used, and the number of sites and habitats examined, the data provided in this report should only be used in a comparative manner to explore differences in coastal fisheries productivity over time. These data should not be considered as indicative of the actual available fisheries resources.

3. Monitoring of Water Temperature

Methodologies

To monitor the water temperature in coastal areas SPC obtained type RBR TR-1060 temperature loggers. In August 2011, two temperature loggers were deployed in Funafuti: one on the outer reef and one on the back reef. The loggers were calibrated to an accuracy of ±0.002ºC and programmed to record temperature every five minutes. For security reasons both loggers were housed in PVC tube with holes to allow flow of water and encased in a concrete block. These blocks were then secured to the sea floor using rebars. Each logger was deployed at a depth of approximately 10 m. Data retrieval and battery replacement is planned after a period ranging from six months (initial trial) to two years. The collected data will be stored on SPC servers and made available to networks of researchers, governmental services and conservation NGOs.

Figure 4 Deployment of temperature loggers in Funafuti, 2011.

Table 7 Details of temperature loggers deployed at Funafuti Atoll.

Details	Funafuti 1	Funafuti 2
Deployment date	01/08/2011	15/08/2011
Location	Fualopa, Funafuti	Fuamanu, Funafuti
Habitat	Outer reef	Back reef
Longitude (E)	179.050169	179.132789
Latitude (S)	8.483362	8.563798
Depth	12 m	11 m

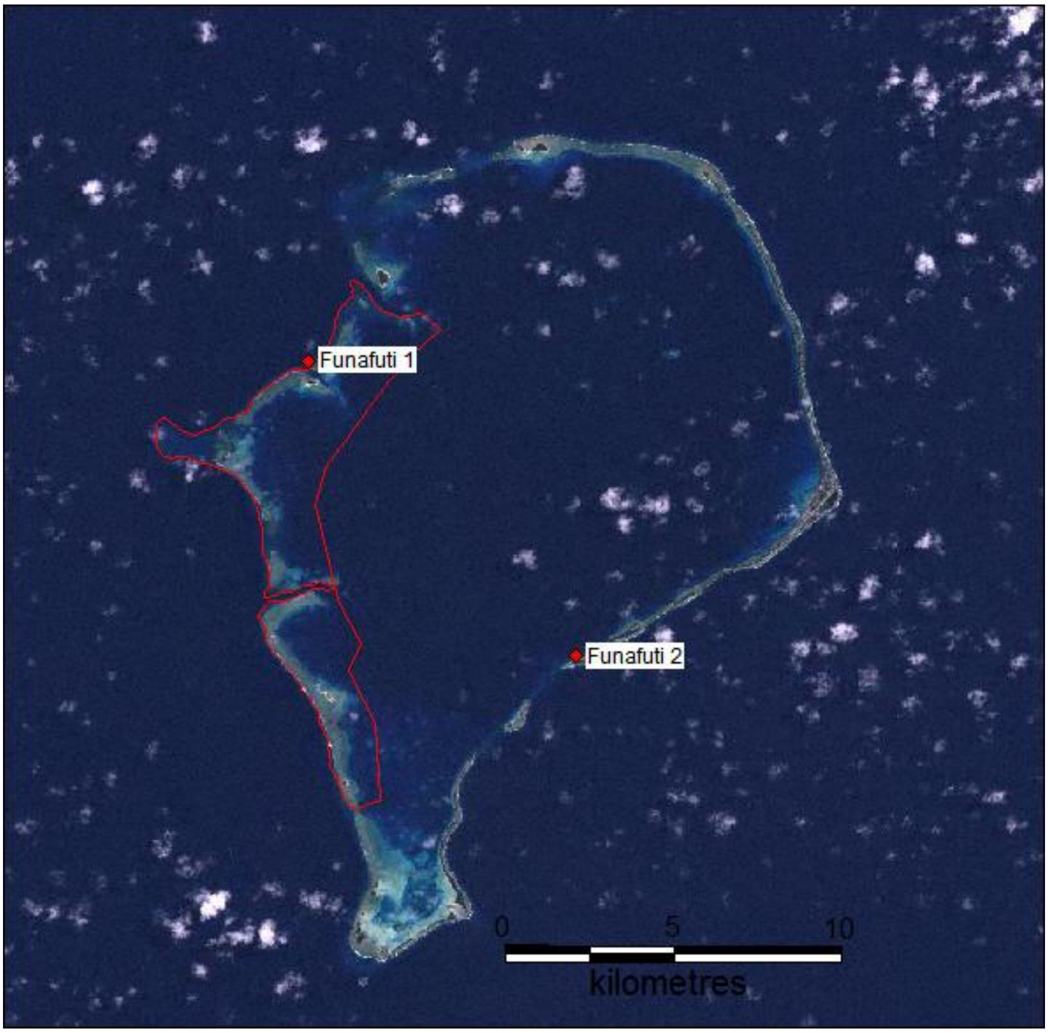

Figure 5 **Location of water temperature loggers deployed in Funafuti Atoll, 2011.**

Results

Water temperatures on both the outer- and back-reefs increased over October 2011 to reach a peak in November 2011. Water temperatures were generally slightly higher on the back-reef than on the outer-reef, particularly from October to mid November (Figure 6). The logger (Funafuti 1) deployed on the outer-reef within the FCA recorded data from August to February 2012 while the logger (Funafuti 2) deployed on the back reef of the Fongafale site recorded data from August 2011 to November 2011 before batteries on both loggers failed. These loggers have subsequently been replaced with a newer model (Seabird SBE 56).

Figure 6 **Mean daily water temperature in the outer-reef (Funafuti 1) and lagoon (Funafuti 2) of Funafuti Atoll. See Figure 5 for logger locations.**

4. Benthic Habitat Assessments

Methodologies

Data collection

For the assessments of benthic habitat and finfish resources, two survey stations were established in each of the Fongafale and FCA sites. Within each station, benthic habitat assessments were focused on three habitats: reef flats, back-reefs and outer-reefs with a target of three replicate 50 m transects planned in each habitat for each station (Figure 7). To monitor benthic habitats, up to 50 photographs of the benthos were taken per transect (with one photo taken approximately every metre) using a housed underwater camera and a quadrat frame measuring approximately 1 m high that captured an area of 0.25 m^2. Transects were laid parallel to the reef. A GPS position was recorded at the beginning of each replicate transect. To maximise survey efficiency, the same transects were used for both the benthic habitat and finfish assessments.

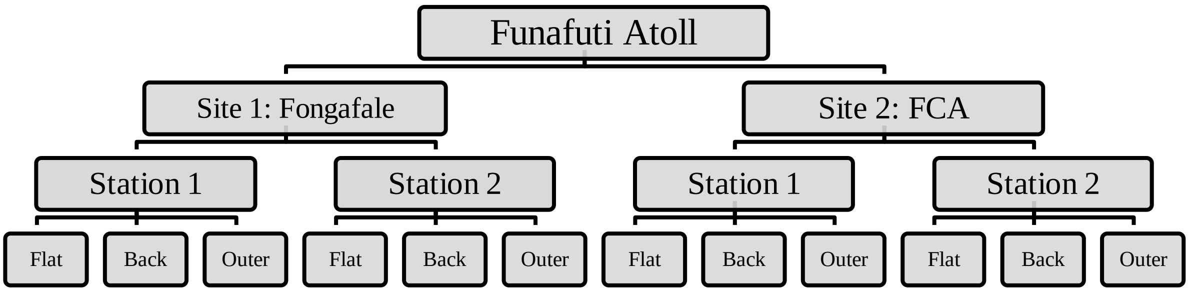

Figure 7 Survey design of the benthic habitat and finfish assessments in Funafuti Atoll, Tuvalu. Three replicate 50 m transects were planned in each reef flat, back-reef and outer-reef habitat.

Data processing and analysis

The habitat photographs were analyzed using SPC software (available online: http://www.spc.int/CoastalFisheries/CPC/BrowseCPC), which is similar to the Coral Point Count (CPC) analysis software by Kohler and Gill (2006). Using this software, five randomly generated points were created on the downloaded photographs. The substrate under each point was identified based on the following substrate categories:

1. Hard coral – sum of the different types of hard coral, identified to genus level[1];
2. Other invertebrates – sum of invertebrate types including *Anemones*, *Ascidians*, *Cup sponge*, *Discosoma*, *Dysidea sponge*, *Gorgonians*, *Olive sponge*, *Terpios sponge*, *Other sponges*, *Soft coral*, *Zoanthids*, and *Other invertebrates* (other invertebrates not included in this list);
3. Macroalgae – sum of different types of macroalgae *Asparagopsis*, *Blue-green algae*, *Boodlea*, *Bryopsis*, *Chlorodesmis*, *Caulerpa*, *Dicotyota*, *Dictosphyrea*,

[1] *Porites* species were further divided into *Porites*, *Porites-rus* and *Porites*-massive categories.

Galaxura, *Halimeda*, *Liagora*, *Lobophora*, *Mastophora*, *Microdictyton*, *Neomeris*, *Padina*, *Sargassum*, *Schizothrix*, *Turbinaria*, *Tydemania*, *Ulva* and *Other macroalgae* (other macroalgae not included in this list);

4. Branching coralline algae – *Amphiroa*, *Jania*, *Branching coralline general*;
5. Crustose coralline algae;
6. Fleshy coralline algae;
7. Turf algae;
8. Seagrass – sum of seagrass genera *Enhalus*, *Halodule*, *Halophila*, *Syringodium*, *Thalassia*, *Thalassodendron*;
9. Chrysophytes;
10. Sand – 0.1 mm < hard particles < 30 mm;
11. Rubble – carbonated structures of heterogeneous sizes, broken and removed from their original locations; and
12. Pavement.

In addition, the status of corals (live, recently dead or bleached) was noted for each coral genera data point. Recently dead coral was defined as coral with newly exposed white skeletons with visible corallites and no polyps present, while bleached coral was defined as white coral with polyps still present. Resulting data were then summarized as percentages and extracted to MS Excel. To assess broad-scale patterns in benthic habitat among sites and habitats, principle component analysis (PCA) was conducted on log(x+1) transformed mean percent cover values of each major substrate category, using Primer 6. To explore differences among sites and habitats, coverage data of each major benthic category in each individual transect were square-root transformed to reduce heterogeneity of variances and analysed by two-way analysis of variance (ANOVA) using Statistica 7.1, with site (Fongafale and FCA) and habitat (reef flat, back-reef and outer-reef) as fixed factors in the analysis. Tukey-Kramer post-hoc pairwise tests were used to identify specific differences between factors at $P = 0.05$. Where transformed data failed Cochran's test for homogeneity of variances ($P < 0.05$), an increased level of significance of $P = 0.01$ was used. Summary graphs of mean percentage cover (± SE) were generated to further explore patterns of each major substrate category by habitat.

Results

Survey coverage

A total of 35 benthic habitat assessment transects were completed across the reef flat, back- and outer-reef habitats of Funafuti Atoll, with 18 transects completed at Fongafale and 17 completed within the FCA (Figure 8). One transect within the reef-flat of the FCA site could not be completed due to strong currents. A list of GPS positions for each benthic habitat assessment transect is presented as Appendix 1.

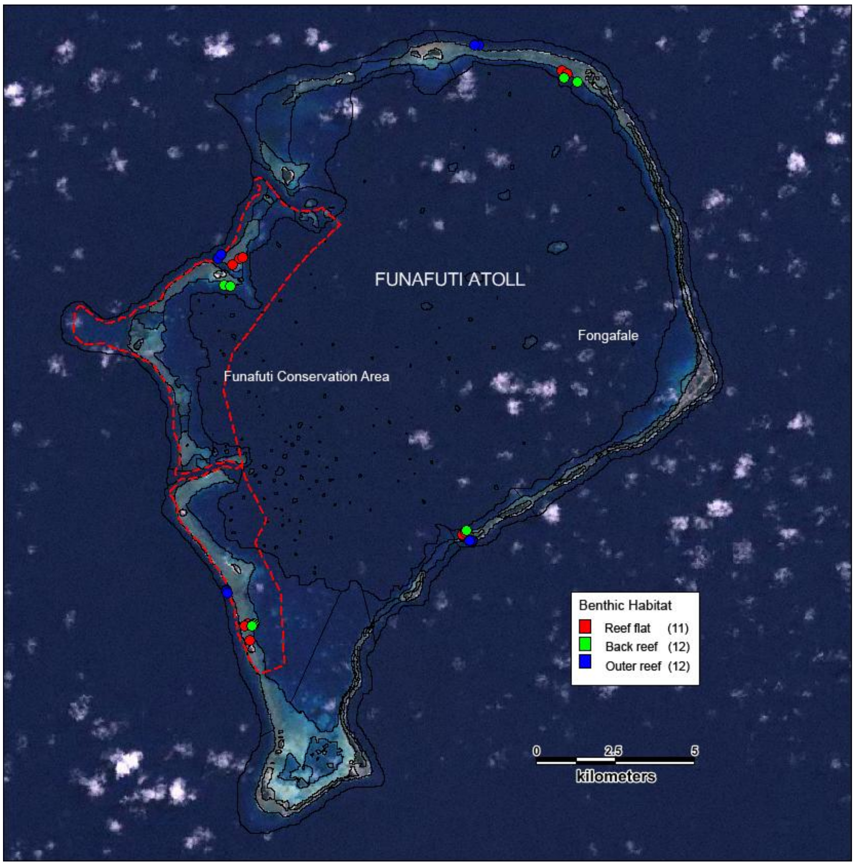

Figure 8 **Location of benthic habitat assessment stations established in Funafuti Atoll, 2011.**

Table 8 **Summary of benthic habitat assessment transects within the Fongafale and FCA monitoring sites, 2011.**

Site	Station	Habitat	No. of transects
Fongafale	Fongafale 1	Reef flat	3
		Back-reef	3
		Outer-reef	3
	Fongafale 2	Reef flat	3
		Back-reef	3
		Outer-reef	3
FCA	FCA 1	Reef flat	3
		Back-reef	3
		Outer-reef	3
	FCA 2	Reef flat	2
		Back-reef	3
		Outer-reef	3

Reef flat habitats

Reef flat habitats of Fongafale were typically characterised by high percent cover of turf algae and rubble, while those of the FCA were characterised by high cover of sand (Figure 9; Figure 10). Among sites, the cover of sand was significantly higher within the reef flat habitats of the FCA compared to Fongafale ($P < 0.001$), while the cover of turf algae was significantly higher within the reef flat habitats of Fongafale ($P = 0.010$) (Figure 10).

Hard coral diversity was low on the reef flat habitats of both sites, with two genera (*Acropora* and *Montipora*) observed at the Fongafale site, and seven genera (*Acropora*, *Cyphastrea*, *Favia*, *Leptastrea*, *Oulophyllia*, *Pocillopora* and *Porites*) observed at the FCA site (Figure 10). Hard coral cover was relatively low at both sites; with hard corals constituting 24.3±6.6% and 6.0±3.0% of overall cover at the Fongafale and FCA sites, respectively, and did differ significantly among sites (Figure 10). *Acropora* was the most common coral of the reef flat habitats within the Fongafale site, representing 24.2±6.6% of overall cover, respectively, while *Porites*-massive and *Acropora* were the most common coral types of the FCA site, representing 3.9±2.4% and 1.6±1.4% of overall cover, respectively (Figure 10). The cover of bleached corals was low at the Fongafale site (0.1±0.1%) while no bleached corals were observed in the reef flat habitats of the FCA site. No recently dead corals were observed on the reef flat habitats of the Fongafale site, while the percentage cover of recently dead corals at the FCA site was low (0.1±0.1%).

The cover of macroalgae on reef flat habitats of both sites was relatively low. *Lobophora*, *Halimeda*, *Caulerpa* and *Ulva* were the most common macroalgae at Fongafale, while *Halimeda* was the most common macroalgae at the FCA (Figure 12).

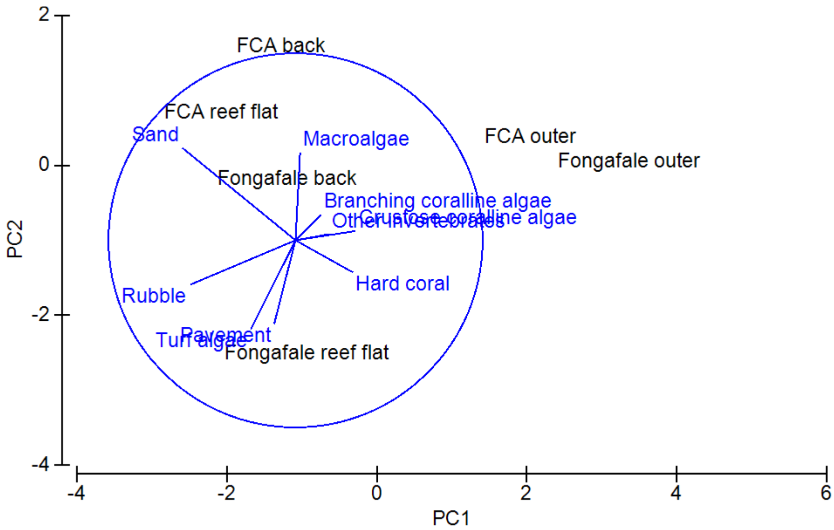

Figure 9 **Principle Component Analysis (PCA) of each major benthic substrate category for each site and habitat. Sites separate along a gradient of hard coral versus sand and rubble (PC1) and turf algae versus macroalgae (PC2).**

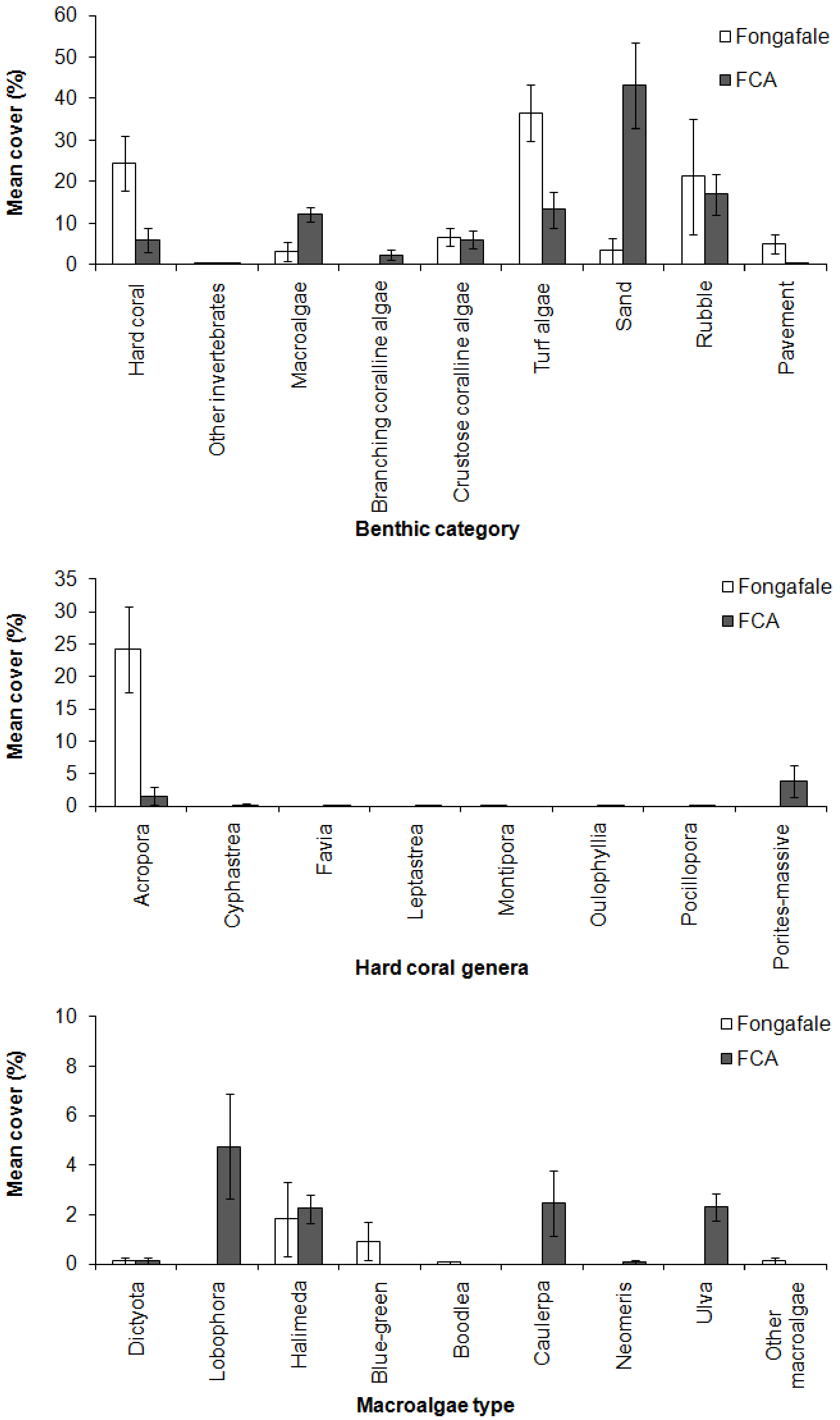

Figure 10 **Mean cover (± SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at reef flat habitats during benthic habitat assessments at Fongafale and FCA monitoring sites, 2011.**

Back-reef habitats

Back-reef habitats of the Fongafale and FCA monitoring stations were largely similar to reef-flat habitats, with back-reefs at Fongafale stations characterised by a high percent cover of turf algae and those at the FCA characterised by a high percent cover of sand. Back-reefs of the Fongafale stations had a significantly higher mean percent cover of turf algae (34.4±4.1% vs. 3.7±0.8%; $P < 0.001$), than the back-reefs at the FCA stations (Figure 11).

As with reef flat habitats, hard coral diversity on the back-reef habitats of both sites was low, with two genera (*Acropora* and *Porites*) observed at the Fongafale stations and six genera (*Acropora*, *Cyphastrea*, *Favia*, *Fungia*, *Leptastrea* and *Porites*) observed at the FCA site (Figure 11). Hard coral cover was largely similar to that observed at reef-flat habitats, with hard corals constituting 23.2±4.1% and 12.9±4.9% of overall cover at the Fongafale and FCA sites, respectively. In terms of cover, *Acropora* was the most common genera at the back-reef habitats of both sites, representing 23.1±4.1% and 8.8±5.7% of overall cover at the Fongafale and FCA sites, respectively (Figure 11). The percent cover of bleached corals was low within the Fongafale stations (0.1±0.1%), while no bleached corals were observed in the back-reef habitats of the FCA stations. The percentage cover of recently dead corals at both sites was low, constituting 2.1±0.9% and 0.2±0.2% of overall mean cover of hard corals at the Fongafale and FCA sites, respectively.

The cover of macroalgae on back-reef habitats was moderate, representing 17.0±4.1% overall cover at the Fongafale site, and 31.6±14.2% of overall cover at the FCA site (Figure 11). *Halimeda* was the most common macroalgae within the back-reef habitats of Fongafale monitoring stations, representing 16.9±4.2% of the total cover, while *Lobophora* was the most common macroalgae within the FCA monitoring stations representing 25.2±13.7% of the total cover.

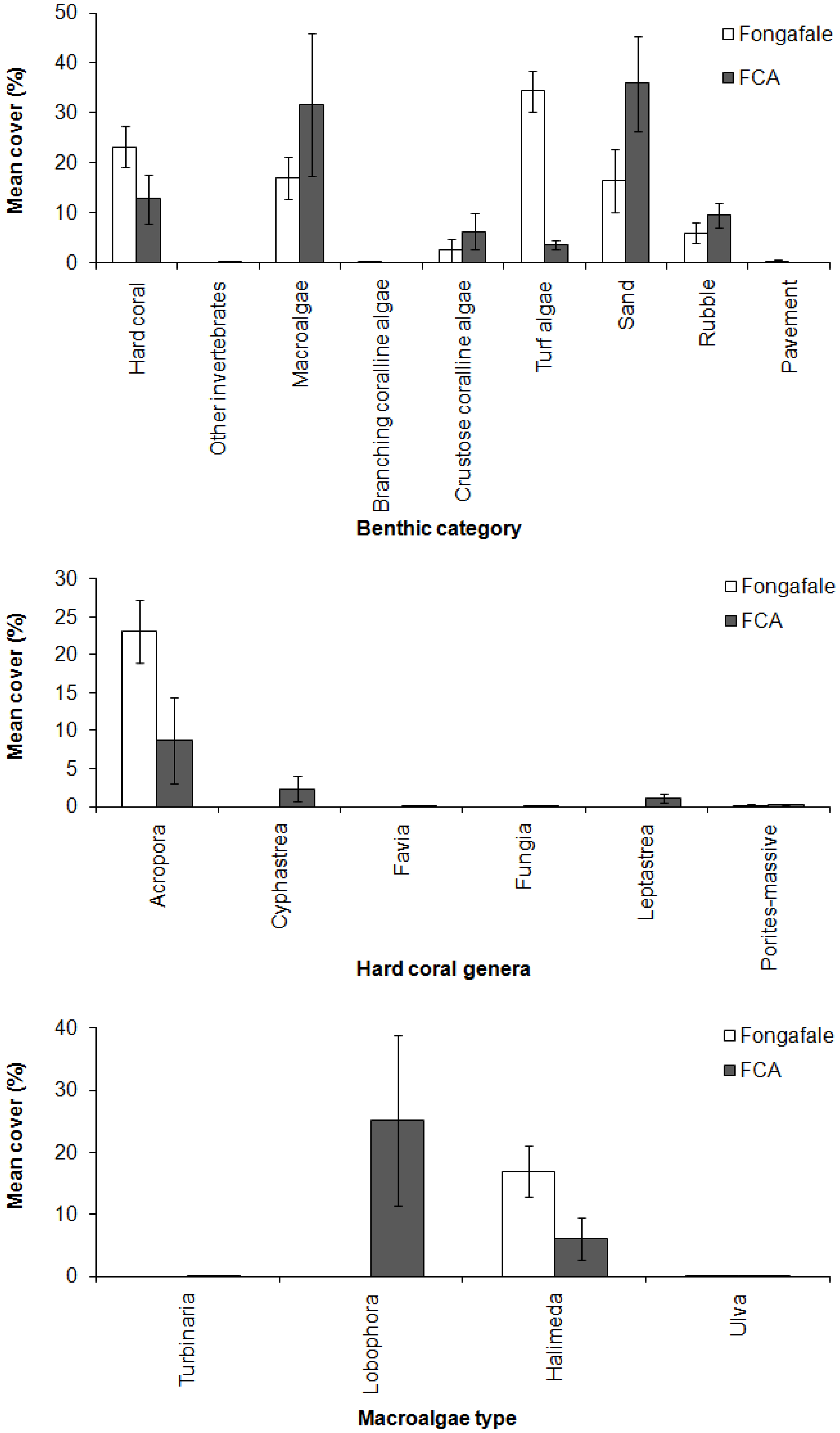

Figure 11 **Mean cover (± SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at back-reef habitats during benthic habitat assessments at Fongafale and FCA monitoring sites, 2011.**

Outer-reef habitats

Outer-reef habitats of both the Fongafale and FCA monitoring stations differed from the reef flat and back-reef habitats by a relatively high percent cover of hard coral and crustose coralline algae (Figure 9). Hard corals were the dominant substrate category of both the Fongafale and FCA stations, constituting 56.3±5.7% of overall cover at Fongafale stations and 41.4±4.8% of overall cover within the FCA stations. A total of 13 types of hard coral were recorded on the outer-reef habitat of the Fongafale monitoring stations, while 23 types were recorded within the outer-reefs of the FCA stations (Figure 12). In terms of cover, *Acropora* was the most common genera within the outer-reefs of the Fongafale stations, representing 43.0±9.4% of overall cover, while *Favia, Acropora. Montipora* and *Pocillopora* were the most common coral genera on the outer-reef of the FCA site, representing 7.6±1.8%, 7.0±0.8%, 6.7±1.8% and 4.9±1.3% of overall cover at this site, respectively (Figure 12). No bleached coral was observed on the outer-reefs of the Fongafale stations, while the cover of bleached corals was low at the FCA stations (0.1±0.1%). The percentage cover of recently dead corals was low at both sites, constituting 0.3±0.2% and 0.1±0.l% of the overall mean cover of hard corals at the Fongafale and FCA sites, respectively.

For macroalgae, *Halimeda* had the highest percent cover within the outer-reef habitats of Fongafale monitoring stations, representing 12.0±3.9% of the total cover, while *Lobophora* had the highest percent cover within the FCA monitoring stations, representing 9.2±3.1% of the total cover (Figure 12).

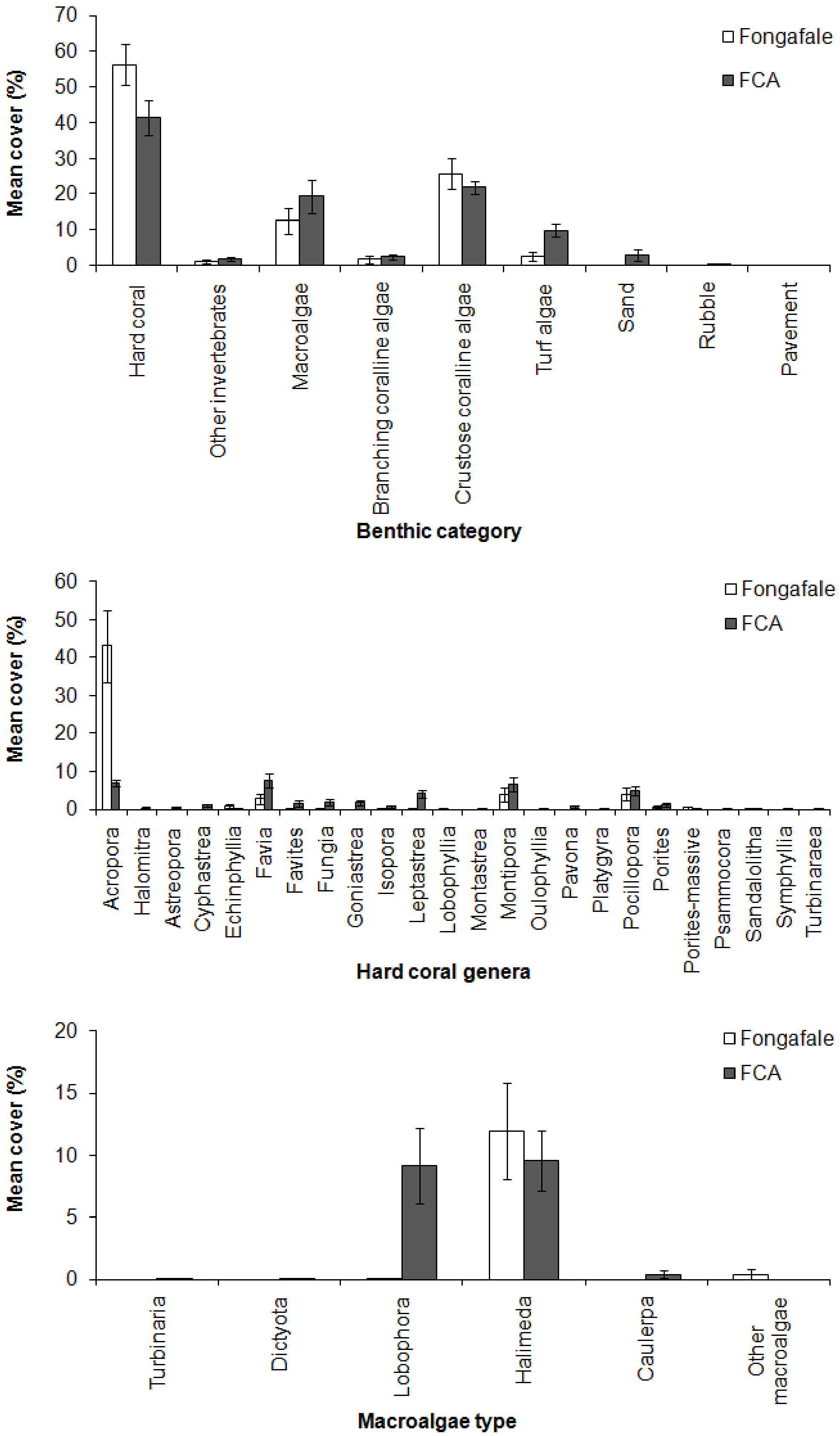

Figure 12 **Mean cover (± SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at outer-reef habitats during benthic habitat assessments at Fongafale and FCA monitoring sites, 2011.**

5. Finfish surveys

Methods and Materials

Data collection

Finfish surveys

Fish on reef habitats of Funafuti Atoll were surveyed using distance-sampling underwater visual census (D-UVC) techniques. As per the benthic habitat assessments, three replicate 50 m transects were planned to be surveyed in the reef flat, back-reef and outer-reef habitats at each of two stations within the Fongafale and FCA monitoring sites (Figure 7; Figure 13). Each transect census was completed by two SCUBA divers who recorded the species name, abundance and total length (TL) of all fish observed (Appendix 2). The distance of the fish from the transect line was also recorded. Two distance measurements were recorded for a school of fish belonging to the same species and size (the distance from the transect tape to the nearest individual (D1) and the distance from the transect tape to the furthest individual (D2); Figure 13), while for individual fish only one distance was recorded (D1). Regular review of identification books and cross-checks between divers after the dive ensured that accurate and consistent data were collected.

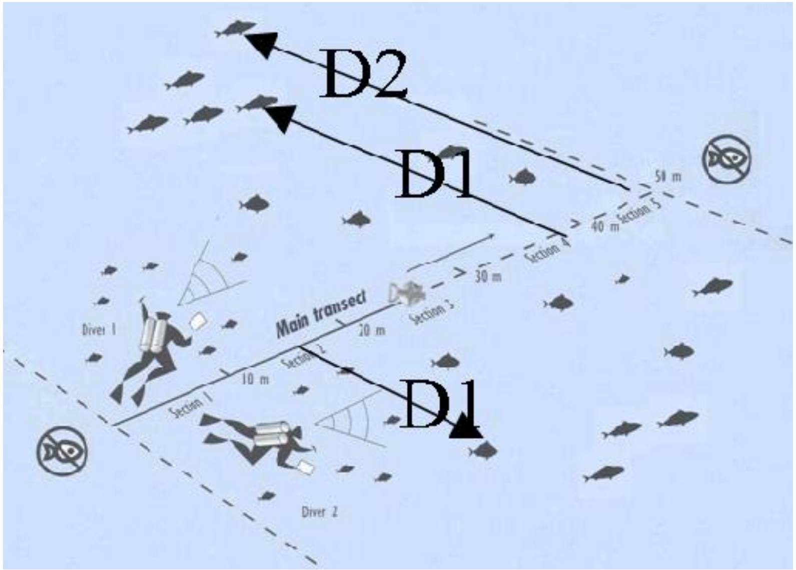

Figure 13 Diagram portraying the D-UVC method.

Habitats supporting finfish

Habitats supporting finfish were documented after the finfish survey using a modified version of the medium scale approach of Clua et al (2006). This component uses a separate form (Appendix 3) from that of the finfish assessment, consisting of information on depth, habitat complexity, oceanic influence and an array of substrate parameters (percentage coverage of certain substrate type) within five 10 x 10 m quadrats (one for each 10 m of transect) on each side of the 50 m transect.

The substrate types were grouped into the following six categories:

1. Soft substrate (% cover) — sum of substrate components *silt* (sediment particles < 0.1 mainly on covering other substrate types like coral and algae), *mud*, and *sand* and *gravel* (0.1 mm < hard particles < 30 mm);
2. Hard substrate (% cover) — sum of hard substrate categories including *hard coral status* and hard *abiotic*;
3. Abiotic (% cover) — sum of substrate components *rocky substratum* (slab) (flat rock with no relief), *silt*, *mud*, *sand*, *rubbles* (carbonated structures of heterogeneous sizes, broken and removed from their original locations), *gravels and small boulders* (< 30 cm), *large boulders* (< 1m) and *rocks* (> 1m);
4. Hard corals status (% cover) – sum of substrate components *live coral*, *bleaching coral* (dead white corals) and *long dead algae covered coral* (dead carbonated edifices that are still in place and retain a general coral shape covered in algae);
5. Hard coral growth form (% cover) — sum of substrate component live coral consisting of *encrusting coral*, *massive coral*, *sub-massive coral*, *digitate coral*, *branching coral*, *foliose coral* and *tabulate coral*;
6. Others – % cover of *soft coral*, *sponge*, *plants and algae*, *silt covering coral* and *cyanophycae* (blue-green algae). The *plants and algae* category is divided into *macroalge*, *turf algae*, *calcareous algae*, *encrusting algae* (crustose coralline algae) and *seagrass* components.

Data analysis

Finfish surveys

In this report, the status of finfish resources has been characterised using the following parameters:

1) richness – the number of families, genera and species counted in D-UVC transects;
2) diversity – total number of observed species per habitat and site divided by the number of transects conducted in each individual habitat and site;
3) community structure – overall mean density and biomass compared among habitats and sites (based on all observations within 5 m from the transect line);
4) mean density (fish/m^2) – estimated from fish abundance in D-UVC, calculated at both a family, trophic group and individual species level;
5) mean biomass (g/m^2) – obtained by combining densities, size, and weight–size ratios, calculated at both a family, trophic group and individual species level;
6) weighted mean size (cm total length) – direct record of fish size by D-UVC, calculated at both a family, trophic group and individual species level;
7) weighted mean size ratio (%) – the ratio between fish size and maximum reported size of the species, calculated at both a family, trophic group and individual species level. This ratio can range from nearly zero when fish are very small to 100% when a given fish has reached the maximum size reported for the species;

8) trophic structure – density, size and biomass of trophic groups compared among habitats and sites. Trophic groups were based on accounts from published literature. Each species was classified into one of five broad trophic groups: 1) carnivore (feed predominantly on zoobenthos), 2) herbivore (feed predominantly on plants and algae), 3) piscivore (feed predominantly on nekton, other fish and cephalopods), 4) planktivore (feed predominantly on zooplankton), and 5) detritivore (feeding predominantly on detritus. More details on fish diet can be found online at: http://www.fishbase.org/manual/english/FishbaseThe_FOOD_ITEMS_Table.htm.

To account for differences in visibility among sites and habitats, only fish recorded within five metres of the transect line were included in the analysis. While all observed finfish species were recorded, including both commercial and non-commercial species, for the purposes of this report, results of analyses of density, biomass, size, size ratio, and trophic structure are presented based on data for 18 selected families, namely Acanthuridae, Balistidae, Chaetodontidae, Ephippidae, Haemulidae, Holocentridae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Mullidae, Nemipteridae, Pomacanthidae, Pomacentridae, Scaridae, Serranidae, Siganidae and Zanclidae. These families were selected as they comprise the dominant finfish families of tropical reefs (and are thus most likely to indicate changes where they occur), and constitute species with a wide variety of trophic and habitat requirements. Other families abundant on reefs, such as Blenniidae and Gobiidae, were not analysed due to the difficulties in enumerating these cryptic species.

Given the baseline nature of this report, relationships between environmental parameters and finfish resources have not been fully explored. Rather, the finfish resources are described and compared amongst habitats within sites and between the Fongafale and FCA sites. To explore differences among sites and reef environments, habitat category data and density, biomass, mean size and mean size ratio data of each of the 18 indicator families and five trophic groups in each individual transect were square-root transformed to reduce heterogeneity of variances and analysed by two-way analysis of variance (ANOVA) using Statistica 7.1, with site (Fongafale and FCA) and habitat (back-reef, lagoon-reef, and outer-reef) as fixed factors in the analysis. Tukey-Kramer post-hoc pairwise tests were used to identify specific differences between factors at $P = 0.05$. Where transformed data failed Cochran's test for homogeneity of variances ($P < 0.05$), an increased level of significance of $P = 0.01$ was used. Additionally, family-specific density and biomass data from both the Fongafale and FCA sites were combined and compared against those collected during the PROCFish surveys in Funafuti Atoll in 2004–2005 (Sauni et al. 2008) for back- and outer-reef habitats using one-way ANOVA. While the PROCFish project collected data relating to species of interest to fisheries only, precluding comparisons of overall density and biomass and comparisons among trophic groups against the current study, data of commonly recorded families (Acanthuridae, Balistidae, Chaetodontidae, Holocentridae, Kyphosidae, Lethrinidae, Lutjanidae, Mullidae, Nemipteridae, Scaridae, Siganidae and Zanclidae) can nevertheless be compared, providing an important starting point from which to explore changes over time.

Results

Coverage

A total of 35 D-UVC transects were completed during the baseline monitoring program, with 17 transects completed in the Fongafale site and 18 transects completed in the FCA (Figure 14; Table 9). GPS coordinates for each D-UVC transect is presented as Appendix 4.

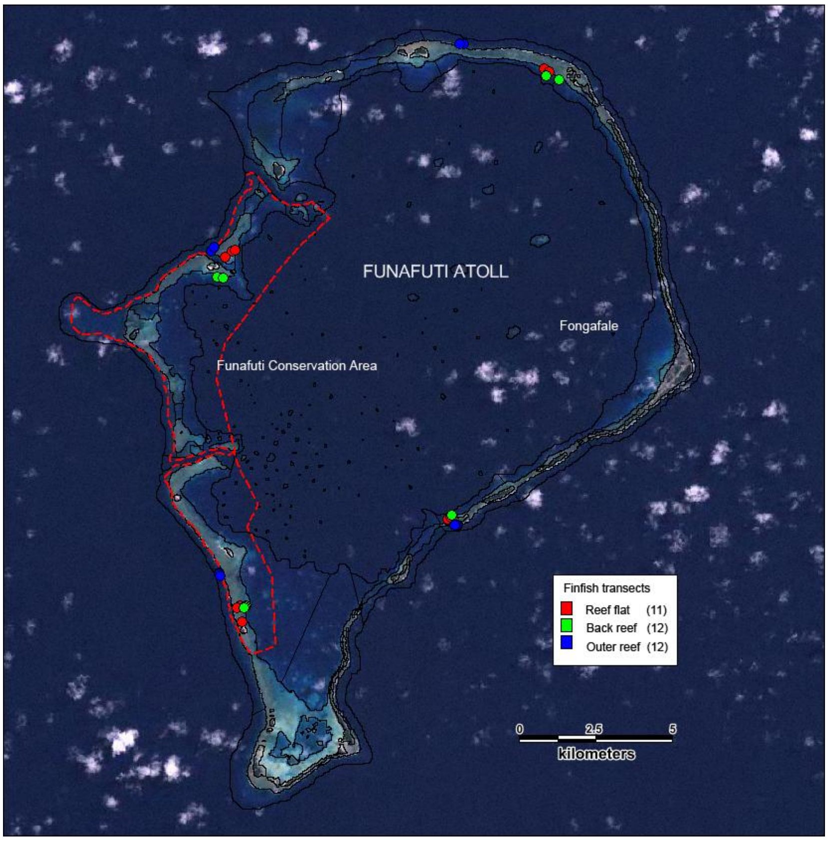

Figure 14 **Location of finfish assessment stations established in Funafuti Atoll, 2011.**

Table 9 **Summary of distance underwater visual census (D-UVC) transects among habitats for the Fongafale and FCA monitoring sites.**

Site	Station	Habitat	No. of transects
Fongafale	Fongafale 1	Reef flat	3
		Back-reef	3
		Outer-reef	3
	Fongafale 2	Reef flat	3
		Back-reef	3
		Outer-reef	3
FCA	FCA 1	Reef flat	3
		Back-reef	3
		Outer-reef	3
	FCA 2	Reef flat	2
		Back-reef	3
		Outer-reef	3

Finfish surveys

Overall

A total of 23 families, 69 genera, 197 species and 11,319 individual fish were recorded from the 35 transects. Of these, 18 families, 54 genera, 144 species and 7,004 individual fish were recorded from the Fongafale monitoring stations, while 22 families, 59 genera, 144 species and 4,315 individual fish were recorded from the FCA monitoring stations (see Appendices 5–8 for a full list of families species recorded at both Fongafale and FCA sites). Finfish diversity was largely similar between the Fongafale and FCA sites (Table 10). Overall mean density and mean biomass at reef flat habitats were higher in Fongafale than the FCA, while no difference in overall mean density or mean biomass was observed between Fongafale and FCA for back-reef or outer-reef habitats (Figure 15; Figure 16). Within Fongafale, no difference was observed in overall mean density among the three habitats (Figure 15). Within the FCA stations, overall mean density was lower within reef flat habitats compared to back- or outer-reef habitats (Figure 15). Within the FCA stations, mean biomass was lower at reef flat habitats than back- or outer-reefs. At the Fongafale stations, overall mean biomass appeared lower in the back-reef compared to the outer-reef, however overall mean biomass of either habitat did not differ to reef flat sites (Figure 16).

Table 10 Total number of families, genera and species, and diversity of finfish observed at the reef-flat back- and outer-reef habitats of Fongafale and FCA monitoring sites, 2011.

Parameter	Reef flat		Back-reef		Outer-reef	
	Fongafale	FCA	Fongafale	FCA	Fongafale	FCA
No. of families	15	10	17	21	16	17
No. of genera	38	23	38	45	40	47
No. of species	82	53	88	94	88	100
Diversity	13.7	10.6	14.7	15.7	14.7	16.7

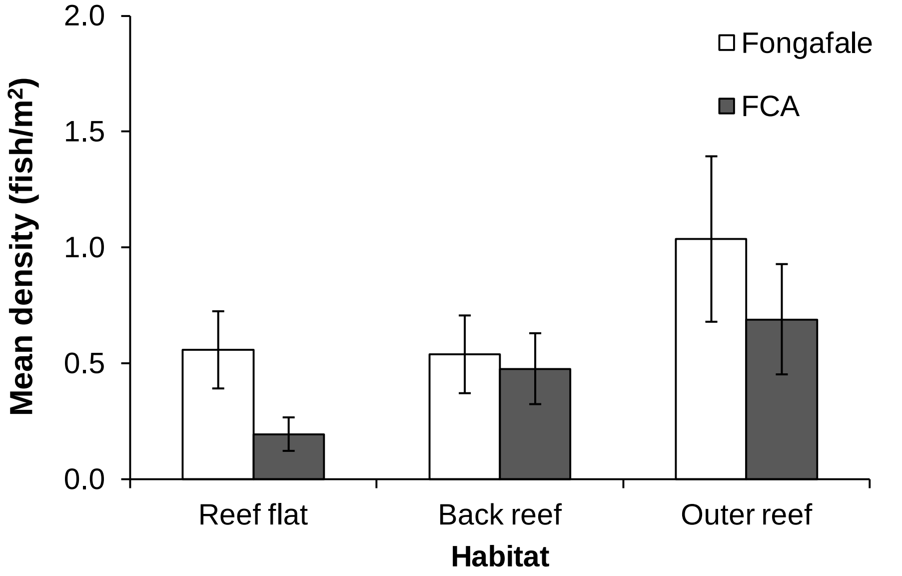

Figure 15 Overall mean density of finfish (± SE) within back-, lagoon and outer-reef habitats within the Fongafale and FCA monitoring sites, 2011.

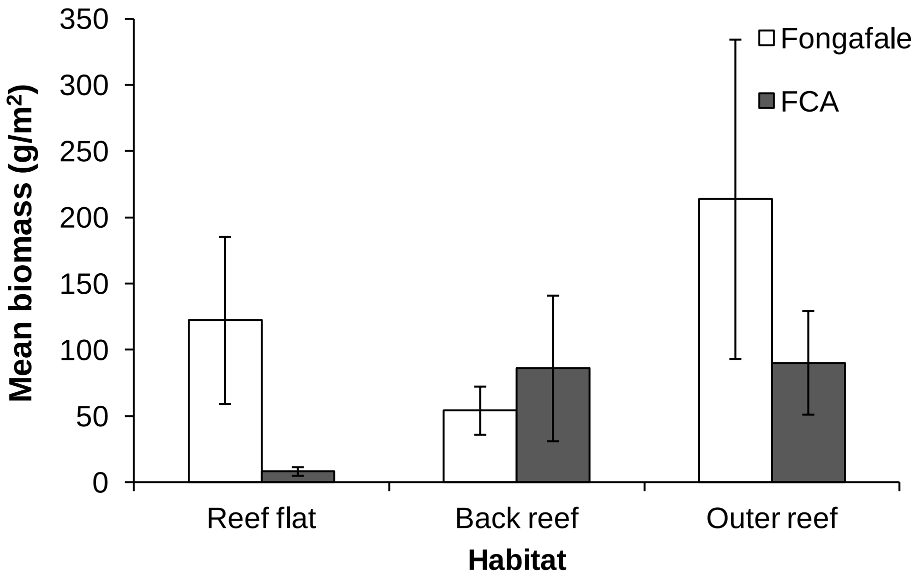

Figure 16 Overall mean biomass of finfish (± SE) within back-, lagoon and outer-reef habitats within the Fongafale and FCA monitoring sites, 2011.

Reef flat habitats

Habitats supporting finfish

Live hard coral cover of reef flat habitats was moderate at the Fongafale D-UVC stations, and low at the FCA stations (Figure 17). Of the corals present, branching coral was the most common growth form present at the Fongafale stations, while massive and encrusting corals were the most common growth forms at the FCA stations. No significant differences were observed in the depth, topography, or complexity where D-UVC transects were conducted on the reef flat habitats of the Fongafale of FCA stations (P = 0.05). Of the substrate categories, only the cover of sand, branching corals and tabulate corals differed among sites, with reef flats of FCA stations having a greater mean percent cover of sand than those at Fongafale (P = 0.046), and Fongafale stations having a greater mean percent cover of branching and tabulate corals than those of the FCA (P < 0.001 and P = 0.040, respectively) (Figure 17).

Finfish

A total of 15 families, 38 genera, 82 species and 1,947 individual fish were recorded from the reef flat habitats of the Fongafale monitoring stations, while 10 families, 23 genera, 53 species and 503 individuals were recorded from the reef flat habitats of the FCA monitoring stations. Of the 18 selected 'indicator' families, the family Acanthuridae occurred in the greatest mean density within the reef flat environments of the Fongafale stations, followed to a lesser extent by members of the families Scaridae, Pomacentridae, Chaetodontidae and Labridae. Similarly, for FCA monitoring stations, the family Acanthuridae occurred in the greatest mean density, followed by the families Pomacentridae, Mullidae, Labridae and Scaridae. For the Fongafale stations, these families comprised 46.7%, 22.9%, 14.3%, 5.3% and 4.6% of the total recorded biomass, respectively, while at the FCA stations these families comprised 34.1%, 20.0%, 12.2%, 9.8% and 9.7% of the overall recorded biomass, respectively. The mean density of Acanthuridae was significantly greater within Fongafale monitoring stations (0.26±0.05 fish/m^2) compared to the FCA (0.07±0.01 fish/m^2) (P = 0.016). No differences in mean density were observed for any other indicator family within reef flat habitats among sites. The species observed in the highest densities within the reef flat habitats of Fongafale site were the acanthurids *Acanthurus lineatus*, *Ctenochaetus striatus*, the scarids *Chlorurus sordidus* and *Scarus ghobban*, and the pomacentrid *Chromis viridis*. In contrast, the species observed in the highest densities within the reef flat habitats of the FCA site were the acanthurid *Acanthurus triostegus*, the pomacentrid *Chromis xanthura*, the labrid *Halichoeres trimaculatus* and the mullids *Mulloidichthys flavolineatus* and *Parupeneus multifasciatus* (Table 11). A full list of densities by family and individual species can be found in Appendices 5 to 8, respectively.

For reef flat habitats of the Fongafale stations, members of the Acanthuridae had the greatest biomass (75.88±35.12 g/m^2), comprising 62.1% of the total observed biomass, followed by members of the families Scaridae (24.8% of overall biomass), Mullidae (4.1% of total observed biomass), Labridae (2.6% of total observed biomass), Chaetodontidae (1.8% of total observed biomass) and Lethrinidae (1.6% of total observed biomass). Overall biomass at reef flat habitats of the FCA site was low. At this site, members of the Acanthuridae had the greatest biomass (2.78±0.68 g/m^2), comprising 34.1% of total observed biomass, followed by members of the families Scaridae (21.0% of total observed biomass), Mullidae (16.4% of total observed biomass), Serranidae (7.5% of total observed biomass), Pomacentridae (7.5% of total observed biomass), and Chaetodontidae (5.3% of total observed biomass). No significant differences in mean biomass were observed for any indicator family within reef flat habitats among the Fongafale and FCA sites. For individual species, the highest biomass observed within the reef flat habitats of Fongafale site were the acanthurids *Acanthurus lineatus, Ctenochaetus striatus* and *Naso lituratus* and the scarids *Scarus ghobban* and *Chlorurus sordidus.* In contrast, the species observed in the highest biomass within the reef flat habitats of the FCA site were again the acanthurids *Acanthurus triostegus* and *Acanthurus nigricans*, followed by the scarid *Scarus ghobban*, the serranid *Epinephelus merra* and the mullid *Parupeneus cyclostomus* (Table 12). A full list of biomass by family and individual species can be found in Appendices 5 to 8, respectively.

The mean size and mean size ratio of Acanthuridae, and mean size ratio of Labridae, were significantly higher in reef flat habitats of Fongafale stations than those within the FCA ($P < 0.05$) (Figure 18).

In terms of trophic group, herbivores (0.41±0.09 fish/m^2) occurred in the greatest mean density within the reef flat habitats of the Fongafale stations, followed by carnivores (0.08±0.06 fish/m^2). Similarly herbivores (0.10±0.02 fish/m^2) were the most common trophic group in terms of density within the FCA stations (Figure 19). Consistent with their relatively high density, herbivores (107.52±50.75 g/m^2) were the dominant trophic group in terms of biomass within the Fongafale stations. Mean density, biomass, size and size ratio of herbivores, and mean size ratio of carnivores, were significantly greater in the Fongafale stations than the FCA ($P < 0.05$) (Figure 19). The size ratio of all trophic groups was low (typically below 60% of average maximum values) for both the Fongafale and FCA stations (Figure 19).

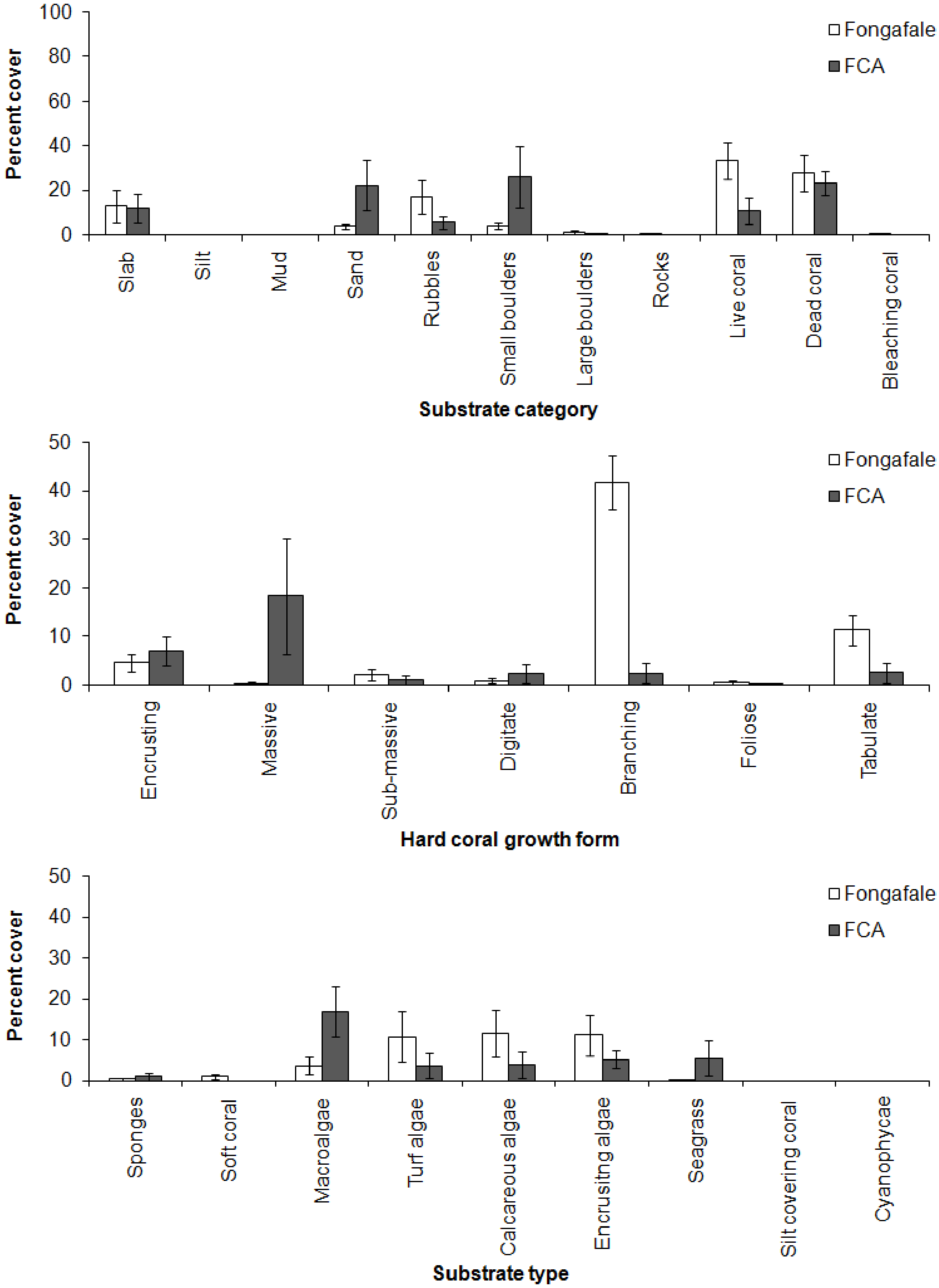

Figure 17 **Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate types (bottom) present at reef flat habitats during finfish surveys at the Fongafale and FCA monitoring sites, 2011.**

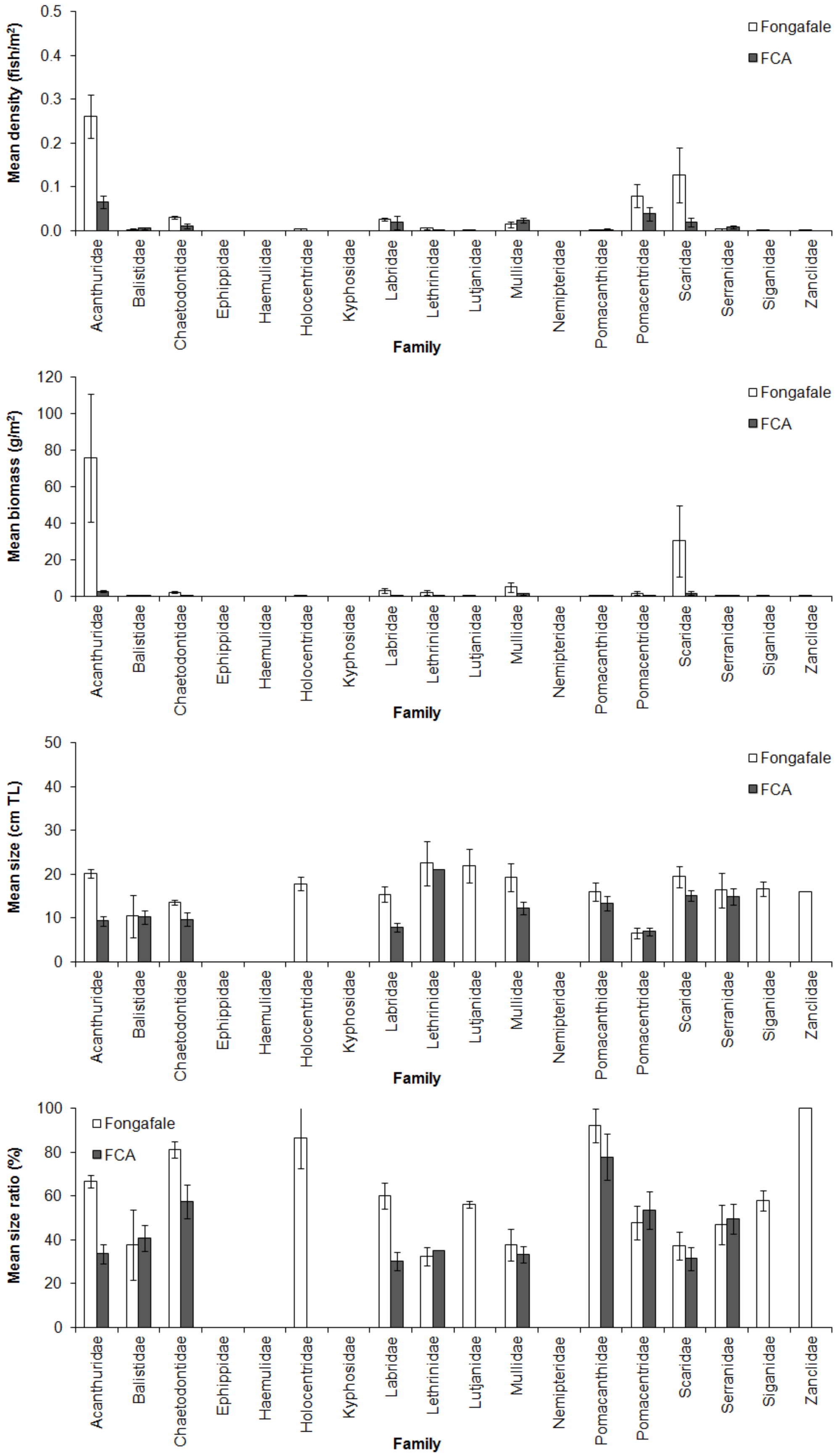

Figure 18 **Profile of finfish indicator families in reef flat habitats of the Fongafale and FCA monitoring sites, 2011.**

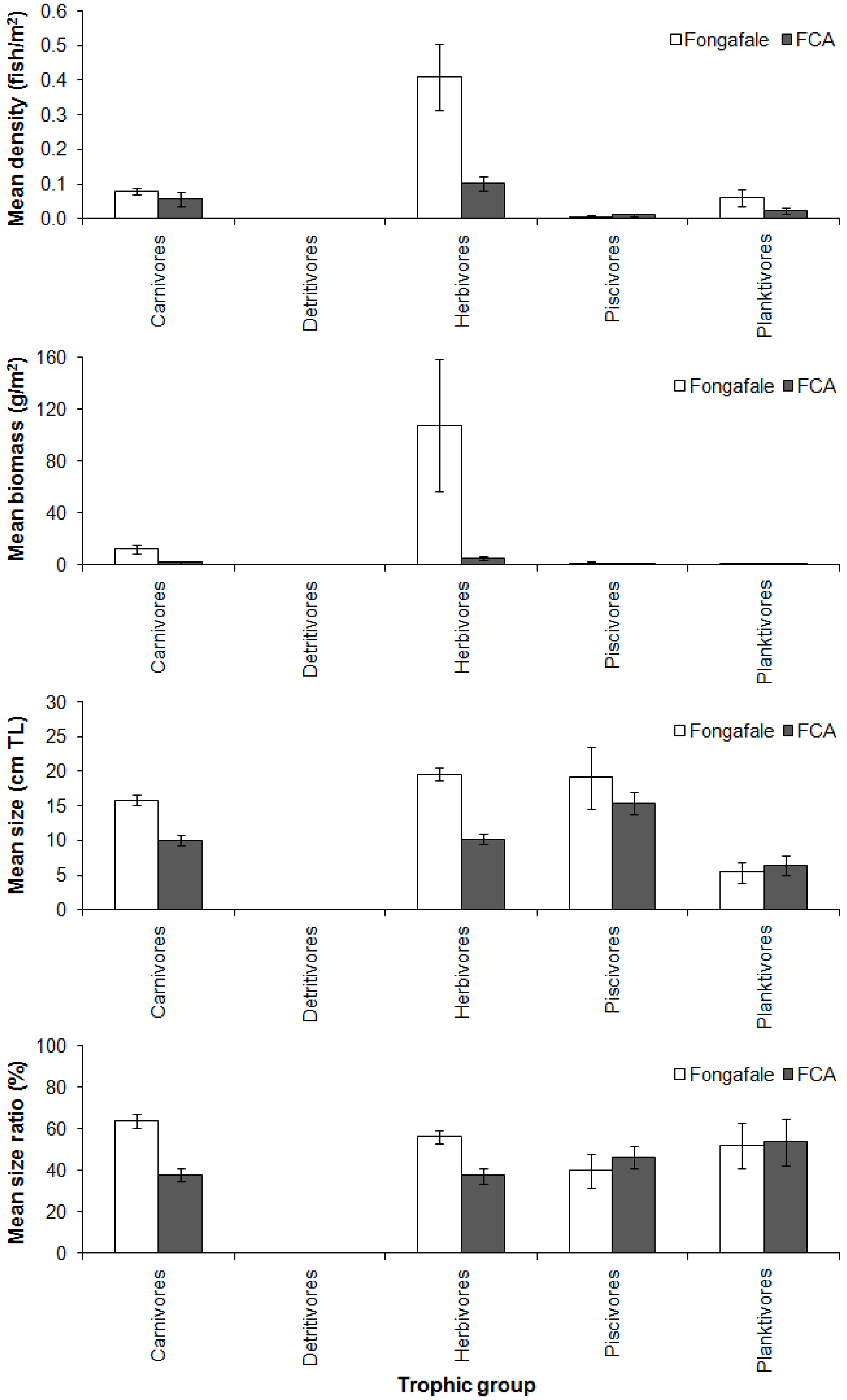

Figure 19 **Profile of finfish by trophic level in reef flat habitats of the Fongafale and FCA monitoring sites, 2011.**

Table 11 Finfish species observed in the highest densities in reef flat habitats of the Fongafale and FCA monitoring sites, 2011. See Appendix 7 and 8 for a full list of densities of individual fish species observed at each monitoring site.

Site	Species	Family	Density (fish/m^2±SE)
Fongafale	*Acanthurus lineatus*	Acanthuridae	0.08±0.04
	Ctenochaetus striatus	Acanthuridae	0.08±0.03
	Chlorurus sordidus	Scaridae	0.06±0.05
	Chromis viridis	Pomacentridae	0.04±0.02
	Scarus ghobban	Scaridae	0.04±0.03
FCA	*Acanthurus triostegus*	Acanthuridae	0.04±0.01
	Chromis xanthura	Pomacentridae	0.02±0.01
	Halichoeres trimaculatus	Labridae	0.01±0.01
	Mulloidichthys flavolineatus	Mullidae	0.01±0.01
	Parupeneus multifasciatus	Mullidae	0.01±0.00

Table 12 Finfish species with the highest biomass in reef flat habitats of the Fongafale and FCA monitoring sites, 2011. See Appendix 7 and 8 for a full list of biomass of individual fish species observed at each monitoring site.

Site	Species	Family	Biomass (g/m^2±SE)
Fongafale	*Acanthurus lineatus*	Acanthuridae	30.65±20.67
	Ctenochaetus striatus	Acanthuridae	20.47±11.02
	Scarus ghobban	Scaridae	18.91±17.02
	Naso lituratus	Acanthuridae	16.06±15.50
	Chlorurus sordidus	Scaridae	4.19±3.23
FCA	*Acanthurus triostegus*	Acanthuridae	1.09±0.36
	Scarus ghobban	Scaridae	0.74±0.53
	Acanthurus nigricans	Acanthuridae	0.57±0.53
	Epinephelus merra	Serranidae	0.47±0.20
	Parupeneus cyclostomus	Mullidae	0.44±0.37

Back-reef habitats

Habitats supporting finfish

Back-reef habitats of both the Fongafale and FCA monitoring sites were largely characterised by high cover of live and dead corals, and sand (Figure 20). Live and dead coral cover was higher at the back-reefs of Fongafale than the FCA (Figure 20). Branching coral was the most common growth form within the Fongafale stations, while branching, encrusting and massive corals were the most common growth forms at the FCA stations (Figure 20). No significant differences were observed in the depth, topography, or complexity of the D-UVC transects among the back-reef habitats of the Fongafale and FCA sites (P = 0.05). Of the substrate categories, only the cover of branching coral (P < 0.001) differed significantly among sites, with back-reefs at Fongafale stations having a greater percent cover compared to FCA stations (Figure 20).

Finfish

A total of 17 families, 38 genera, 88 species and 1,746 individuals were recorded from back-reef habitats of the Fongafale monitoring stations, while 21 families, 45 genera, 94 species and 1,446 individual fishes were recorded from back-reef habitats of the FCA monitoring stations (Table 10). For the Fongafale monitoring stations, the families Acanthuridae (0.11±0.02 fish/m^2, 21.2% of total recorded density), Scaridae (0.09±0.01 fish/m^2, 16.4%), Pomacentridae (0.07±0.03 fish/m^2, 12.9%) and Mullidae (0.07±0.03 fish/m^2, 12.9%) were observed in the highest densities, while the families Pomacentridae (0.14±0.02 fish/m^2, 29.3%), Acanthuridae (0.14±0.03 fish/m^2, 28.8%), Labridae (0.04±0.02 fish/m^2, 9.0%) and Mullidae (0.04±0.02 fish/m^2, 7.7%) were observed in the highest density within the FCA monitoring stations (Figure 21). No significant differences in mean density were observed for any of the 18 indicator families among back-reef habitats of the Fongafale and FCA stations (Figure 21). The species observed in the highest densities were the mullid *Mulloidichthys flavolineatus*, the acanthurid *Ctenochaetus striatus*, the pomacentrids *Chromis viridis* and *Chromis xanthura* and the scarid *Scarus ghobban* (Table 14). The species observed in the highest densities within the back-reef habitats of the FCA site were the pomacentrids *Chromis viridis* and *Chromis xanthura*, followed by the acanthurids *Ctenochaetus striatus* and *Acanthurus nigricans* and *Naso lituratus* (Table 14). A full list of densities by family and individual species can be found in Appendices 5–8, respectively.

For back-reef habitats of the Fongafale stations, members of the Acanthuridae had the greatest biomass (17.16±5.39 g/m^2), comprising 31.8% of the mean observed biomass at this site, followed by members of the families Scaridae (14.01±2.02 g/m^2, 25.9% of mean observed biomass), Lethrinidae (4.65±2.62 g/m^2) and Mullidae (4.29±1.72 g/m^2). Similarly, members of the Acanthuridae had the greatest biomass in back-reef habitats of the FCA monitoring stations (36.97±17.25 g/m^2), comprising 43.0% of mean observed biomass at this site, followed by Mullidae (6.65±5.57 g/m^2), Lethrinidae (6.22±3.91 g/m^2) and Scaridae (5.51±2.29 g/m^2). No significant differences in mean biomass were observed for any of the 18 indicator families among back-reef habitats of the Fongafale and FCA stations (Figure 21). The species that had the greatest biomass within the back-reef habitats of Fongafale stations were the acanthurids *Ctenochaetus striatus* and *Acanthurus gahhm*, the lethrinid *Monotaxis grandoculis* and the scarids *Scarus oviceps* and *Chlorurus sordidus* (Table 14). The species with the greatest biomass within the back-reef habitats of the FCA stations were the acanthurids *Naso lituratus*, *Naso unicornis* and *Ctenochaetus striatus*, the lethrinid *Monotaxis grandoculis* and the siganid *Siganus argentus* (Table 14). A full list of biomass by family and individual species can be found in Appendices 5–8.

No significant difference was observed in mean size or mean size ratio of any of the 18 indicator families at back-reef habitats among the Fongafale and FCA sites.

In terms of trophic group, herbivores occurred in the greatest mean density within the back-reef habitats of both the Fongafale and FCA monitoring sites, with 0.20±0.02 fish/m^2 and 0.22±0.04 fish/m^2, respectively. In terms of mean biomass, herbivores and carnivores were the dominant trophic groups within both the Fongafale and FCA sites (Figure 22). No significant differences in mean density, biomass, mean size or mean size ratio were observed among any trophic group among sites. As with reef flat habitats, the mean size ratio of all trophic groups was low (typically below 60% of average maximum values) for both the Fongafale and FCA stations (Figure 22).

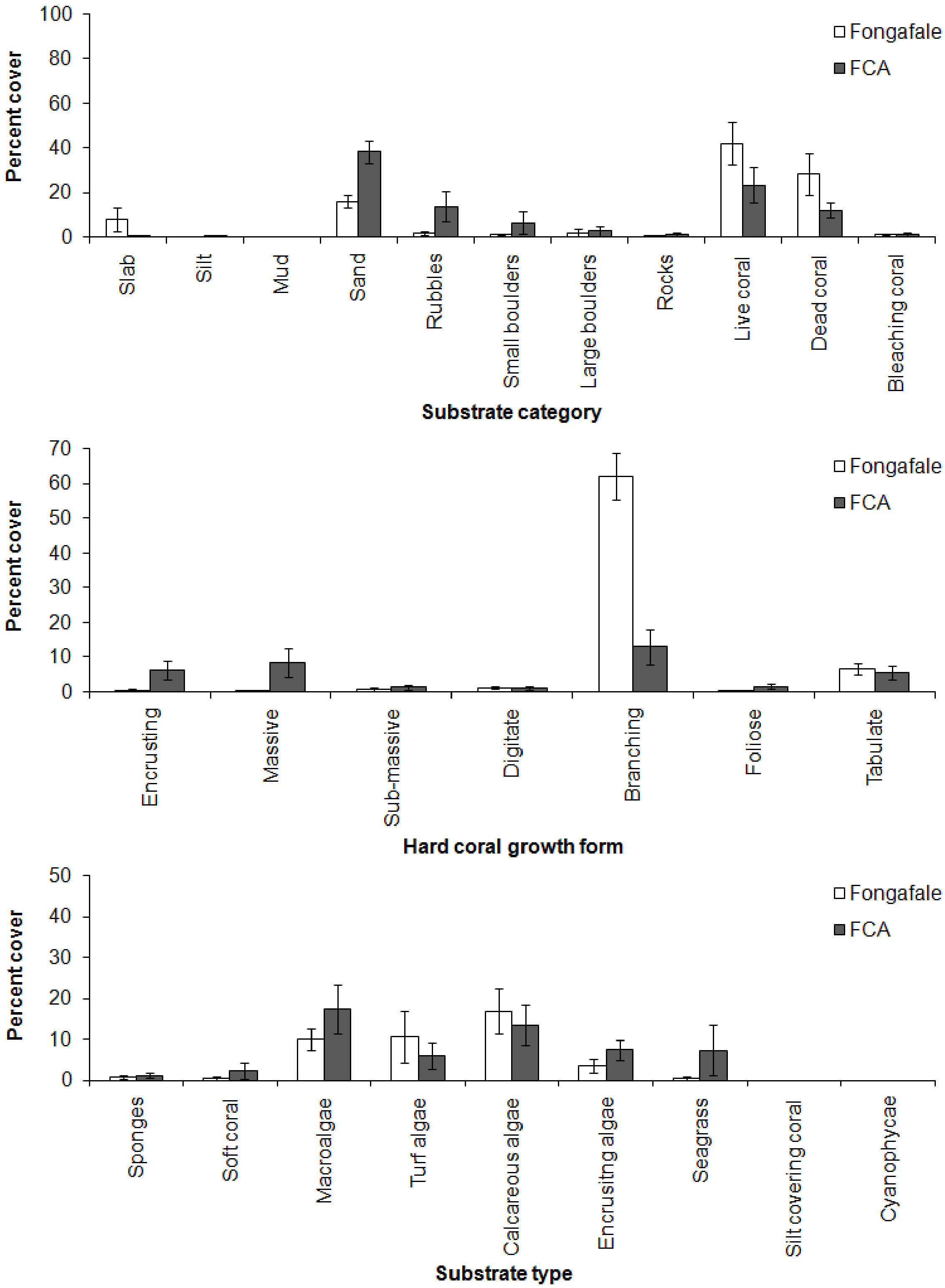

Figure 20 Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate type (bottom) present at back-reef habitats during finfish surveys at the Fongafale and FCA monitoring sites, 2011.

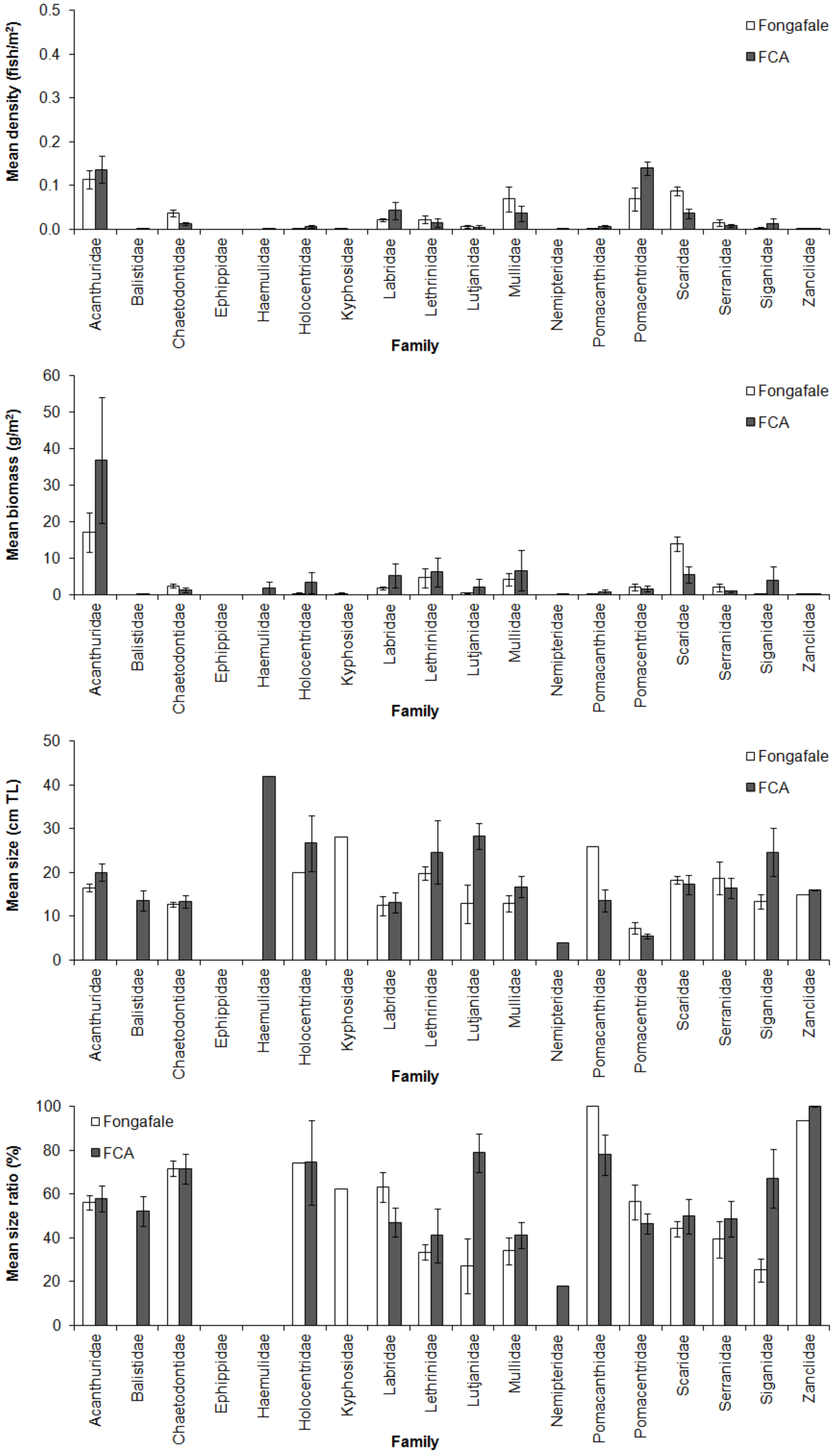

Figure 21 Profile of finfish indicator families in back-reef habitats of the Fongafale and FCA monitoring sites, 2011.

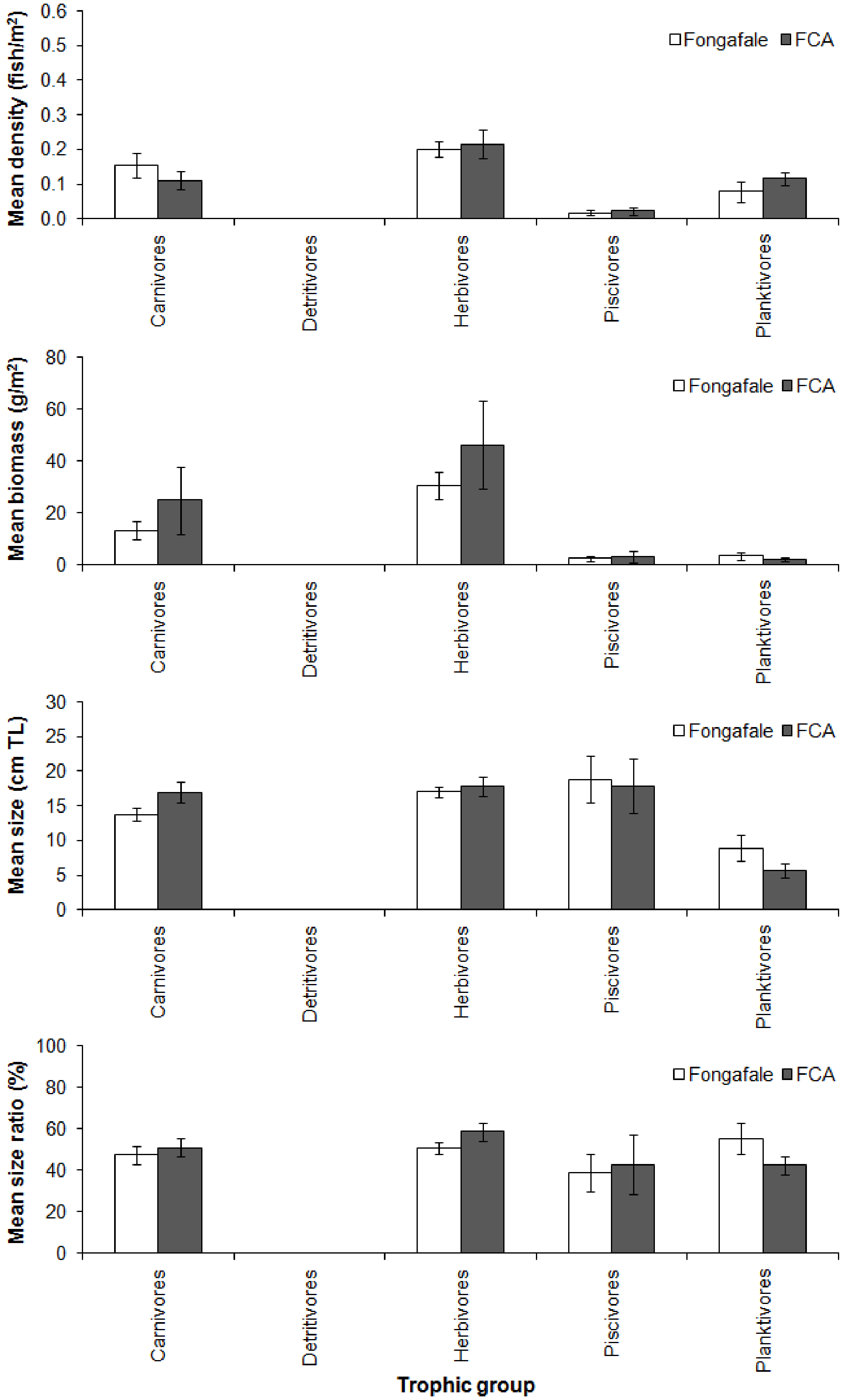

Figure 22 Profile of finfish by trophic level in back-reef habitats of the Fongafale and FCA monitoring sites, 2011.

Table 13 Finfish species observed in highest densities in back-reef habitats of the Fongafale and FCA monitoring sites, 2011. See Appendix 7 and 8 for a full list of densities of individual fish species observed at each monitoring site.

Site	Species	Family	Density (fish/m^2±SE)
Fongafale	*Mulloidichthys flavolineatus*	Mullidae	0.05±0.02
	Ctenochaetus striatus	Acanthuridae	0.04±0.01
	Chromis viridis	Pomacentridae	0.03±0.02
	Chromis xanthura	Pomacentridae	0.03±0.02
	Scarus ghobban	Scaridae	0.03±0.01
FCA	*Chromis viridis*	Pomacentridae	0.06±0.02
	Chromis xanthura	Pomacentridae	0.06±0.02
	Ctenochaetus striatus	Acanthuridae	0.03±0.01
	Acanthurus nigricans	Acanthuridae	0.02±0.01
	Naso lituratus	Acanthuridae	0.02±0.02

Table 14 Finfish species with the highest biomass in back-reef habitats of the Fongafale and FCA monitoring sites, 2011. See Appendix 7 and 8 for a full list of biomass of individual fish species observed at each monitoring site.

Site	Species	Family	Biomass (g/m^2±SE)
Fongafale	*Ctenochaetus striatus*	Acanthuridae	5.13±1.30
	Monotaxis grandoculis	Lethrinidae	4.40±2.69
	Scarus oviceps	Scaridae	3.47±0.86
	Acanthurus gahhm	Acanthuridae	3.17±2.68
	Chlorurus sordidus	Scaridae	3.08±2.04
FCA	*Naso lituratus*	Acanthuridae	16.41±15.10
	Monotaxis grandoculis	Lethrinidae	5.74±3.65
	Naso unicornis	Acanthuridae	4.94±4.94
	Ctenochaetus striatus	Acanthuridae	4.26±1.91
	Siganus argenteus	Siganidae	3.94±3.83

Comparisons with PROCFish surveys

Observed mean densities of Acanthuridae (P = 0.028), Chaetodontidae (P = 0.040) and Scaridae (P = 0.001) on back-reefs of Funafuti Atoll were signficantly higher during the PROCFish (2004–2005) surveys than the current (2011) survey (Figure 23). It should be noted that these surveys were not conducted at exactly the same locations, thus these results may be at least partially influenced by spatial differences in habitat cover or depth among survey locations. Further monitoring is required to determine whether these differences are consistent over time.

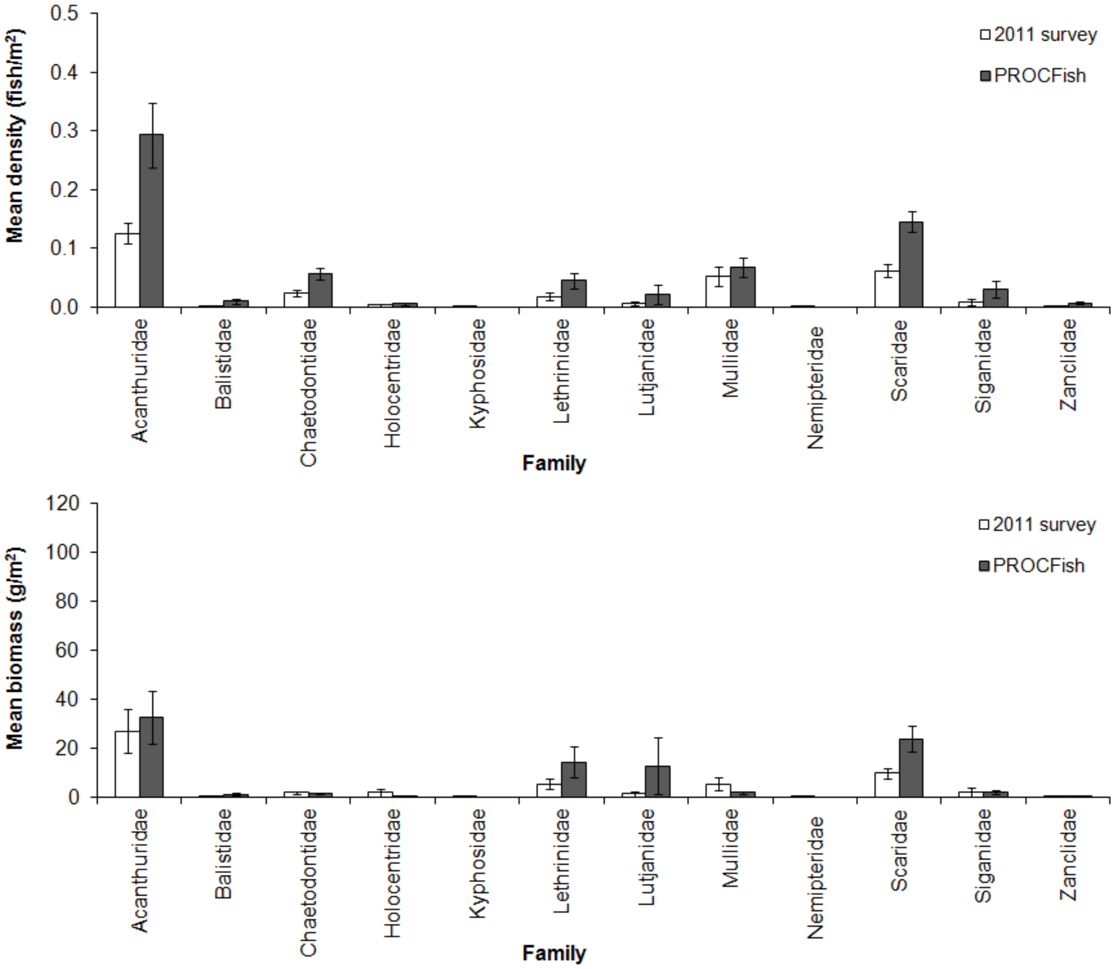

Figure 23 **Comparison of mean density (top) and biomass (bottom) (± SE) of families recorded from back-reef habitats of Funafuti Atoll in the current study (Fongafale and FCA sites combined) and during PROCFish surveys in 2004–2005.**

Outer-reef habitats

Habitats supporting finfish

Of the three habitat types, outer-reef habitats at both the Fongafale and FCA sites had the greatest mean percent cover of hard substrate, and consequently the lowest percent of soft substrate. Live hard coral cover was relatively high at both sites, representing 57.7±11.9% and 71.7±5.3% of overall cover at the Fongafale and FCA sites, respectively (Figure 24). Of the corals present, branching, encrusting and tabulate growth forms were the most common growth forms on the outer-reefs of both sites (Figure 24). No significant differences were observed in the depth, topography, or complexity or any substrate variable of the D-UVC transects among the outer-reefs of the Fongafale and FCA sites (Figure 24).

Finfish

A total of 16 families, 40 genera, 88 species and 3,311 individual fishes recorded from outer-reef habitats of the Fongafale monitoring stations, while 17 families, 47 genera, 100 species and 2,366 individual fishes were recorded from outer-reef habitats of the FCA monitoring stations (Table 10). Consistent with reef flat and back-reef habitats, members of the Pomacentridae and Acanthuridae occurred in the greatest densities at both the Fongafale and FCA sites (Figure 25). No significant differences in mean density were observed for any of the 18 indicator families among outer-reef habitats of the Fongafale and FCA stations (Figure 25). The species observed in the highest densities within the outer-reef habitats of Fongafale were the acanthurids *Acanthurus nigricans* and *Ctenochaetus striatus,* and pomacentrids *Chromis xanthura, Chromis margaritifer* and *Chromis viridis* (Table 15). The species observed in the highest densities within the outer-reef habitats of the FCA site were the pomacentrids *Chromis xanthura, Chromis margaritifera* and *Pomacentrus vaiuli,* and the acanthurids *Ctenochaetus striatus* and *Acanthurus nigricans* (Table 15). A full list of densities by family and individual species can be found in Appendices 5–8.

For outer-reef habitats of the Fongafale stations, members of the Acanthuridae had the greatest biomass (102.09±65.90 g/m^2, comprising 47.8% of the total biomass observed at this site), followed to a lesser extent by the families Scaridae (14.54±7.09 g/m^2, 6.8% of the total observed biomass), and Labridae (6.42±4.17 g/m^2, 3.0% of the total observed biomass). In the outer-reef habitats of the FCA monitoring stations, Acanthuridae had the greatest biomass (37.16±10.97 g/m^2, comprising 41.2% of total observed biomass at this site), followed by Lutjanidae (12.35±7.97 g/m^2, 13.7% of total observed biomass) and Scaridae (7.09±3.35 g/m^2, 9.5% of total observed biomass). No significant differences in mean biomass were evident for any of the 18 indicator families among back-reef habitats of the Fongafale and FCA stations (Figure 25). The individual species that occurred in the greatest biomass within the outer-reef habitats of Fongafale sites were the acanthurids

Naso caesius, *Acanthurus nigricans*, *Ctenochaetus striatus* and the scarids *Scarus rubroviolaceus* and *S. ghobban.* The species with the greatest biomass within the outer-reef habitats of FCA sites were the acanthurids *Ctenochaetus striatus, Naso unicornis* and *Naso caesius,* the lutjanid *Lutjanus gibbus* and the lethrinid *Monotaxis grandoculis* (Table 16). A full list of biomass by family and individual species can be found in Appendices 5–8.

No significant difference was observed in mean size or mean size ratio of any of the 18 indicator families at outer-reef habitats among the Fongafale and FCA sites.

Herbivores and planktivores occurred in the greatest mean density within the outer-reef habitats of the both the Fongafale and FCA stations (Figure 26). In terms of mean biomass, planktivores (71.24±64.95 g/m^2) and herbivores (49.59±14.41 g/m^2) were the dominant trophic groups within the Fongafale stations, while herbivores (37.20±8.77 g/m^2) and carnivores (25.35±9.59 g/m^2) had the greatest biomass within the FCA sites. No significant differences in mean density, biomass, mean size or mean size ratio were observed among any trophic group among sites. As with both the reef flat and back-reef habitats, the size ratio of most trophic groups was low relative to average maximum sizes for both the Fongafale and FCA stations, however the mean size ratio of piscivores in the outer-reef habitats of the FCA was relatively high (> 70%) (Figure 26).

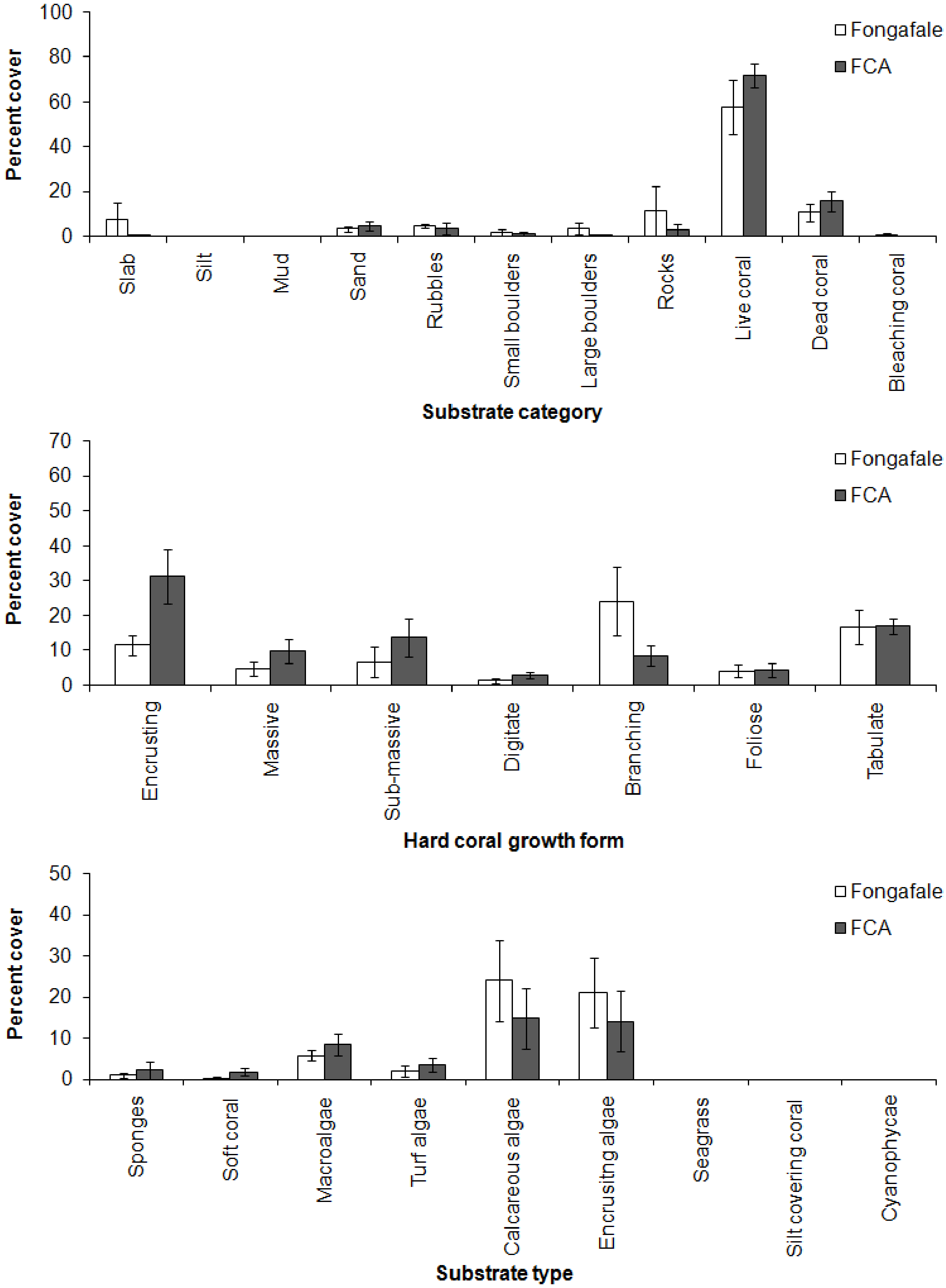

Figure 24 Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate type (bottom) present at outer-reef habitats during finfish surveys at the Fongafale and FCA monitoring sites, 2011.

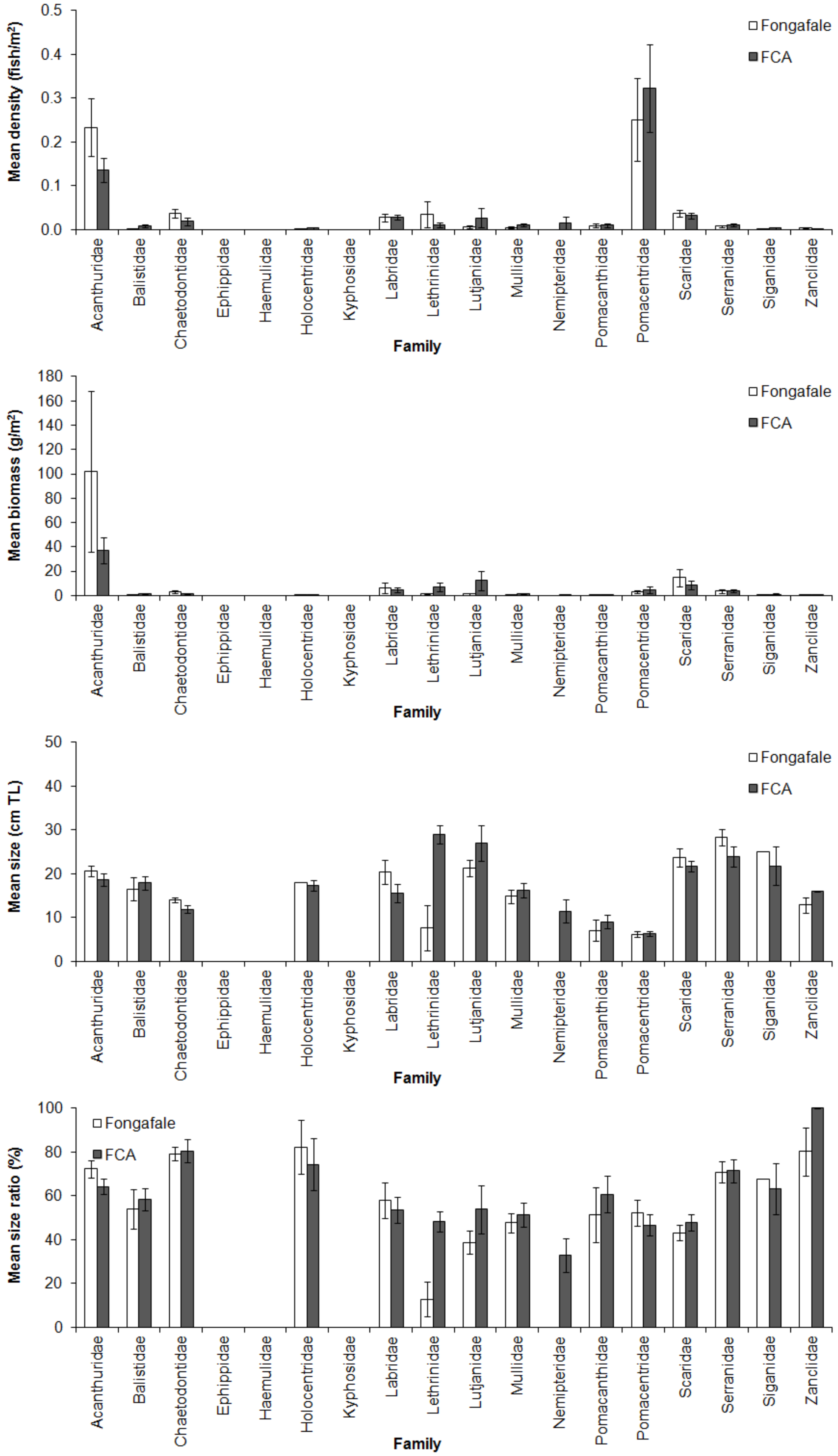

Figure 25 **Profile of finfish indicator families in outer-reef habitats of the Fongafale and FCA monitoring stations, 2011.**

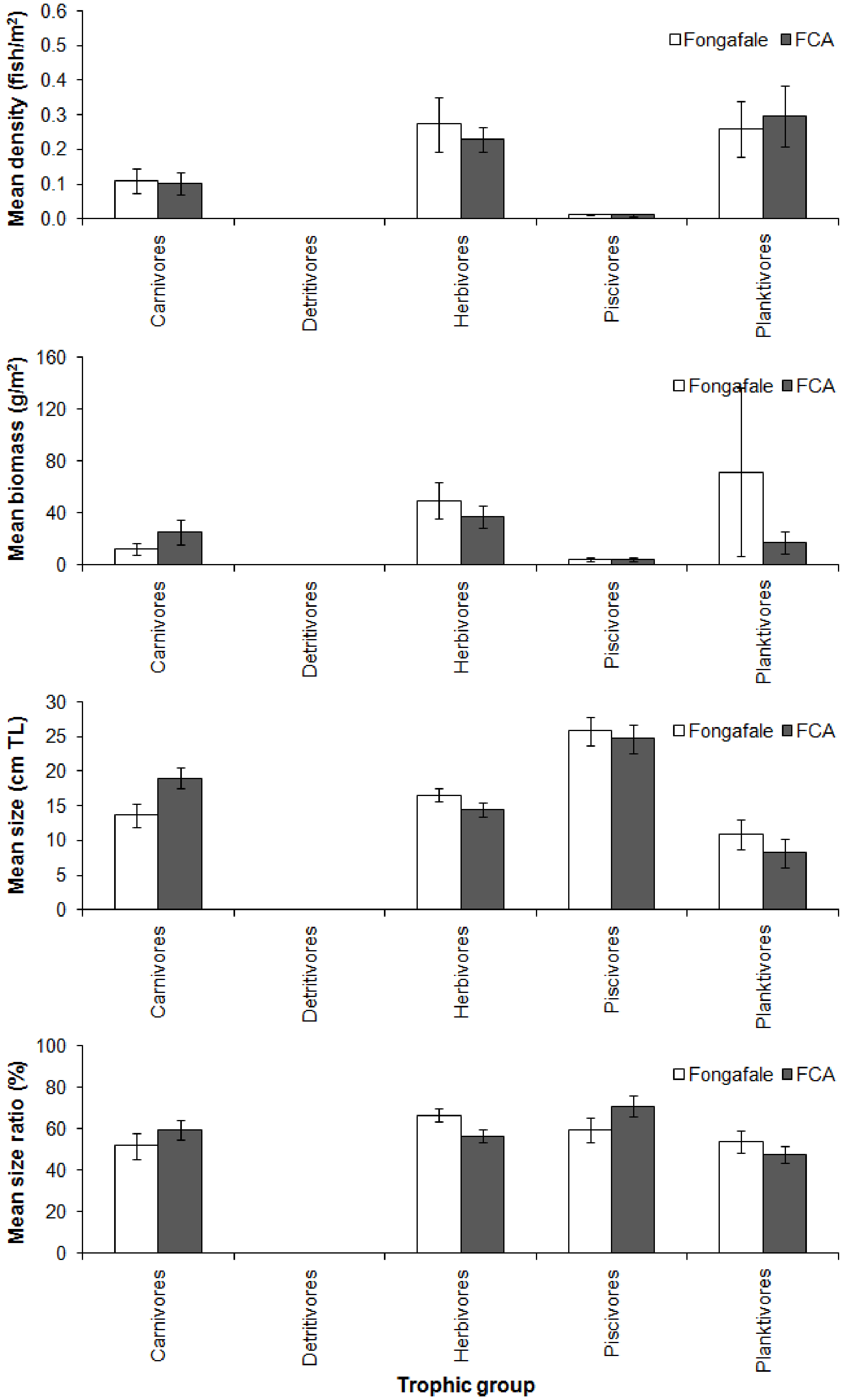

Figure 26 Profile of finfish by trophic level in outer-reef habitats of the Fongafale and FCA monitoring stations, 2011.

Table 15 Finfish species observed in highest densities in outer-reef habitats of the Fongafale and FCA monitoring sites, 2011. See Appendix 7 and 8 for a full list of densities of individual fish species observed at each monitoring site.

Site	Species	Family	Density (fish/m^2±SE)
Fongafale	*Acanthurus nigricans*	Acanthuridae	0.11±0.04
	Chromis xanthura	Pomacentridae	0.10±0.02
	Chromis margaritifer	Pomacentridae	0.07±0.06
	Ctenochaetus striatus	Acanthuridae	0.07±0.03
	Chromis viridis	Pomacentridae	0.04±0.02
FCA	*Chromis xanthura*	Pomacentridae	0.23±0.10
	Ctenochaetus striatus	Acanthuridae	0.04±0.01
	Chromis margaritifer	Pomacentridae	0.04±0.03
	Pomacentrus vaiuli	Pomacentridae	0.04±0.02
	Acanthurus nigricans	Acanthuridae	0.04±0.01

Table 16 Finfish species with the highest biomass in outer-reef habitats of the Fongafale and FCA monitoring sites, 2011. See Appendix 7 and 8 for a full list of biomass of individual fish species observed at each monitoring site.

Site	Species	Family	Biomass (g/m^2±SE)
Fongafale	*Naso caesius*	Acanthuridae	67.10±65.48
	Acanthurus nigricans	Acanthuridae	19.26±8.62
	Ctenochaetus striatus	Acanthuridae	9.89±5.65
	Scarus rubroviolaceus	Scaridae	6.46±6.20
	Scarus ghobban	Scaridae	5.47±2.62
FCA	*Chromis xanthura*	Pomacentridae	0.23±0.10
	Ctenochaetus striatus	Acanthuridae	0.04±0.01
	Chromis margaritifer	Pomacentridae	0.04±0.03
	Pomacentrus vaiuli	Pomacentridae	0.04±0.02
	Acanthurus nigricans	Acanthuridae	0.04±0.01

Comparisons with PROCFish surveys

Observed mean densities and mean biomass of Balistidae and Scaridae ($P < 0.001$), and mean density of Chaetodonitdae ($P = 0.036$) on outer-reefs of Funafuti Atoll were significantly higher during the PROCFish (2004–2005) survey than the current survey (Figure 27). As with the back-reef habitats, it should be noted that these surveys were not conducted at exactly the same locations, thus these results may be at least partially influenced by spatial differences in habitat cover or depth among survey locations. Further monitoring is required to determine whether these differences are consistent over time.

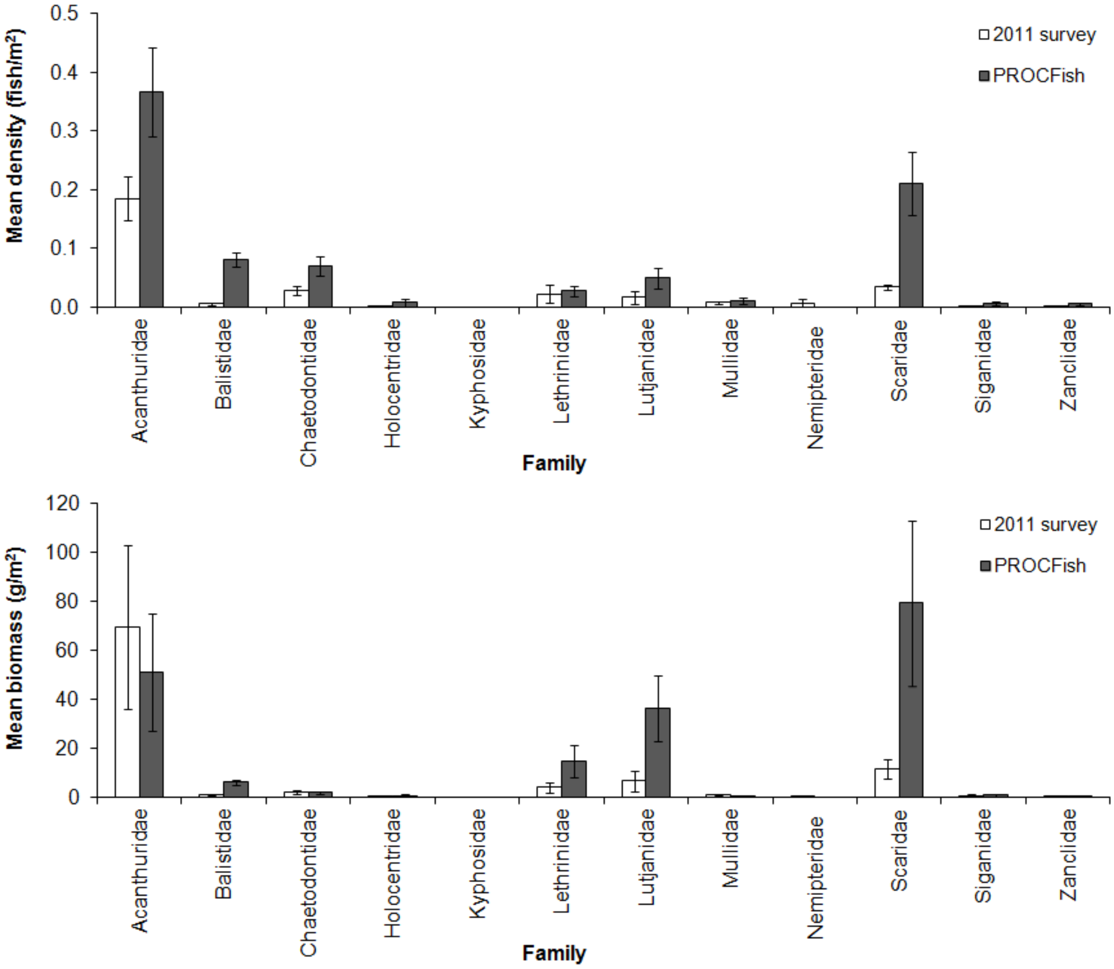

Figure 27 **Comparison of mean density (top) and biomass (bottom) (± SE) of families recorded from outer-reef habitats of Funafuti Atoll in the current study (Fongafale and FCA sites combined) and during PROCFish surveys in 2004–2005.**

6. Invertebrate Surveys

Methods and Materials

Data collection

Invertebrates

Two survey methods were used to assess the abundance, size and condition of reef-associated invertebrate resources and their habitat across reef zones. Manta tows were used to provide a broad-scale assessment of invertebrate resources associated with reef areas. In this assessment, a snorkeller was towed behind a boat with a manta board for recording the abundance of large sedentary invertebrates (e.g. sea cucumbers) at an average speed of approximately 4 km/hour (Figure 28). Hand tally counters were also mounted on the manta board to assist with enumerating the common species on site. The snorkeler's observation belt was two metres wide and tows were conducted in depths typically ranging from one to ten metres. Each tow replicate was 300 m in length and was calibrated using the odometer function within the trip computer option of a Garmin 76Map GPS. Six 300 m manta tow replicates were conducted within each station, with the start and end GPS positions of each tow recorded to an accuracy of less than ten meters.

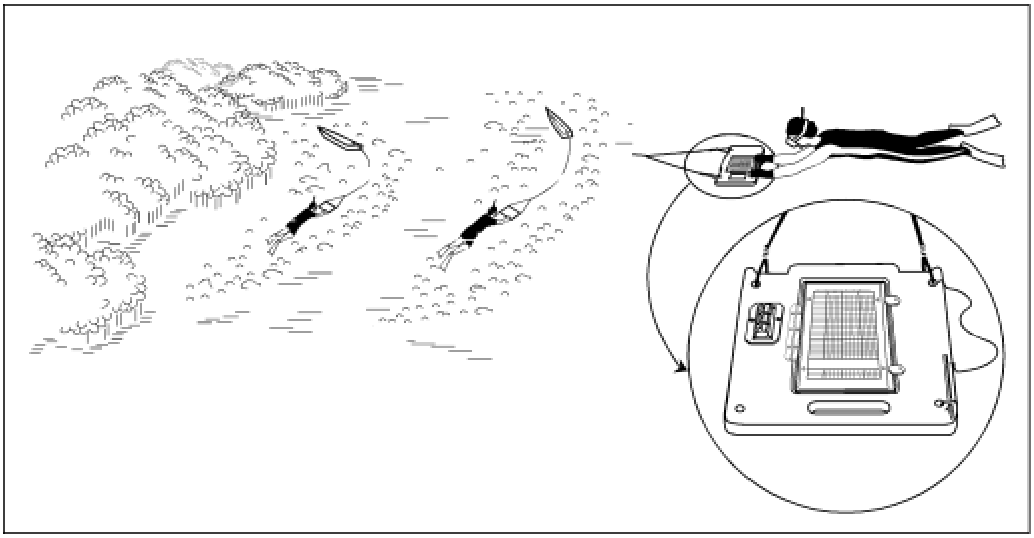

Figure 28 Broad-scale method: manta tow survey

To assess the abundance, size and condition of invertebrate resources and their habitat at finer-spatial scales, reef-benthos transects (RBT) were conducted. Reef-benthos transects were conducted by two snorkellers equipped with measuring instruments attached to their record boards (slates) for recording the abundance and size of invertebrate species. For some species, such as sea urchins (e.g. *Echinometra sp.*), only abundance was recorded due to difficulty in measuring the size of these organisms. Each transect was 40 meters long with a one meter wide observation belt, conducted in depths ranging from one to three meters. The two snorkellers conducted three transects each, totalling six 40 m transects for each station (Figure 29). The GPS position of each station was recorded in the centre of the station.

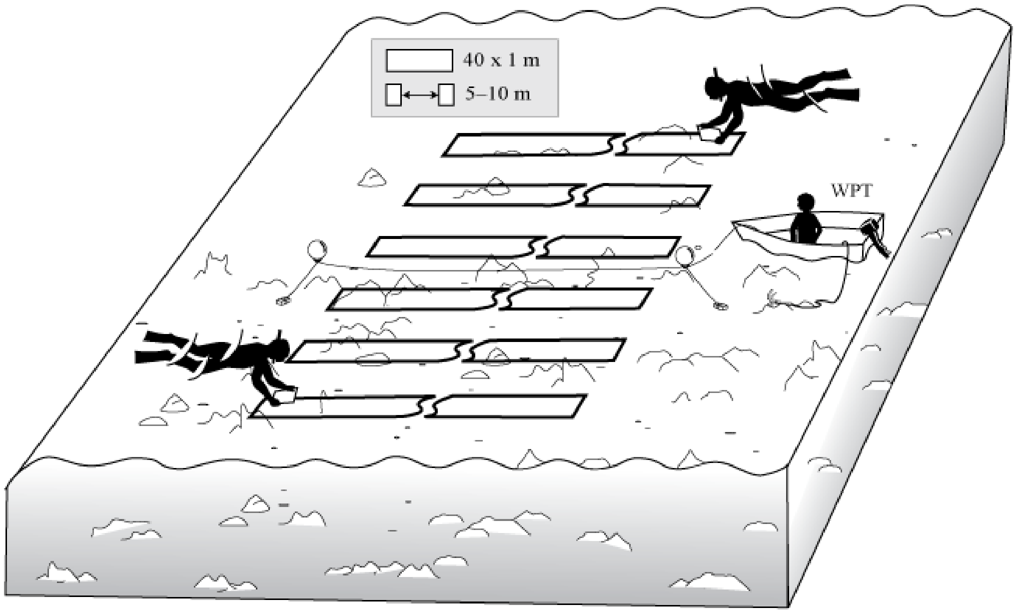

Figure 29 Fine-scale method: reef-benthos transects

Habitats supporting invertebrates

The manta tow and reef-benthos transects used the same survey form (Appendix 9) which also includes a section for recording substrate cover. Following each invertebrate assessment transect, habitat data was recorded in seven broad categories:

1. Relief and complexity
   - Relief – describes average height variation for hard and soft benthos (scale 1–5, with 1 = low relief and 5 = high relief);
   - Complexity – describes average surface variation for substrates (relative to places for animals to find shelter; scale 1–5, with 1= low complexity and 5 = high complexity);
2. Ocean influence – describes the distance and influence of area to open sea (scale 1–5, with 1 = low ocean influence and 5 = high ocean influence);
3. Depth – average depth of the surveyed area (in meters);
4. Substrate categories (totalling to 100%):
   - Soft sediments including (1) *mud*, (2) *mud and sand*, (3) *sand* and (4) *coarse sand*;
   - (5) *rubble* - small fragments of coral between 0.5 and 15 cm;
   - (6) *boulders* - detached big pieces of coral stone more than 30 cm;
   - (7) c*onsolidated rubble* - cemented pieces of coral and limestone debris,
   - (8) *pavement* - solid fixed flat limestone;
   - (9) *coral live* any live hard coral; and

- (10) *coral dead* any dead carbonated edifices that are still in place and retain a general coral shape;

5. Other substrate types (recorded in occurrences not totalling 100%)
   - (11) s*oft coral*;
   - (12) *sponges*; and,
   - (13) *fungids*;
   - (14) *crustose coralline algae*;
   - (15) *coralline algae* (e.g. *Halimeda*);
   - (16) *other algae* - includes all fleshy macroalgae not having calcium carbonate deposits; and
   - (17) *seagrass* (e.g. *Halophila*);
6. Epiphytes and silt
   - Epiphytes – describes the coverage of filamentous algae such as turf algae on hard substrate (scale 1–5, with 1 = no cover and 5 = high cover);
   - Silt – easily suspended fine particles (scale 1–5, as 1 = no silt and 5 = high silt);
7. Bleaching - the percentage of bleached live coral.

Data analysis

In this report, the status of invertebrate resources of the individual methods has been characterised using the following parameters:

1) richness – the number of genera and species counted in each survey method;
2) diversity – total number of observed species per site divided by the number of stations at that site;
3) mean density (individuals/ha);
4) mean size (mm).

As with the finfish analyses, relationships between environmental parameters and invertebrate resources have not been fully explored in this report. To explore differences in invertebrate densities and their habitats among sites, density data for each individual invertebrate species, and habitat categorical data, of each transect was square-root transformed to reduce heterogeneity of variances and analysed by one-way ANOVA at P = 0.05, using Statistica 7.1. Where transformed data failed Cochran's test for homogeneity of variances ($P < 0.05$), an increased level of significance of $P = 0.01$ was used. Additionally, density data from the current study were compared against that collected during the PROCFish surveys in Funafuti Atoll region in 2007 (Pinca et al. 2009) for both manta tow and RBT methodologies using one-way ANOVA. As the PROCFish data was collected from across Funafuti Atoll, the data for Fongafale and the FCA collected during the present study were combined for these analyses. Comparisons were conducted based on data from similar habitat types only (i.e. reef-flat and back-reefs).

Results

Manta tow

Survey coverage

A total of 12 manta tow stations were established, with 6 manta tows conducted in each of the Fongafale and FCA monitoring sites (Figure 30; Table 17). All manta tows were conducted over reef-flat and back-reef habitats. GPS positions of all manta tow replicates are tabulated in Appendix 10.

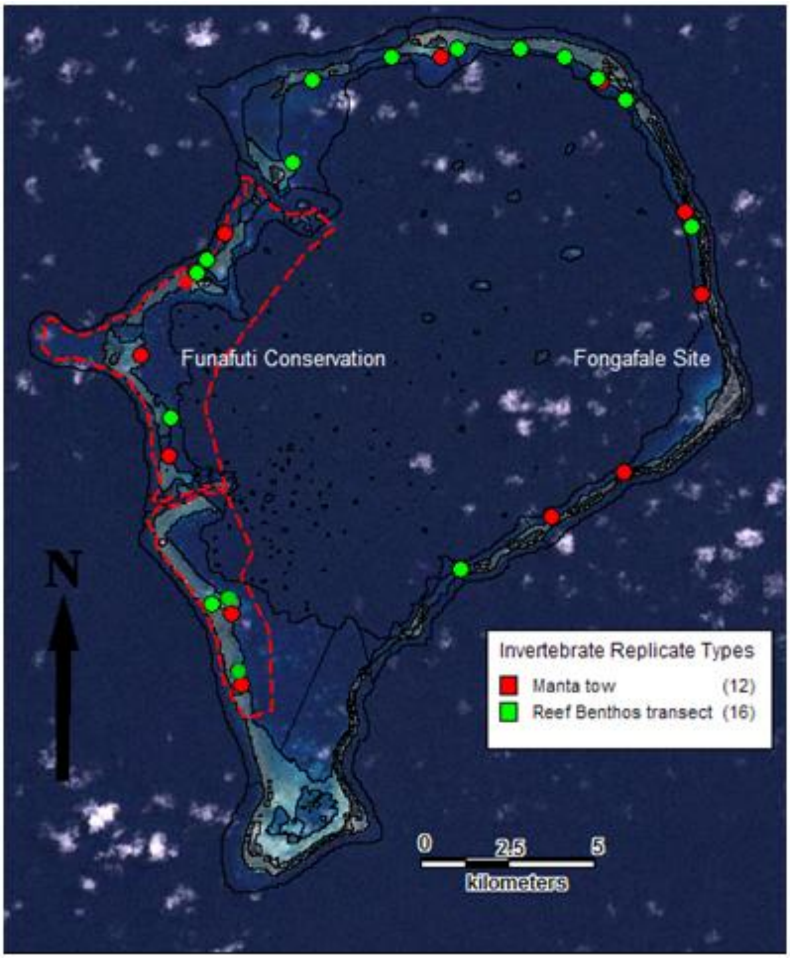

Figure 30 **Locations of manta tow and reef-benthos transect stations established in Funafuti Atoll, 2011.**

Table 17 **Summary of manta tow stations established within the Fongafale and FCA monitoring sites, 2011.**

Site	Number of stations	Number of replicates	Area surveyed (m^2)
Fongafale	6	36	21,600
FCA	6	36	21,600

Habitats supporting invertebrates

The substrate of both Fongafale and FCA manta tow stations was characterised by coral (both live and dead), sand and rubble (Figure 31). Locations where manta tow transects were conducted within the FCA had significantly greater relief, complexity and oceanic influence, and a greater mean cover of rubble, consolidated rubble, coralline algae, crustose coralline algae and sponge, than those of the Fongafale site ($P < 0.05$) (Figure 31). In contrast, locations of manta tow transects within Fongafale had significantly greater cover of sand, and boulders ($P < 0.05$). A full list of percent cover of each habitat variable recorded during the manta tow surveys can be found in Appendix 11.

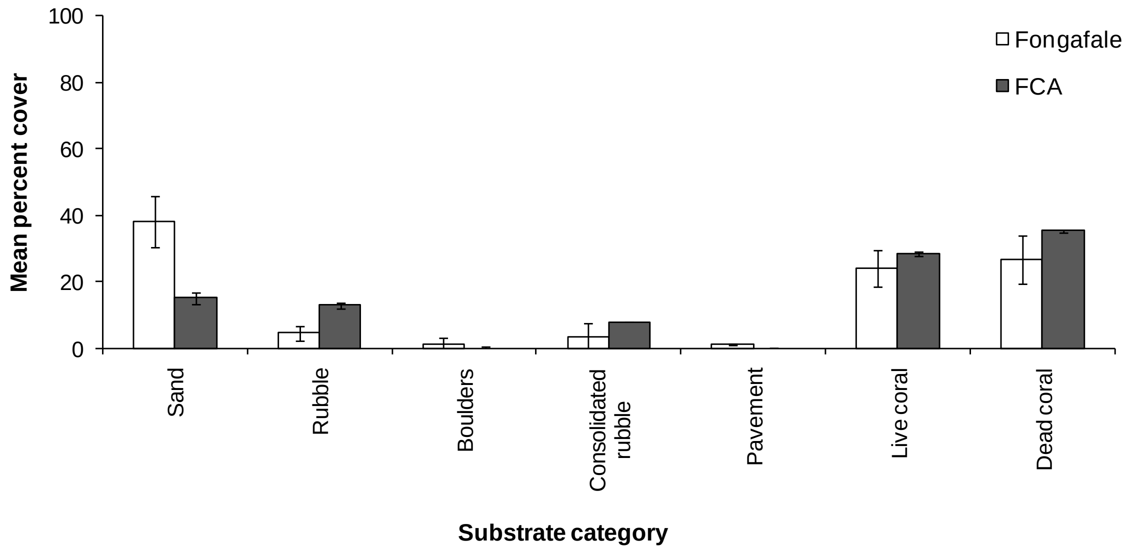

Figure 31 Mean percent cover (± SE) of each major substrate category of manta tow survey stations at the Fongafale and FCA monitoring sites, 2011.

Invertebrates

A total of 15 invertebrate species were recorded during the manta tow surveys, with six species observed at the Fongafale site and 12 at the FCA site (Figure 32). Species diversity was considerably higher within the FCA than the Fongafale site (Table 18). Mean observed densities of individual species in both the Fongafale and FCA sites were low, with no individual species observed in densities greater than 35 individuals/ha (Figure 32). Mean observed densities of sea cucumber species was particularly low at both the Fongafale and FCA sites, with no species observed in densities greater than 6 individuals/ha (Figure 32). The mean densities of *Lambis* sp. ($P = 0.010$), *Tridacna maxima* ($P < 0.001$) and *Tridacna squamosa* ($P < 0.001$) were significantly higher within the FCA than the Fongafale site (Figure 32). No crown-of-thorns starfish (*Acanthaster planci*) were recorded during manta tow surveys at either site. The density of individual species observed during the manta tow surveys at each site is presented as Appendix 12.

Table 18 Number of genera and species, and diversity of invertebrates observed during manta tow surveys at the Fongafale and FCA monitoring sites, 2011.

Parameter	Site	
	Fongafale	FCA
Number of genera	5	9
Number of species	6	12
Diversity	1.0	6.0

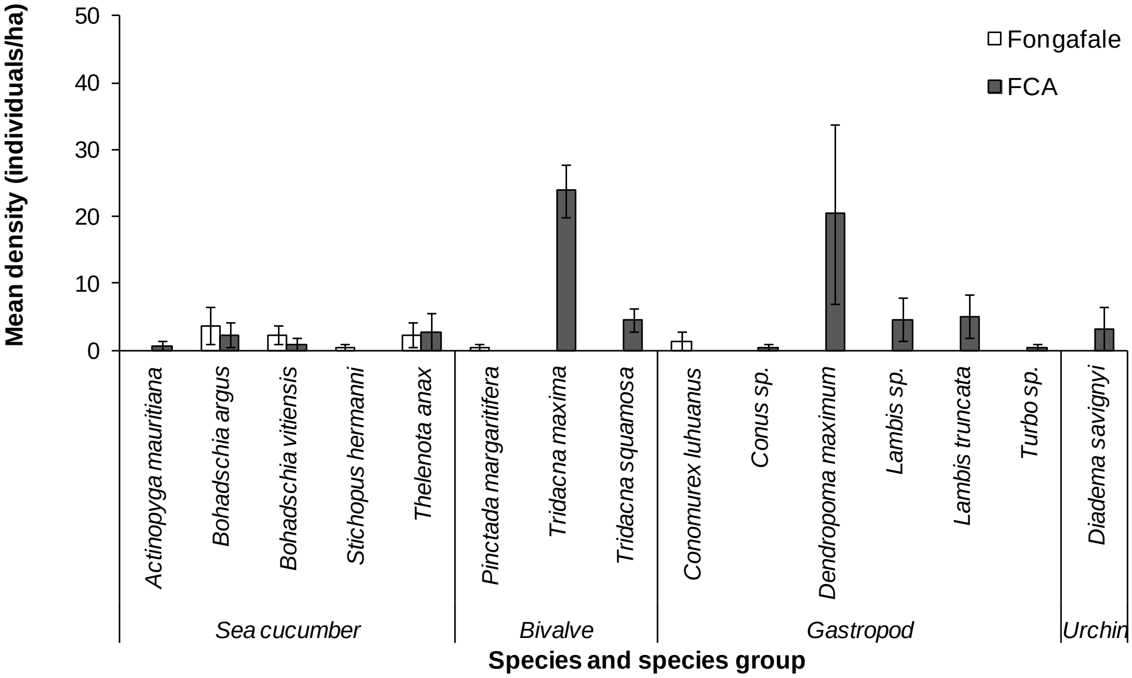

Figure 32 Overall mean density of invertebrate species (± SE) observed during manta tow surveys at the Fongafale and FCA monitoring sites, 2011.

Comparisons with PROCFish surveys

Observed mean densities of the starfish *Culcita novaeguineae*, the urchin *Echinometra mathaei*, and the gastropod *Tectus pyramis* were significantly higher during manta tow surveys of the PROCFish study than those of the current survey ($P < 0.05$) (Figure 33). While differences were observed for other species (e.g. *Holothuria atra*; Figure 33), these were not statistically significant. It should be noted that as with the finfish surveys, these surveys were not conducted at exactly the same locations, thus these results may be at least partially influenced by spatial differences among locations. Further monitoring is required to determine whether these differences are consistent over time.

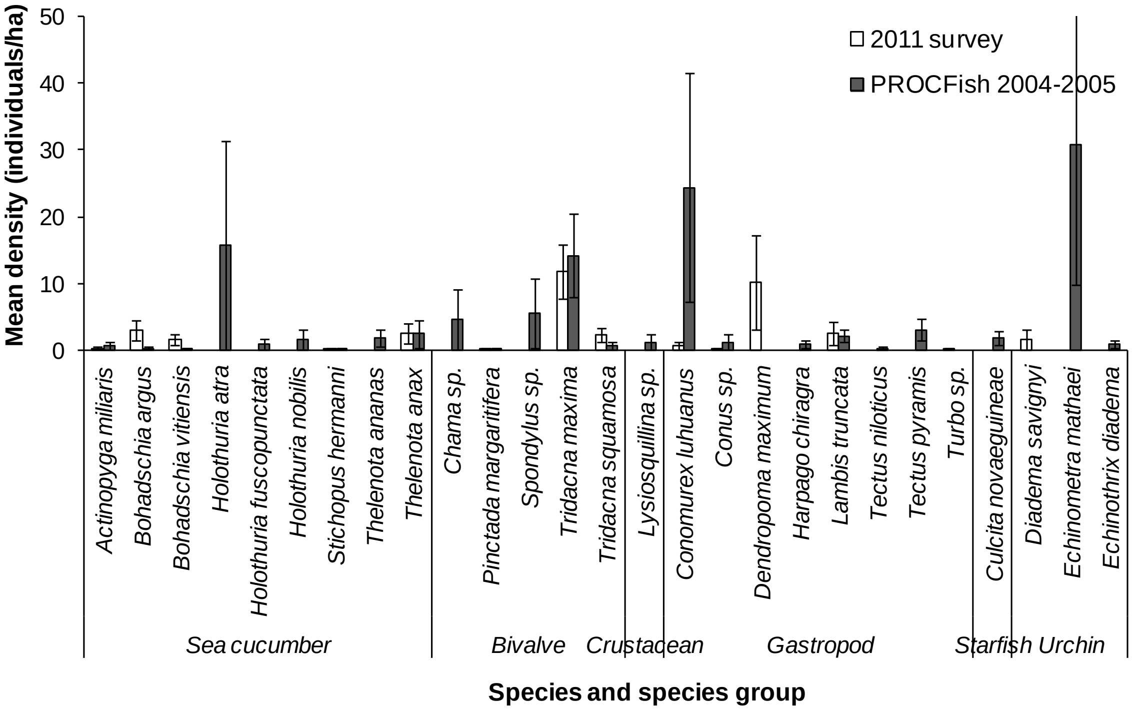

Figure 33 Comparison of mean density (± SE) of invertebrate species recorded on Funafuti Atoll during manta tow surveys in the current study (Fongafale and FCA sites combined) and during PROCFish surveys in 2004–2005.

Reef-benthos transects

Coverage

A total of 16 RBT stations were established within Funafuti Atoll, with 10 established within Fongafale and six within the FCA (Figure 30; Table 19). GPS positions of reef-benthos stations are tabulated in Appendix 13.

Table 19 Summary of reef-benthos transect stations established within the Fongafale and FCA monitoring sites, 2011.

Site	Number of stations	Number of replicates	Area surveyed (m^2)
Fongafale	10	60	2,400
FCA	6	36	1,440

Habitats supporting invertebrates

The substrate at RBT stations of both the Fongafale and FCA sites was largely similar, and dominated by dead and live coral (Figure 34). RBT stations within the Fongafale site had a significantly higher cover of live and coral than those established in the FCA ($P \leq 0.030$), while RBT stations within the FCA had a greater cover of sand, pavement, crustose coralline algae and 'other' algae than those within the Fongafale site ($P < 0.001$) (Figure 34). A full list of percent cover of each habitat variable recorded during the RBT surveys is presented as Appendix 11.

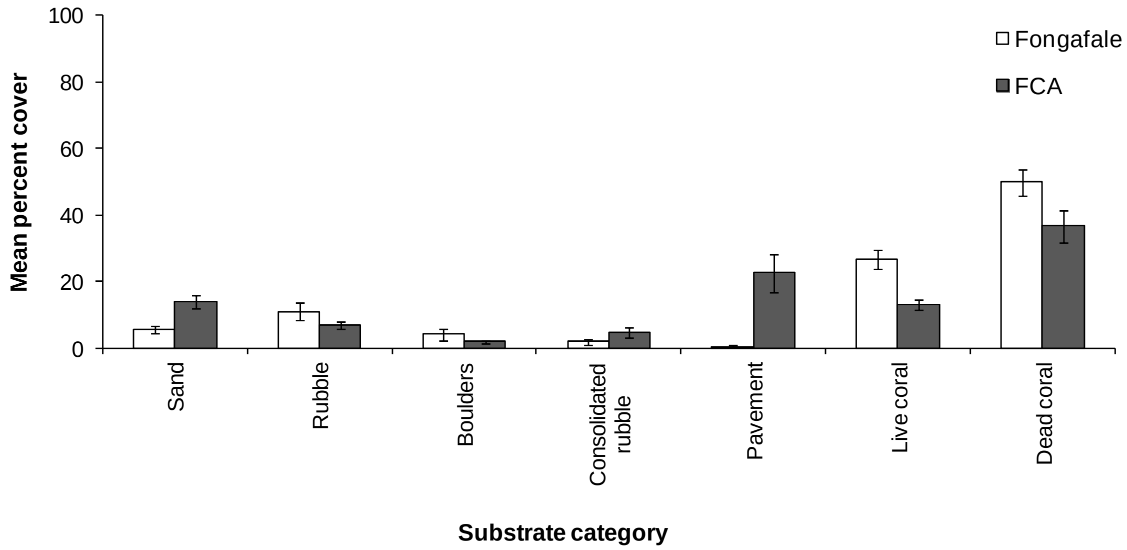

Figure 34 Mean percent cover (± SE) of each major substrate category at reef-benthos transect stations at the Fongafale and FCA monitoring sites, 2011.

Invertebrates

A total of 47 invertebrate species were recorded during the RBT surveys. As with the manta tow surveys, species diversity was slightly higher within the FCA than the Fongafale site (Table 20). The invertebrate species observed in the highest mean densities during the RBT surveys within the Fongafale site included the gastropods *Dendropoma maximum* (1362.50±927.50 individuals/ha), *Drupa* sp. (483.33±455.72 individuals/ha) and *Thais* sp. (433.33±415.15 individuals/ha) (Appendix 14). The invertebrate species observed in the highest mean densities during the RBT surveys within the FCA site included the sea urchins *Diadema savignyi* (2354.17±1391.47 individuals/ha) and *Echinometra mathaei* (513.89±364.78 individuals/ha), the gastropod *Lambis truncata* (145.83±145.83 individuals/ha) and the bivalve *Tridacna maxima* (125.00±90.01 individuals/ha) (Appendix 14). The mean densities of *Diadema savignyi* ($P < 0.001$) and *Echinometra mathaei* ($P = 0.003$) were significantly higher within the FCA than the Fongafale site (Appendix 14). A single individual of the crown-of-thorns starfish, *A. planci*, was observed at Fongafale, while no individuals were observed within the FCA stations. The density of individual species observed during the RBT surveys at each site is presented as Appendix 14. No differences in mean size were evident for species common to both Fongafale and FCA monitoring sites (Table 21).

Comparisons with PROCFish surveys

Observed mean densities of the sea cucumber Holothuria atra, the gastropod *Dendropoma maximum* and the urchin *Diadema savignyi* were significantly higher during the RBT assessments of the current (2011) survey than those of PROCFish 2004-2005 ($P < 0.05$)

(Appendix 15). It should be noted that as with the finfish surveys, these surveys were not conducted at exactly the same locations, thus these results may be at least partially influenced by spatial differences among locations. Further monitoring is required to determine whether these differences are consistent over time.

Table 20 Number of genera and species, and diversity of invertebrates observed during reef-benthos transects at the Fongafale and FCA monitoring sites, 2011.

Parameter	Site	
	Fongafale	FCA
Number of genera	23	17
Number of species	31	29
Diversity	3.1	4.8

Table 21 Mean size (± SE) of measured invertebrates during reef-benthos transects at the Fongafale and FCA monitoring sites, 2011. Only those species with ≥ 5 individuals measured are presented.

Group	Species	Mean size (mm)	
		Fongafale	FCA
Sea cucumber	*Holothuria atra*	138.2±12.6	-
Bivalve	*Tridacna maxima*	171.8±35.8	121.4±13.4
Gastropod	*Conus* sp.	39.4±13.1	53.9.3±3.7
	Conus vexillum	-	49.4±4.7
	Lambis truncata	-	-260±7.1
	Tectus pyramis	52.6±7.8	56.0±3.1
	Turbo argyrostomus	63.4±4.2	53.6±2.0

7. Capacity Building

One of the key objectives of the project is to train local Fisheries Officers in undertaking monitoring programs and resource assessments. The training includes planning logistics, safety protocols, site selection criteria, species identification, survey methods and other preparations required for conducting resource assessments. This is to build local capacity before conducting the baseline assessment and to provide staff with the skills so regular re-assessments of the pilot sites can be carried out in the future.

A week of training was conducted before the actual baseline assessments of both finfish and invertebrate resources. A total of seven people were trained: six officers from Tuvalu Department of Fisheries and a student from the University of the South Pacific (Table 22). The training initially consisted of classroom sessions where assessment methods and survey forms were explained in detail and slideshows of species photos were presented for identification. This was followed by field activities where the trainees practiced a method, as well as species identification. Only when the results of the trainees were consistent with senior project staff were they able to participate in the baseline assessment.

Table 22 List of trainees who participated in the baseline assessment

Name	Title	Organisation
Siouala Malua	Aquaculture Officer	Fisheries Department
Paeniu Lopati	Diver	Fisheries Department
Panei Togabiri	Diver	Fisheries Department
Filipo Makolo	Diver	Fisheries Department
Neli Seniola	Manaui crew	Fisheries Department
Timon Salesa	Manaui crew	Fisheries Department
Samuelu Telii	PhD student	USP

8. Recommendations for Future Monitoring

The following recommendations are proposed for future monitoring events:

Benthic habitat and finfish assessments

- The decreases in densities and biomass evident for several finfish families between the PROCFish surveys in 2004–2005 and the current (2011) survey is of concern, as it suggests a significant reduction in finfish populations at Funafuti Atoll over a short-term period. Further monitoring of the locations surveyed in this baseline assessment is required to determine whether these differences are consistent over time. In addition, to ensure that these results, and results of future surveys, were not a result of differences in observer skill or experience, the use of non-observer based monitoring techniques, such as videography, in conjunction with the D-UVC surveys are recommended.

- Many of the reef flat monitoring stations established during the baseline survey were established in shallow (< 1 m deep) water. Accordingly, these habitats will likely only support transient finfish communities due to tidal effects. While it is important to monitor these sites, for future surveys it is recommended that deeper water lagoon-reef monitoring sites, situated at the same sites as those examined during the PROCFish study, be established, where possible.

- Due to strong currents and poor weather one reef flat benthic habitat and finfish transect at the FCA site could not be completed. To balance the survey design, this transect should be established during the re-survey event.

Invertebrate surveys

- For this baseline study, manta tow surveys were conducted on back-and lagoon-reef habitats only. As various reef habitats, and the organisms they support, differ greatly in their vulnerability to climate change, it is recommended that manta tow monitoring stations be established on the outer reef of both the Fongafale and FCA sites, where conditions permit.

- During the baseline assessment, 10 RBT stations were established at Fongafale, while six stations were established in the FCA. To balance the sampling design, additional RBT stations should be established within the FCA.

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Appendix 1 GPS positions of benthic habitat assessments

Station ID	Habitat	Transect name	Latitude (S)	Longitude (E)
Fongafale 1	Reef flat	T4	8.433017	179.160367
	Reef flat	T5	8.432617	179.159733
	Reef flat	T6	8.432283	179.158733
	Back-reef	T1	8.434233	179.1595
	Back-reef	T2	8.434233	179.1595
	Back-reef	T3	8.434233	179.1595
	Outer-reef	T19	8.424967	179.134917
	Outer-reef	T20	8.424967	179.134917
	Outer-reef	T21	8.425017	179.13375
Fongafale 2	Reef flat	T31	8.56495	179.13095
	Reef flat	T32	8.564533	179.131467
	Reef flat	T33	8.56445	179.1319
	Back-reef	T34	8.563983	179.132083
	Back-reef	T35	8.563983	179.132083
	Back-reef	T36	8.563983	179.132083
	Outer-reef	T28	8.56685	179.1338
	Outer-reef	T29	8.566833	179.133667
	Outer-reef	T30	8.566933	179.132933
FCA 1	Reef flat	T7	8.486017	179.067467
	Reef flat	T8	8.486267	179.066517
	Reef flat	T9	8.488283	179.064467
	Back-reef	T10	8.49425	179.0639
	Back-reef	T11	8.494217	179.06345
	Back-reef	T12	8.493967	179.061933
	Outer-reef	T22	8.485133	179.061167
	Outer-reef	T23	8.485133	179.061167
	Outer-reef	T24	8.486583	179.060283
FCA 2	Reef flat	T17	8.59145	179.068617
	Reef flat	T18	8.59555	179.070083
	Back-reef	T13	8.591017	179.0711
	Back-reef	T14	8.5911	179.07085
	Back-reef	T15	8.591467	179.0706
	Outer-reef	T25	8.5814	179.0631
	Outer-reef	T26	8.5816	179.063133
	Outer-reef	T27	-8.582217	179.063567

Appendix 2 Finfish distance-sampling underwater visual census (D-UVC) survey form

Campaign |____________________| Site |______________________________| Diver |__|__| Transect |__|__|__|

D |__|__|/|__|__|/20|__|__| Lat.|__|__|°|__|__|,|__|__|__|’ Long.|__|__|__|°|__|__|,|__|__|__|’ Left ☐ Right ☐

ST	SCIENTIFIC NAME	NBER	LGT	D1	D2	COMMENTS

Appendix 3 Form used to assess habitats supporting finfish

Campaign |_____________| **Site** |______________________| **Diver** |__|__| **Transect** |__|__|__|

D |__|__|/|__|__|/20|__|__| **Lat.**|__|__|°|__|__|,|__|__|__|' **Long.**|__|__|__|°|__|__|,|__|__|__|' **WT** |__|__|__|

Start time: |__|__| :|__|__| End time: |__|__| :|__|__| Secchi disc visibility |__|__| m Left ☐ Right ☐

Primary reef: Coastal ☐ Lagoon ☐ Back ☐ Outer ☐ **Secondary Reef:** Coastal ☐ Lagoon ☐ Back ☐ Outer ☐

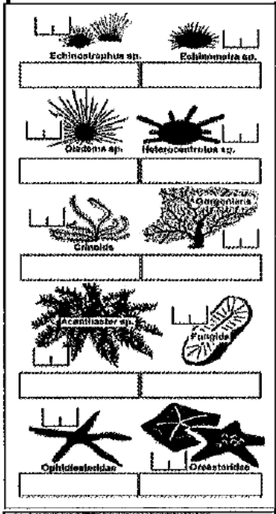
	current	oceanic influence	terrigenous influence
none	☐	☐	☐
medium	☐	☐	☐
strong	☐	☐	☐

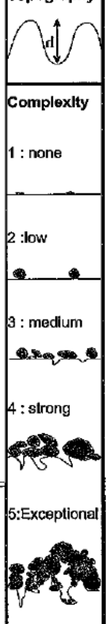
draw profile including estimate of slope in degree
Flat ☐ Floor ☐
Gentle slope ☐ Steep slope ☐

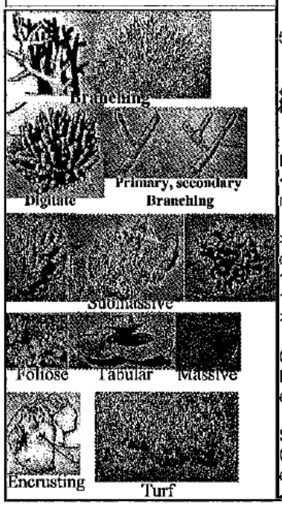
Remarks:

	Quadrat limits	0–10	10–20	20–30	30–40	40–50	%
	Depth of transect line (m)						
	Slope only: Depth of crest (m)						
	Slope only: Depth of floor (m)						
	Line of sight visibility (m)						
	Topography (1-5)						
	Complexity (1-5)						
1st layer	Hard substrate						100
	Soft substrate						
2nd layer	(1) Abiotic						100
	(2) Hard corals (dead & live)						
(1) Abiotic	Rocky substratum (Slab)						100
	Silt						
	Mud						
	Sand						
	Rubbles						
	Gravels, small boulders (< 30 cm)						
	Large boulders (< 1m)						
	Rocks (> 1m)						
(2a) Hard coral status	Live						100
	Bleaching						
	Long dead algae covered						
(2b) Hard coral shape	Encrusting						100
	Massive						
	Sub-massive						
	Digitate						
	Branch						
	Foliose						
	Tabulate						
3rd layer: other	Sponge						
	Soft coral						
3rd layer: Plant & algae	Macro-algae (soft to touch)						
	Turf (filaments)						
	Calcareous algae (hard to touch)						
	Encrusting algae (Crustose coralline)						
	Seagrass						
3rd layer:	Silt covering coral						
3rd layer:	Cyanophycae						

Branching : has secondary branching
Digitate : no secondary branching
Hard coral (dead & live) : Coral attached to substrate with an identifiable shape (otherwise it's abiotic)
Rubble : any piece or whole coral colony of any size that is not attached to substrate
Topography (regardless of surface orientation): 1 : no relief, 2 : low (h<1m), 3: medium (1<h<2m) 4: strong (2<h<3m), 5: exceptional (h>3m)
Complexity (quantity and diversity of holes and cavities): 1: none, 2: low, 3: medium, 4: strong, 5:exceptional
% measured over line of sight visibility







Depth :
<10m : measure it ;
>10 m : estimate as 10-15m 15-20m >20m

Crest side : Floor=transect depth

Slope side : Crest=transect depth

Appendix 4 GPS positions of finfish D-UVC transects

Station ID	Habitat	Transect name	Longitude (E)	Latitude (N)
Fongafale 1	Reef flat	T4	8.433017	179.160367
	Reef flat	T5	8.432617	179.159733
	Reef flat	T6	8.432283	179.158733
	Back-reef	T1	8.434233	179.1595
	Back-reef	T2	8.434233	179.1595
	Back-reef	T3	8.434233	179.1595
	Outer-reef	T19	8.424967	179.134917
	Outer-reef	T20	8.424967	179.134917
	Outer-reef	T21	8.425017	179.13375
Fongafale 2	Reef flat	T31	8.56495	179.13095
	Reef flat	T32	8.564533	179.131467
	Reef flat	T33	8.56445	179.1319
	Back-reef	T34	8.563983	179.132083
	Back-reef	T35	8.563983	179.132083
	Back-reef	T36	8.563983	179.132083
	Outer-reef	T28	8.56685	179.1338
	Outer-reef	T29	8.566833	179.133667
	Outer-reef	T30	8.566933	179.132933
FCA 1	Reef flat	T7	8.486017	179.067467
	Reef flat	T8	8.486267	179.066517
	Reef flat	T9	8.488283	179.064467
	Back-reef	T10	8.49425	179.0639
	Back-reef	T11	8.494217	179.06345
	Back-reef	T12	8.493967	179.061933
	Outer-reef	T22	8.485133	179.061167
	Outer-reef	T23	8.485133	179.061167
	Outer-reef	T24	8.486583	179.060283
FCA 2	Reef flat	T17	8.59145	179.068617
	Reef flat	T18	8.59555	179.070083
	Back-reef	T13	8.591017	179.0711
	Back-reef	T14	8.5911	179.07085
	Back-reef	T15	8.591467	179.0706
	Outer-reef	T25	8.5814	179.0631
	Outer-reef	T26	8.5816	179.063133
	Outer-reef	T27	-8.582217	179.063567

Appendix 5 Mean density and biomass (± SE) of all finfish families recorded at the Fongafale site by habitat

Habitat	Family	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Reef flat	Acanthuridae	0.2603	0.0494	75.8771	35.1193
Reef flat	Balistidae	0.0023	0.0020	0.1289	0.0821
Reef flat	Carangidae	0.0003	0.0003	0.1923	0.1923
Reef flat	Chaetodontidae	0.0297	0.0030	2.2020	0.4256
Reef flat	Holocentridae	0.0033	0.0023	0.5021	0.4145
Reef flat	Labridae	0.0257	0.0039	3.1160	1.3900
Reef flat	Lethrinidae	0.0053	0.0027	1.9122	1.2287
Reef flat	Lutjanidae	0.0023	0.0017	0.5124	0.3248
Reef flat	Mullidae	0.0143	0.0063	4.9676	2.7087
Reef flat	Pomacanthidae	0.0010	0.0010	0.1116	0.1116
Reef flat	Pomacentridae	0.0797	0.0272	1.6796	1.0309
Reef flat	Scaridae	0.1273	0.0623	30.3424	19.5693
Reef flat	Serranidae	0.0037	0.0023	0.4831	0.2763
Reef flat	Siganidae	0.0017	0.0017	0.1444	0.1444
Reef flat	Zanclidae	0.0003	0.0003	0.0560	0.0560
Back	Acanthuridae	0.1142	0.0204	17.1643	5.3918
Back	Blenniidae	0.0210	0.0183	0.0081	0.0074
Back	Caesionidae	0.0677	0.0284	4.3710	2.5243
Back	Chaetodontidae	0.0370	0.0081	2.3876	0.5329
Back	Holocentridae	0.0013	0.0013	0.3227	0.3227
Back	Kyphosidae	0.0007	0.0007	0.3107	0.3107
Back	Labridae	0.0223	0.0035	1.7530	0.4017
Back	Lethrinidae	0.0223	0.0090	4.6462	2.6185
Back	Lutjanidae	0.0067	0.0029	0.4700	0.1723
Back	Mullidae	0.0692	0.0285	4.2858	1.7184
Back	Pomacanthidae	0.0003	0.0003	0.1367	0.1367
Back	Pomacentridae	0.0697	0.0267	2.0124	0.8999
Back	Scaridae	0.0880	0.0100	14.0071	2.0164
Back	Serranidae	0.0147	0.0080	2.0029	0.9850
Back	Siganidae	0.0027	0.0014	0.1371	0.0818
Back	Zanclidae	0.0003	0.0003	0.0450	0.0450
Outer	Acanthuridae	0.2338	0.0655	102.0850	65.8973
Outer	Balistidae	0.0027	0.0012	0.3453	0.2190
Outer	Caesionidae	0.3702	0.1135	69.8992	31.2401
Outer	Carangidae	0.0107	0.0099	6.6309	6.2563
Outer	Chaetodontidae	0.0370	0.0106	3.2446	1.2517
Outer	Holocentridae	0.0010	0.0007	0.1748	0.1192
Outer	Labridae	0.0273	0.0095	6.4209	4.1742
Outer	Lethrinidae	0.0343	0.0292	1.1305	0.3388

Habitat	Family	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Lutjanidae	0.0057	0.0031	1.0947	0.6019
Outer	Mullidae	0.0047	0.0020	0.3846	0.1586
Outer	Pomacentridae	0.2509	0.0946	3.1989	1.0150
Outer	Scaridae	0.0360	0.0077	14.5362	7.0911
Outer	Serranidae	0.0077	0.0025	3.6674	1.6057
Outer	Siganidae	0.0007	0.0007	0.1866	0.1866
Outer	Zanclidae	0.0040	0.0021	0.3902	0.2608

Appendix 6 Mean density and biomass (± SE) of all finfish families recorded at the FCA site by habitat

Habitat	Family	Density (fish/m²)	SE density	Biomass (g/m²)	SE biomass
Reef flat	Acanthuridae	0.0660	0.0139	2.7841	0.6834
Reef flat	Balistidae	0.0056	0.0019	0.1252	0.0465
Reef flat	Chaetodontidae	0.0104	0.0059	0.4298	0.3349
Reef flat	Labridae	0.0189	0.0160	0.2601	0.1860
Reef flat	Lethrinidae	0.0004	0.0004	0.0910	0.0910
Reef flat	Mullidae	0.0236	0.0048	1.3400	0.4856
Reef flat	Pomacanthidae	0.0028	0.0015	0.1995	0.0889
Reef flat	Pomacentridae	0.0388	0.0155	0.6110	0.2652
Reef flat	Scaridae	0.0188	0.0097	1.7122	0.9528
Reef flat	Serranidae	0.0084	0.0027	0.6124	0.1233
Back	Acanthuridae	0.1370	0.0308	36.9725	17.2472
Back	Balistidae	0.0023	0.0016	0.1168	0.0547
Back	Blenniidae	0.0007	0.0004	0.0001	0.0000
Back	Carangidae	0.0017	0.0017	0.2814	0.2814
Back	Chaetodontidae	0.0127	0.0035	1.1901	0.6425
Back	Gerreidae	0.0080	0.0080	8.5415	8.5415
Back	Haemulidae	0.0013	0.0013	1.7316	1.7316
Back	Holocentridae	0.0063	0.0042	3.2927	2.9441
Back	Labridae	0.0427	0.0204	5.2326	3.3271
Back	Lethrinidae	0.0144	0.0101	6.2226	3.9087
Back	Lutjanidae	0.0050	0.0050	2.1461	2.1461
Back	Mullidae	0.0367	0.0175	6.6458	5.5719
Back	Nemipteridae	0.0020	0.0020	0.0022	0.0022
Back	Pomacanthidae	0.0057	0.0033	0.7309	0.5511
Back	Pomacentridae	0.1397	0.0156	1.5984	0.8324
Back	Priacanthidae	0.0010	0.0010	0.5367	0.5367
Back	Scaridae	0.0360	0.0112	5.5054	2.2882
Back	Serranidae	0.0083	0.0025	0.9533	0.3021
Back	Siganidae	0.0130	0.0114	3.9487	3.8266
Back	Tetraodontidae	0.0003	0.0003	0.0699	0.0699
Back	Zanclidae	0.0013	0.0010	0.2239	0.1661
Outer	Acanthuridae	0.1364	0.0274	37.1554	10.9717
Outer	Balistidae	0.0090	0.0034	1.3982	0.5910
Outer	Caesionidae	0.0504	0.0295	5.5516	3.4688
Outer	Carangidae	0.0007	0.0004	0.4251	0.2750
Outer	Chaetodontidae	0.0193	0.0089	1.2124	0.5286
Outer	Holocentridae	0.0030	0.0014	0.4205	0.2193
Outer	Labridae	0.0283	0.0049	4.4552	1.9354
Outer	Lethrinidae	0.0113	0.0059	7.0602	3.8579

Habitat	Family	Density (fish/m²)	SE density	Biomass (g/m²)	SE biomass
Outer	Lutjanidae	0.0270	0.0220	12.3496	7.9696
Outer	Mullidae	0.0113	0.0034	1.2904	0.5224
Outer	Nemipteridae	0.0142	0.0142	0.4160	0.4160
Outer	Pomacentridae	0.3231	0.0997	4.8328	2.6364

Appendix 7 Mean density and biomass of all fish species recorded at the Fongafale site by habitat

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Flat	Acanthuridae	*Acanthurus achilles*	0.0017	0.0017	0.6117	0.6117
Flat	Acanthuridae	*Acanthurus gahhm*	0.0047	0.0039	1.0459	0.9755
Flat	Acanthuridae	*Acanthurus lineatus*	0.0800	0.0357	30.6544	20.6725
Flat	Acanthuridae	*Acanthurus maculiceps*	0.0017	0.0017	0.0774	0.0774
Flat	Acanthuridae	*Acanthurus nigricans*	0.0347	0.0072	3.8006	0.6247
Flat	Acanthuridae	*Acanthurus nigrofuscus*	0.0130	0.0060	0.9712	0.5074
Flat	Acanthuridae	*Acanthurus pyroferus*	0.0047	0.0018	0.7357	0.6825
Flat	Acanthuridae	*Acanthurus triostegus*	0.0197	0.0099	1.4349	0.5300
Flat	Acanthuridae	*Ctenochaetus striatus*	0.0767	0.0250	20.4715	11.0216
Flat	Acanthuridae	*Naso lituratus*	0.0223	0.0197	16.0607	15.4951
Flat	Acanthuridae	*Zebrasoma scopas*	0.0013	0.0010	0.0131	0.0095
Flat	Balistidae	*Balistapus undulatus*	0.0007	0.0004	0.0996	0.0643
Flat	Balistidae	*Rhinecanthus aculeatus*	0.0003	0.0003	0.0284	0.0284
Flat	Balistidae	*Rhinecanthus rectangulus*	0.0013	0.0013	0.0008	0.0008
Flat	Chaetodontidae	*Chaetodon auriga*	0.0020	0.0010	0.0574	0.0283
Flat	Chaetodontidae	*Chaetodon citrinellus*	0.0007	0.0007	0.0338	0.0338
Flat	Chaetodontidae	*Chaetodon ephippium*	0.0017	0.0011	0.1049	0.0748
Flat	Chaetodontidae	*Chaetodon kleinii*	0.0007	0.0007	0.0409	0.0409
Flat	Chaetodontidae	*Chaetodon lunula*	0.0017	0.0008	0.1533	0.1170
Flat	Chaetodontidae	*Chaetodon lunulatus*	0.0077	0.0031	0.5885	0.3037
Flat	Chaetodontidae	*Chaetodon ornatissimus*	0.0007	0.0007	0.0504	0.0504
Flat	Chaetodontidae	*Chaetodon reticulatus*	0.0047	0.0017	0.4298	0.1878
Flat	Chaetodontidae	*Chaetodon trifascialis*	0.0077	0.0020	0.5273	0.2076
Flat	Chaetodontidae	*Chaetodon ulietensis*	0.0017	0.0011	0.1246	0.0811
Flat	Chaetodontidae	*Heniochus chrysostomus*	0.0007	0.0007	0.0911	0.0911
Flat	Holocentridae	*Myripristis murdjan*	0.0003	0.0003	0.0337	0.0337
Flat	Holocentridae	*Sargocentron melanospilos*	0.0007	0.0007	0.0454	0.0454
Flat	Holocentridae	*Sargocentron microstoma*	0.0023	0.0023	0.4230	0.4230
Flat	Labridae	*Cheilinus fasciatus*	0.0050	0.0033	0.6372	0.4597
Flat	Labridae	*Cheilinus undulatus*	0.0007	0.0007	0.0051	0.0051
Flat	Labridae	*Coris gaimard*	0.0010	0.0010	0.0085	0.0085
Flat	Labridae	*Coris venusta*	0.0037	0.0037	0.3639	0.3639
Flat	Labridae	*Gomphosus varius*	0.0010	0.0007	0.0404	0.0256
Flat	Labridae	*Halichoeres hortulanus*	0.0020	0.0014	0.0977	0.0697
Flat	Labridae	*Halichoeres trimaculatus*	0.0010	0.0007	0.1420	0.0901
Flat	Labridae	*Labroides bicolor*	0.0013	0.0010	0.0084	0.0060
Flat	Labridae	*Labroides dimidiatus*	0.0023	0.0011	0.0245	0.0150
Flat	Labridae	*Thalassoma hardwicke*	0.0037	0.0018	0.1829	0.1572
Flat	Labridae	*Thalassoma purpureum*	0.0010	0.0010	1.4093	1.4093

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Flat	Labridae	*Thalassoma trilobatum*	0.0030	0.0030	0.1961	0.1961
Flat	Lethrinidae	*Lethrinus harak*	0.0007	0.0007	0.0429	0.0429
Flat	Lethrinidae	*Lethrinus olivaceus*	0.0010	0.0010	1.1620	1.1620
Flat	Lethrinidae	*Monotaxis grandoculis*	0.0037	0.0026	0.7072	0.5163
Flat	Lutjanidae	*Lutjanus fulviflammus*	0.0017	0.0017	0.2421	0.2421
Flat	Lutjanidae	*Lutjanus gibbus*	0.0007	0.0007	0.2703	0.2703
Flat	Mullidae	*Mulloidichthys sp.*	0.0023	0.0023	1.5587	1.5587
Flat	Mullidae	*Parupeneus barberinus*	0.0013	0.0013	2.5308	2.5308
Flat	Mullidae	*Parupeneus bifasciatus*	0.0017	0.0013	0.4021	0.3212
Flat	Mullidae	*Parupeneus ciliatus*	0.0017	0.0017	0.0579	0.0579
Flat	Mullidae	*Parupeneus cyclostomus*	0.0017	0.0017	0.0575	0.0575
Flat	Mullidae	*Parupeneus multifasciatus*	0.0040	0.0012	0.2918	0.1015
Flat	Mullidae	*Parupeneus pleurostigma*	0.0013	0.0013	0.0460	0.0460
Flat	Mullidae	*Parupeneus spilurus*	0.0003	0.0003	0.0229	0.0229
Flat	Pomacanthidae	*Centropyge flavissimus*	0.0007	0.0007	0.0446	0.0446
Flat	Pomacanthidae	*Pygoplites diacanthus*	0.0003	0.0003	0.0670	0.0670
Flat	Pomacentridae	*Amphiprion perideraion*	0.0043	0.0043	0.1267	0.1267
Flat	Pomacentridae	*Chromis margaritifer*	0.0027	0.0027	0.0020	0.0020
Flat	Pomacentridae	*Chromis viridis*	0.0417	0.0180	0.1508	0.0913
Flat	Pomacentridae	*Chromis xanthura*	0.0120	0.0058	0.2520	0.1129
Flat	Pomacentridae	*Chrysiptera starcki*	0.0003	0.0003	0.0073	0.0073
Flat	Pomacentridae	*Chrysiptera unimaculata*	0.0020	0.0014	0.0071	0.0045
Flat	Pomacentridae	*Dascyllus trimaculatus*	0.0003	0.0003	0.0256	0.0256
Flat	Pomacentridae	*Plectroglyphidodon dickii*	0.0063	0.0063	0.1098	0.1098
Flat	Pomacentridae	*Pomacentrus sp.*	0.0087	0.0061	0.9953	0.7735
Flat	Pomacentridae	*Pomacentrus vaiuli*	0.0013	0.0013	0.0029	0.0029
Flat	Scaridae	*Chlorurus microrhinos*	0.0013	0.0013	2.5326	2.5326
Flat	Scaridae	*Chlorurus sordidus*	0.0617	0.0472	4.1934	3.2287
Flat	Scaridae	*Hipposcarus longiceps*	0.0007	0.0007	0.1086	0.1086
Flat	Scaridae	*Scarus chameleon*	0.0010	0.0010	0.5996	0.5996
Flat	Scaridae	*Scarus forsteni*	0.0093	0.0093	2.6817	2.6817
Flat	Scaridae	*Scarus ghobban*	0.0417	0.0333	18.9136	17.0157
Flat	Scaridae	*Scarus globiceps*	0.0013	0.0007	0.1248	0.0613
Flat	Scaridae	*Scarus oviceps*	0.0097	0.0049	1.0616	0.7326
Flat	Scaridae	*Scarus sp.*	0.0007	0.0007	0.1264	0.1264
Flat	Serranidae	*Cephalopholis argus*	0.0020	0.0013	0.4398	0.2791
Flat	Serranidae	*Epinephelus merra*	0.0017	0.0011	0.0432	0.0321
Flat	Siganidae	*Siganus argenteus*	0.0007	0.0007	0.0792	0.0792
Flat	Siganidae	*Siganus spinus*	0.0010	0.0010	0.0651	0.0651
Flat	Zanclidae	*Zanclus cornutus*	0.0003	0.0003	0.0560	0.0560
Back	Acanthuridae	*Acanthurus achilles*	0.0010	0.0010	0.0903	0.0903

Habitat	Family	Species	Density (fish/m²)	SE density	Biomass (g/m²)	SE biomass
Back	Acanthuridae	*Acanthurus gahhm*	0.0130	0.0096	3.1741	2.6837
Back	Acanthuridae	*Acanthurus lineatus*	0.0020	0.0020	0.3234	0.3234
Back	Acanthuridae	*Acanthurus maculiceps*	0.0053	0.0035	0.7272	0.4700
Back	Acanthuridae	*Acanthurus nigricans*	0.0093	0.0046	0.7515	0.2878
Back	Acanthuridae	*Acanthurus nigrofuscus*	0.0103	0.0052	0.7854	0.3599
Back	Acanthuridae	*Acanthurus olivaceus*	0.0053	0.0035	2.8776	2.5702
Back	Acanthuridae	*Acanthurus pyroferus*	0.0037	0.0017	0.0664	0.0553
Back	Acanthuridae	*Acanthurus sp.*	0.0013	0.0013	0.4446	0.4446
Back	Acanthuridae	*Ctenochaetus striatus*	0.0395	0.0082	5.1250	1.2945
Back	Acanthuridae	*Naso caesius*	0.0070	0.0066	1.1755	0.9366
Back	Acanthuridae	*Naso lituratus*	0.0067	0.0034	0.9192	0.4855
Back	Acanthuridae	*Naso vlamingii*	0.0010	0.0010	0.1213	0.1213
Back	Acanthuridae	*Zebrasoma flavescens*	0.0003	0.0003	0.0289	0.0289
Back	Acanthuridae	*Zebrasoma scopas*	0.0083	0.0052	0.5537	0.2628
Back	Chaetodontidae	*Chaetodon auriga*	0.0030	0.0010	0.1595	0.0729
Back	Chaetodontidae	*Chaetodon ephippium*	0.0007	0.0007	0.0875	0.0875
Back	Chaetodontidae	*Chaetodon lunula*	0.0033	0.0026	0.3063	0.2940
Back	Chaetodontidae	*Chaetodon lunulatus*	0.0073	0.0023	0.5488	0.2233
Back	Chaetodontidae	*Chaetodon meyeri*	0.0007	0.0007	0.0196	0.0196
Back	Chaetodontidae	*Chaetodon ornatissimus*	0.0020	0.0020	0.2202	0.2202
Back	Chaetodontidae	*Chaetodon reticulatus*	0.0033	0.0018	0.3258	0.1748
Back	Chaetodontidae	*Chaetodon sp.*	0.0010	0.0010	0.0293	0.0293
Back	Chaetodontidae	*Chaetodon trifascialis*	0.0143	0.0039	0.5908	0.1629
Back	Chaetodontidae	*Chaetodon ulietensis*	0.0013	0.0013	0.0997	0.0997
Back	Holocentridae	*Myripristis murdjan*	0.0013	0.0013	0.3227	0.3227
Back	Kyphosidae	*Kyphosus cinerascens*	0.0007	0.0007	0.3107	0.3107
Back	Labridae	*Anampses twistii*	0.0007	0.0007	0.0415	0.0415
Back	Labridae	*Cheilinus chlorourus*	0.0007	0.0007	0.0223	0.0223
Back	Labridae	*Cheilinus fasciatus*	0.0057	0.0012	1.1620	0.2363
Back	Labridae	*Choerodon jordani*	0.0007	0.0007	0.0134	0.0134
Back	Labridae	*Epibulus insidiator*	0.0003	0.0003	0.1913	0.1913
Back	Labridae	*Halichoeres hortulanus*	0.0007	0.0004	0.0371	0.0350
Back	Labridae	*Halichoeres trimaculatus*	0.0007	0.0007	0.0302	0.0302
Back	Labridae	*Labroides bicolor*	0.0017	0.0008	0.0034	0.0017
Back	Labridae	*Labroides dimidiatus*	0.0010	0.0010	0.0005	0.0005
Back	Labridae	*Pseudocheilinus hexataenia*	0.0050	0.0050	0.0322	0.0322
Back	Labridae	*Thalassoma hardwicke*	0.0040	0.0015	0.2000	0.1361
Back	Labridae	*Thalassoma lutescens*	0.0013	0.0013	0.0191	0.0191
Back	Lethrinidae	*Lethrinus atkinsoni*	0.0003	0.0003	0.1115	0.1115
Back	Lethrinidae	*Lethrinus harak*	0.0007	0.0007	0.0125	0.0125
Back	Lethrinidae	*Lethrinus miniatus*	0.0010	0.0010	0.0469	0.0469

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back	Lethrinidae	*Lethrinus obsoletus*	0.0007	0.0007	0.0726	0.0726
Back	Lethrinidae	*Monotaxis grandoculis*	0.0197	0.0097	4.4026	2.6851
Back	Lutjanidae	*Lutjanus fulviflammus*	0.0007	0.0004	0.1353	0.0946
Back	Lutjanidae	*Lutjanus gibbus*	0.0033	0.0033	0.0599	0.0599
Back	Lutjanidae	*Lutjanus monostigma*	0.0007	0.0007	0.1744	0.1744
Back	Lutjanidae	*Macolor niger*	0.0007	0.0007	0.0954	0.0954
Back	Lutjanidae	*Paracaesio xanthura*	0.0013	0.0013	0.0050	0.0050
Back	Mullidae	*Mulloidichthys flavolineatus*	0.0452	0.0215	1.2053	0.5766
Back	Mullidae	*Mulloidichthys vanicolensis*	0.0080	0.0080	0.8590	0.8590
Back	Mullidae	*Parupeneus barberinus*	0.0037	0.0014	0.7858	0.4621
Back	Mullidae	*Parupeneus bifasciatus*	0.0003	0.0003	0.2023	0.2023
Back	Mullidae	*Parupeneus cyclostomus*	0.0003	0.0003	0.0032	0.0032
Back	Mullidae	*Parupeneus indicus*	0.0010	0.0010	0.0184	0.0184
Back	Mullidae	*Parupeneus multifasciatus*	0.0093	0.0040	1.1858	0.7374
Back	Mullidae	*Parupeneus pleurostigma*	0.0013	0.0013	0.0260	0.0260
Back	Pomacanthidae	*Pygoplites diacanthus*	0.0003	0.0003	0.1367	0.1367
Back	Pomacentridae	*Amblyglyphidodon leucogaster*	0.0037	0.0037	0.1818	0.1818
Back	Pomacentridae	*Chromis viridis*	0.0337	0.0159	0.0950	0.0536
Back	Pomacentridae	*Chromis xanthura*	0.0290	0.0204	1.4800	0.9461
Back	Pomacentridae	*Pomacentrus sp.*	0.0013	0.0013	0.2541	0.2541
Back	Pomacentridae	*Pomacentrus vaiuli*	0.0020	0.0014	0.0015	0.0013
Back	Scaridae	*Chlorurus sordidus*	0.0210	0.0102	3.0840	2.0411
Back	Scaridae	*Hipposcarus longiceps*	0.0093	0.0032	2.4526	1.0202
Back	Scaridae	*Scarus dimidiatus*	0.0007	0.0007	0.3628	0.3628
Back	Scaridae	*Scarus ghobban*	0.0277	0.0079	3.0287	0.9119
Back	Scaridae	*Scarus globiceps*	0.0054	0.0032	0.5035	0.1836
Back	Scaridae	*Scarus oviceps*	0.0196	0.0044	3.4738	0.8560
Back	Scaridae	*Scarus rubroviolaceus*	0.0007	0.0007	0.1094	0.1094
Back	Scaridae	*Scarus schlegeli*	0.0023	0.0010	0.8988	0.4350
Back	Scaridae	*Scarus tricolor*	0.0010	0.0010	0.0701	0.0701
Back	Scaridae	*Scarus xanthopleura*	0.0003	0.0003	0.0234	0.0234
Back	Serranidae	*Anyperodon leucogrammicus*	0.0003	0.0003	0.0566	0.0566
Back	Serranidae	*Cephalopholis argus*	0.0040	0.0012	1.0158	0.3518
Back	Serranidae	*Epinephelus fuscoguttatus*	0.0067	0.0067	0.3509	0.3509
Back	Serranidae	*Epinephelus merra*	0.0030	0.0011	0.2033	0.0993
Back	Serranidae	*Epinephelus polyphekadion*	0.0007	0.0004	0.3764	0.2415
Back	Siganidae	*Siganus corallinus*	0.0010	0.0010	0.0729	0.0729
Back	Siganidae	*Siganus sp.*	0.0013	0.0013	0.0579	0.0579
Back	Siganidae	*Siganus spinus*	0.0003	0.0003	0.0062	0.0062
Back	Zanclidae	*Zanclus cornutus*	0.0003	0.0003	0.0450	0.0450
Outer	Acanthuridae	*Acanthurus achilles*	0.0003	0.0003	0.0710	0.0710

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Acanthuridae	*Acanthurus leucopareius*	0.0033	0.0033	0.0114	0.0114
Outer	Acanthuridae	*Acanthurus lineatus*	0.0087	0.0063	2.4976	1.7408
Outer	Acanthuridae	*Acanthurus nigricans*	0.1095	0.0381	19.2603	8.6222
Outer	Acanthuridae	*Acanthurus nigrofuscus*	0.0027	0.0020	0.0202	0.0185
Outer	Acanthuridae	*Acanthurus pyroferus*	0.0013	0.0008	0.0951	0.0705
Outer	Acanthuridae	*Ctenochaetus marginatus*	0.0003	0.0003	0.1870	0.1870
Outer	Acanthuridae	*Ctenochaetus striatus*	0.0706	0.0302	9.8948	5.6536
Outer	Acanthuridae	*Naso caesius*	0.0277	0.0265	67.1038	65.4816
Outer	Acanthuridae	*Naso lituratus*	0.0043	0.0026	2.1087	1.7127
Outer	Acanthuridae	*Naso vlamingii*	0.0010	0.0010	0.4794	0.4794
Outer	Acanthuridae	*Paracanthurus hepatus*	0.0003	0.0003	0.0681	0.0681
Outer	Acanthuridae	*Zebrasoma flavescens*	0.0007	0.0007	0.0181	0.0181
Outer	Acanthuridae	*Zebrasoma scopas*	0.0030	0.0016	0.2693	0.1663
Outer	Balistidae	*Balistapus undulatus*	0.0023	0.0012	0.3267	0.2187
Outer	Balistidae	*Melichthys vidua*	0.0003	0.0003	0.0186	0.0186
Outer	Chaetodontidae	*Chaetodon auriga*	0.0027	0.0010	0.1425	0.0617
Outer	Chaetodontidae	*Chaetodon baronessa*	0.0003	0.0003	0.0163	0.0163
Outer	Chaetodontidae	*Chaetodon ephippium*	0.0010	0.0007	0.1979	0.1264
Outer	Chaetodontidae	*Chaetodon lunula*	0.0007	0.0007	0.0871	0.0871
Outer	Chaetodontidae	*Chaetodon lunulatus*	0.0087	0.0040	0.4979	0.2973
Outer	Chaetodontidae	*Chaetodon pelewensis*	0.0020	0.0014	0.0800	0.0728
Outer	Chaetodontidae	*Chaetodon punctatofasciatus*	0.0007	0.0007	0.0196	0.0196
Outer	Chaetodontidae	*Chaetodon reticulatus*	0.0050	0.0020	0.4282	0.1831
Outer	Chaetodontidae	*Chaetodon semeion*	0.0007	0.0007	0.1191	0.1191
Outer	Chaetodontidae	*Chaetodon sp.*	0.0013	0.0013	0.2786	0.2786
Outer	Chaetodontidae	*Chaetodon trifascialis*	0.0073	0.0048	0.7414	0.5915
Outer	Chaetodontidae	*Chaetodon ulietensis*	0.0050	0.0027	0.3394	0.1767
Outer	Chaetodontidae	*Heniochus acuminatus*	0.0017	0.0010	0.2965	0.1956
Outer	Holocentridae	*Myripristis murdjan*	0.0003	0.0003	0.0586	0.0586
Outer	Holocentridae	*Myripristis pralinia*	0.0007	0.0007	0.1161	0.1161
Outer	Labridae	*Anampses twistii*	0.0003	0.0003	0.0241	0.0241
Outer	Labridae	*Cheilinus fasciatus*	0.0023	0.0010	0.2902	0.1485
Outer	Labridae	*Cheilinus undulatus*	0.0040	0.0032	4.0618	3.9613
Outer	Labridae	*Epibulus insidiator*	0.0003	0.0003	0.0013	0.0013
Outer	Labridae	*Gomphosus varius*	0.0153	0.0069	1.3563	0.5624
Outer	Labridae	*Halichoeres hortulanus*	0.0007	0.0007	0.0348	0.0348
Outer	Labridae	*Hemigymnus fasciatus*	0.0003	0.0003	0.0024	0.0024
Outer	Labridae	*Labroides bicolor*	0.0010	0.0010	0.0021	0.0021
Outer	Labridae	*Labroides dimidiatus*	0.0010	0.0007	0.0005	0.0004
Outer	Labridae	*Thalassoma hardwicke*	0.0010	0.0010	0.0909	0.0909
Outer	Labridae	*Thalassoma purpureum*	0.0003	0.0003	0.2483	0.2483

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Labridae	*Thalassoma trilobatum*	0.0007	0.0007	0.3081	0.3081
Outer	Lethrinidae	*Gnathodentex aureolineatus*	0.0003	0.0003	0.0069	0.0069
Outer	Lethrinidae	*Lethrinus microdon*	0.0007	0.0007	0.1977	0.1977
Outer	Lethrinidae	*Monotaxis grandoculis*	0.0333	0.0294	0.9259	0.3752
Outer	Lutjanidae	*Lutjanus bohar*	0.0010	0.0007	0.0714	0.0509
Outer	Lutjanidae	*Lutjanus gibbus*	0.0003	0.0003	0.1881	0.1881
Outer	Lutjanidae	*Lutjanus monostigma*	0.0013	0.0013	0.3097	0.3097
Outer	Lutjanidae	*Macolor niger*	0.0030	0.0019	0.5255	0.2934
Outer	Mullidae	*Parupeneus bifasciatus*	0.0010	0.0007	0.1168	0.0755
Outer	Mullidae	*Parupeneus multifasciatus*	0.0037	0.0016	0.2678	0.1570
Outer	Pomacanthidae	*Centropyge bispinosus*	0.0037	0.0037	0.0134	0.0134
Outer	Pomacanthidae	*Centropyge flavissimus*	0.0030	0.0015	0.0682	0.0276
Outer	Pomacanthidae	*Centropyge heraldi*	0.0003	0.0003	0.0094	0.0094
Outer	Pomacanthidae	*Centropyge loriculus*	0.0010	0.0010	0.0102	0.0102
Outer	Pomacanthidae	*Pygoplites diacanthus*	0.0010	0.0007	0.1675	0.1082
Outer	Pomacentridae	*Amblyglyphidodon leucogaster*	0.0013	0.0013	0.0213	0.0213
Outer	Pomacentridae	*Chromis acares*	0.0050	0.0050	0.0037	0.0037
Outer	Pomacentridae	*Chromis margaritifer*	0.0707	0.0620	0.8607	0.7860
Outer	Pomacentridae	*Chromis sp.*	0.0167	0.0167	0.1126	0.1126
Outer	Pomacentridae	*Chromis viridis*	0.0350	0.0213	0.0625	0.0335
Outer	Pomacentridae	*Chromis xanthura*	0.0979	0.0190	1.8605	0.9065
Outer	Pomacentridae	*Dascyllus aruanus*	0.0007	0.0007	0.0166	0.0166
Outer	Pomacentridae	*Plectroglyphidodon dickii*	0.0040	0.0023	0.1374	0.0734
Outer	Pomacentridae	*Pomacentrus coelestis*	0.0167	0.0167	0.1052	0.1052
Outer	Pomacentridae	*Pomacentrus vaiuli*	0.0030	0.0020	0.0183	0.0161
Outer	Scaridae	*Chlorurus microrhinos*	0.0003	0.0003	0.1910	0.1910
Outer	Scaridae	*Chlorurus sordidus*	0.0047	0.0021	0.5914	0.3310
Outer	Scaridae	*Scarus chameleon*	0.0013	0.0013	0.4233	0.4233
Outer	Scaridae	*Scarus ghobban*	0.0177	0.0077	5.4687	2.6205
Outer	Scaridae	*Scarus globiceps*	0.0033	0.0015	0.2590	0.1626
Outer	Scaridae	*Scarus longipinnis*	0.0007	0.0007	0.8493	0.8493
Outer	Scaridae	*Scarus niger*	0.0003	0.0003	0.0232	0.0232
Outer	Scaridae	*Scarus oviceps*	0.0030	0.0014	0.2715	0.1252
Outer	Scaridae	*Scarus rubroviolaceus*	0.0047	0.0036	6.4589	6.1985
Outer	Serranidae	*Cephalopholis argus*	0.0073	0.0025	3.5046	1.5569
Outer	Serranidae	*Gracila albomarginata*	0.0003	0.0003	0.1629	0.1629
Outer	Siganidae	*Siganus argenteus*	0.0007	0.0007	0.1866	0.1866
Outer	Zanclidae	*Zanclus cornutus*	0.0040	0.0021	0.3902	0.2608

Appendix 8 Mean density and biomass of all fish recorded at the FCA site by habitat

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Flat	Acanthuridae	*Acanthurus blochii*	0.0048	0.0048	0.1816	0.1816
Flat	Acanthuridae	*Acanthurus gahhm*	0.0024	0.0024	0.0153	0.0153
Flat	Acanthuridae	*Acanthurus lineatus*	0.0016	0.0012	0.2688	0.2003
Flat	Acanthuridae	*Acanthurus nigricans*	0.0044	0.0039	0.5696	0.5256
Flat	Acanthuridae	*Acanthurus olivaceus*	0.0012	0.0008	0.0465	0.0432
Flat	Acanthuridae	*Acanthurus pyroferus*	0.0052	0.0043	0.2319	0.2183
Flat	Acanthuridae	*Acanthurus triostegus*	0.0408	0.0130	1.0857	0.3624
Flat	Acanthuridae	*Ctenochaetus striatus*	0.0032	0.0015	0.2904	0.1608
Flat	Acanthuridae	*Naso lituratus*	0.0012	0.0008	0.0595	0.0568
Flat	Acanthuridae	*Naso unicornis*	0.0012	0.0012	0.0348	0.0348
Flat	Balistidae	*Rhinecanthus aculeatus*	0.0048	0.0021	0.1058	0.0396
Flat	Balistidae	*Rhinecanthus rectangulus*	0.0008	0.0005	0.0194	0.0135
Flat	Chaetodontidae	*Chaetodon auriga*	0.0016	0.0012	0.2670	0.2265
Flat	Chaetodontidae	*Chaetodon citrinellus*	0.0020	0.0013	0.0391	0.0290
Flat	Chaetodontidae	*Chaetodon kleinii*	0.0004	0.0004	0.0009	0.0009
Flat	Chaetodontidae	*Chaetodon lunulatus*	0.0012	0.0012	0.0027	0.0027
Flat	Chaetodontidae	*Chaetodon ornatissimus*	0.0004	0.0004	0.0196	0.0196
Flat	Chaetodontidae	*Chaetodon reticulatus*	0.0020	0.0020	0.0423	0.0423
Flat	Chaetodontidae	*Chaetodon trifascialis*	0.0028	0.0028	0.0582	0.0582
Flat	Labridae	*Cheilinus fasciatus*	0.0008	0.0008	0.0490	0.0490
Flat	Labridae	*Cheilinus trilobatus*	0.0004	0.0004	0.0054	0.0054
Flat	Labridae	*Cheilinus undulatus*	0.0004	0.0004	0.0141	0.0141
Flat	Labridae	*Halichoeres richmondi*	0.0016	0.0012	0.0028	0.0023
Flat	Labridae	*Halichoeres trimaculatus*	0.0124	0.0124	0.1592	0.1592
Flat	Labridae	*Labroides dimidiatus*	0.0012	0.0008	0.0030	0.0028
Flat	Labridae	*Thalassoma hardwicke*	0.0021	0.0021	0.0267	0.0267
Flat	Lethrinidae	*Monotaxis grandoculis*	0.0004	0.0004	0.0910	0.0910
Flat	Mullidae	*Mulloidichthys flavolineatus*	0.0096	0.0063	0.3966	0.2425
Flat	Mullidae	*Parupeneus bifasciatus*	0.0020	0.0015	0.0243	0.0164
Flat	Mullidae	*Parupeneus cyclostomus*	0.0024	0.0007	0.4409	0.3653
Flat	Mullidae	*Parupeneus multifasciatus*	0.0088	0.0034	0.3416	0.1684
Flat	Mullidae	*Parupeneus pleurostigma*	0.0008	0.0008	0.1364	0.1364
Flat	Pomacanthidae	*Centropyge flavissimus*	0.0020	0.0015	0.1028	0.0894
Flat	Pomacanthidae	*Pomacanthus imperator*	0.0004	0.0004	0.0599	0.0599
Flat	Pomacanthidae	*Pygoplites diacanthus*	0.0004	0.0004	0.0368	0.0368
Flat	Pomacentridae	*Chromis viridis*	0.0088	0.0088	0.0755	0.0755
Flat	Pomacentridae	*Chromis xanthura*	0.0148	0.0092	0.2745	0.2153
Flat	Pomacentridae	*Pomacentrus sp.*	0.0044	0.0044	0.0413	0.0413
Flat	Pomacentridae	*Pomacentrus vaiuli*	0.0068	0.0068	0.1393	0.1393
Flat	Pomacentridae	*Stegastes nigricans*	0.0040	0.0040	0.0803	0.0803

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Flat	Scaridae	*Chlorurus sordidus*	0.0036	0.0022	0.2535	0.1583
Flat	Scaridae	*Scarus ghobban*	0.0088	0.0050	0.7398	0.5248
Flat	Scaridae	*Scarus globiceps*	0.0012	0.0008	0.2624	0.2520
Flat	Scaridae	*Scarus oviceps*	0.0024	0.0015	0.2811	0.1939
Flat	Scaridae	*Scarus rubroviolaceus*	0.0016	0.0016	0.1498	0.1498
Flat	Scaridae	*Scarus schlegeli*	0.0004	0.0004	0.0086	0.0086
Flat	Scaridae	*Scarus tricolor*	0.0008	0.0008	0.0169	0.0169
Flat	Serranidae	*Cephalopholis argus*	0.0012	0.0008	0.1206	0.0800
Flat	Serranidae	*Epinephelus merra*	0.0068	0.0034	0.4735	0.2014
Flat	Serranidae	*Plectropomus maculatus*	0.0004	0.0004	0.0182	0.0182
Back	Acanthuridae	*Acanthurus achilles*	0.0017	0.0017	0.3551	0.3551
Back	Acanthuridae	*Acanthurus blochii*	0.0070	0.0059	2.0447	2.0324
Back	Acanthuridae	*Acanthurus lineatus*	0.0163	0.0082	2.4958	1.1994
Back	Acanthuridae	*Acanthurus nigricans*	0.0217	0.0141	2.7788	1.9841
Back	Acanthuridae	*Acanthurus nigrofuscus*	0.0003	0.0003	0.0006	0.0006
Back	Acanthuridae	*Acanthurus olivaceus*	0.0013	0.0013	0.5527	0.5527
Back	Acanthuridae	*Acanthurus pyroferus*	0.0087	0.0043	1.6915	1.6516
Back	Acanthuridae	*Acanthurus triostegus*	0.0020	0.0020	0.1748	0.1748
Back	Acanthuridae	*Acanthurus xanthopterus*	0.0010	0.0010	0.3973	0.3973
Back	Acanthuridae	*Ctenochaetus binotatus*	0.0007	0.0007	0.1887	0.1887
Back	Acanthuridae	*Ctenochaetus striatus*	0.0307	0.0104	4.2618	1.9063
Back	Acanthuridae	*Naso lituratus*	0.0207	0.0167	16.4103	15.0947
Back	Acanthuridae	*Naso sp.*	0.0013	0.0013	0.0363	0.0363
Back	Acanthuridae	*Naso unicornis*	0.0203	0.0203	4.9436	4.9436
Back	Acanthuridae	*Naso vlamingii*	0.0010	0.0010	0.5352	0.5352
Back	Acanthuridae	*Zebrasoma scopas*	0.0023	0.0023	0.1051	0.1051
Back	Balistidae	*Balistapus undulatus*	0.0003	0.0003	0.0493	0.0493
Back	Balistidae	*Rhinecanthus aculeatus*	0.0007	0.0007	0.0130	0.0130
Back	Balistidae	*Rhinecanthus rectangulus*	0.0013	0.0010	0.0545	0.0345
Back	Chaetodontidae	*Chaetodon auriga*	0.0010	0.0007	0.0689	0.0639
Back	Chaetodontidae	*Chaetodon citrinellus*	0.0003	0.0003	0.0135	0.0135
Back	Chaetodontidae	*Chaetodon kleinii*	0.0010	0.0010	0.0054	0.0054
Back	Chaetodontidae	*Chaetodon lineolatus*	0.0010	0.0010	0.2572	0.2572
Back	Chaetodontidae	*Chaetodon lunulatus*	0.0010	0.0007	0.0051	0.0036
Back	Chaetodontidae	*Chaetodon melannotus*	0.0013	0.0013	0.1370	0.1370
Back	Chaetodontidae	*Chaetodon ornatissimus*	0.0003	0.0003	0.0163	0.0163
Back	Chaetodontidae	*Chaetodon reticulatus*	0.0013	0.0010	0.1123	0.0772
Back	Chaetodontidae	*Chaetodon sp.*	0.0007	0.0007	0.0028	0.0028
Back	Chaetodontidae	*Chaetodon trifascialis*	0.0033	0.0026	0.2791	0.2214
Back	Chaetodontidae	*Chaetodon ulietensis*	0.0003	0.0003	0.0131	0.0131
Back	Chaetodontidae	*Forcipiger flavissimus*	0.0010	0.0010	0.2793	0.2793

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back	Haemulidae	*Plectorhinchus sp.*	0.0013	0.0013	1.7316	1.7316
Back	Holocentridae	*Myripristis murdjan*	0.0003	0.0003	0.0099	0.0099
Back	Holocentridae	*Myripristis violacea*	0.0003	0.0003	0.0503	0.0503
Back	Holocentridae	*Sargocentron microstoma*	0.0013	0.0013	0.2417	0.2417
Back	Holocentridae	*Sargocentron spiniferum*	0.0043	0.0043	2.9908	2.9908
Back	Labridae	*Bodianus anthioides*	0.0003	0.0003	0.0006	0.0006
Back	Labridae	*Cheilinus fasciatus*	0.0083	0.0047	3.1300	2.1475
Back	Labridae	*Choerodon jordani*	0.0007	0.0007	0.0700	0.0700
Back	Labridae	*Epibulus insidiator*	0.0010	0.0010	0.2531	0.2531
Back	Labridae	*Gomphosus varius*	0.0007	0.0007	0.0106	0.0106
Back	Labridae	*Halichoeres hortulanus*	0.0003	0.0003	0.0300	0.0300
Back	Labridae	*Halichoeres trimaculatus*	0.0050	0.0050	0.1505	0.1505
Back	Labridae	*Hemigymnus fasciatus*	0.0017	0.0017	1.2994	1.2994
Back	Labridae	*Hemigymnus melapterus*	0.0013	0.0013	0.0357	0.0357
Back	Labridae	*Labrichthys unilineatus*	0.0003	0.0003	0.0001	0.0001
Back	Labridae	*Labroides bicolor*	0.0010	0.0007	0.0009	0.0007
Back	Labridae	*Labroides dimidiatus*	0.0040	0.0036	0.0106	0.0097
Back	Labridae	*Thalassoma hardwicke*	0.0167	0.0155	0.2337	0.2284
Back	Labridae	*Thalassoma lunare*	0.0013	0.0013	0.0073	0.0073
Back	Lethrinidae	*Lethrinus xanthochilus*	0.0010	0.0010	0.4822	0.4822
Back	Lethrinidae	*Monotaxis grandoculis*	0.0134	0.0091	5.7404	3.6502
Back	Lutjanidae	*Lutjanus fulviflammus*	0.0047	0.0047	1.9157	1.9157
Back	Lutjanidae	*Lutjanus gibbus*	0.0003	0.0003	0.2303	0.2303
Back	Mullidae	*Mulloidichthys flavolineatus*	0.0017	0.0017	0.0886	0.0886
Back	Mullidae	*Parupeneus barberinus*	0.0033	0.0016	0.7043	0.2325
Back	Mullidae	*Parupeneus ciliatus*	0.0063	0.0063	3.2764	3.2764
Back	Mullidae	*Parupeneus cyclostomus*	0.0127	0.0100	2.0791	2.0481
Back	Mullidae	*Parupeneus multifasciatus*	0.0117	0.0061	0.4946	0.2157
Back	Mullidae	*Parupeneus pleurostigma*	0.0010	0.0007	0.0029	0.0021
Back	Nemipteridae	*Scolopsis lineatus*	0.0020	0.0020	0.0022	0.0022
Back	Pomacanthidae	*Centropyge bicolor*	0.0030	0.0017	0.1105	0.0814
Back	Pomacanthidae	*Centropyge flavissimus*	0.0020	0.0014	0.1080	0.0874
Back	Pomacanthidae	*Pomacanthus semicirculatus*	0.0007	0.0007	0.5124	0.5124
Back	Pomacentridae	*Amblyglyphidodon leucogaster*	0.0003	0.0003	0.0019	0.0019
Back	Pomacentridae	*Chromis margaritifer*	0.0007	0.0007	0.0163	0.0163
Back	Pomacentridae	*Chromis viridis*	0.0560	0.0232	0.0782	0.0321
Back	Pomacentridae	*Chromis xanthura*	0.0557	0.0168	1.3105	0.8785
Back	Pomacentridae	*Chrysiptera unimaculata*	0.0043	0.0043	0.0590	0.0590
Back	Pomacentridae	*Pomacentrus coelestis*	0.0083	0.0083	0.0226	0.0226
Back	Pomacentridae	*Pomacentrus vaiuli*	0.0143	0.0143	0.1098	0.1098
Back	Scaridae	*Chlorurus sordidus*	0.0083	0.0065	0.2726	0.2572

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back	Scaridae	*Hipposcarus longiceps*	0.0043	0.0029	1.3159	1.2010
Back	Scaridae	*Scarus ghobban*	0.0053	0.0032	0.5792	0.3391
Back	Scaridae	*Scarus globiceps*	0.0063	0.0046	1.2534	0.9205
Back	Scaridae	*Scarus oviceps*	0.0103	0.0063	1.9582	1.3890
Back	Scaridae	*Scarus schlegeli*	0.0003	0.0003	0.0561	0.0561
Back	Scaridae	*Scarus xanthopleura*	0.0010	0.0010	0.0701	0.0701
Back	Serranidae	*Cephalopholis argus*	0.0017	0.0008	0.4943	0.2847
Back	Serranidae	*Cephalopholis boenak*	0.0007	0.0007	0.1432	0.1432
Back	Serranidae	*Cephalopholis urodeta*	0.0003	0.0003	0.0570	0.0570
Back	Serranidae	*Epinephelus howlandi*	0.0017	0.0017	0.0856	0.0856
Back	Serranidae	*Epinephelus merra*	0.0027	0.0013	0.1709	0.0896
Back	Serranidae	*Epinephelus tukula*	0.0013	0.0013	0.0022	0.0022
Back	Siganidae	*Siganus argenteus*	0.0123	0.0116	3.9383	3.8287
Back	Siganidae	*Siganus corallinus*	0.0007	0.0007	0.0103	0.0103
Back	Zanclidae	*Zanclus cornutus*	0.0013	0.0010	0.2239	0.1661
Outer	Acanthuridae	*Acanthurus achilles*	0.0017	0.0011	0.1633	0.1042
Outer	Acanthuridae	*Acanthurus blochii*	0.0167	0.0151	2.1357	1.8060
Outer	Acanthuridae	*Acanthurus gahhm*	0.0027	0.0018	0.4654	0.3501
Outer	Acanthuridae	*Acanthurus lineatus*	0.0007	0.0007	0.2383	0.2383
Outer	Acanthuridae	*Acanthurus nigricans*	0.0351	0.0131	5.7572	2.2998
Outer	Acanthuridae	*Acanthurus nigrofuscus*	0.0050	0.0034	0.4024	0.2547
Outer	Acanthuridae	*Acanthurus nigroris*	0.0010	0.0010	0.0903	0.0903
Outer	Acanthuridae	*Acanthurus olivaceus*	0.0007	0.0007	0.2764	0.2764
Outer	Acanthuridae	*Acanthurus pyroferus*	0.0103	0.0066	0.2158	0.2077
Outer	Acanthuridae	*Acanthurus sp.*	0.0003	0.0003	0.0090	0.0090
Outer	Acanthuridae	*Acanthurus triostegus*	0.0020	0.0020	0.0617	0.0617
Outer	Acanthuridae	*Ctenochaetus striatus*	0.0422	0.0098	8.2034	2.2128
Outer	Acanthuridae	*Ctenochaetus strigosus*	0.0017	0.0017	0.2708	0.2708
Outer	Acanthuridae	*Naso caesius*	0.0067	0.0067	6.4531	6.4531
Outer	Acanthuridae	*Naso lituratus*	0.0027	0.0014	0.9264	0.6649
Outer	Acanthuridae	*Naso unicornis*	0.0038	0.0030	7.7933	7.3818
Outer	Acanthuridae	*Naso vlamingii*	0.0023	0.0013	3.6725	2.4348
Outer	Acanthuridae	*Zebrasoma scopas*	0.0010	0.0007	0.0202	0.0128
Outer	Balistidae	*Balistapus undulatus*	0.0040	0.0022	0.3622	0.2238
Outer	Balistidae	*Melichthys vidua*	0.0023	0.0015	0.1838	0.1165
Outer	Balistidae	*Odonus niger*	0.0003	0.0003	0.0493	0.0493
Outer	Balistidae	*Pseudobalistes flavimarginatus*	0.0003	0.0003	0.3453	0.3453
Outer	Balistidae	*Rhinecanthus aculeatus*	0.0020	0.0014	0.4577	0.4147
Outer	Chaetodontidae	*Chaetodon citrinellus*	0.0007	0.0004	0.0188	0.0166
Outer	Chaetodontidae	*Chaetodon ephippium*	0.0007	0.0007	0.0004	0.0004
Outer	Chaetodontidae	*Chaetodon lunulatus*	0.0033	0.0016	0.2531	0.1244

Habitat	Family	Species	Density (fish/m²)	SE density	Biomass (g/m²)	SE biomass
Outer	Chaetodontidae	*Chaetodon ornatissimus*	0.0007	0.0007	0.0046	0.0046
Outer	Chaetodontidae	*Chaetodon pelewensis*	0.0060	0.0038	0.2864	0.2024
Outer	Chaetodontidae	*Chaetodon punctatofasciatus*	0.0003	0.0003	0.0163	0.0163
Outer	Chaetodontidae	*Chaetodon reticulatus*	0.0050	0.0023	0.4096	0.2007
Outer	Chaetodontidae	*Chaetodon trifascialis*	0.0003	0.0003	0.0458	0.0458
Outer	Chaetodontidae	*Chaetodon ulietensis*	0.0010	0.0010	0.0512	0.0512
Outer	Chaetodontidae	*Forcipiger longirostris*	0.0013	0.0010	0.1261	0.0847
Outer	Holocentridae	*Myripristis berndti*	0.0013	0.0013	0.1831	0.1831
Outer	Holocentridae	*Sargocentron caudimaculatum*	0.0007	0.0007	0.0561	0.0561
Outer	Holocentridae	*Sargocentron microstoma*	0.0010	0.0010	0.1813	0.1813
Outer	Labridae	*Bodianus axillaris*	0.0050	0.0050	0.0805	0.0805
Outer	Labridae	*Cheilinus fasciatus*	0.0027	0.0008	1.0420	0.7763
Outer	Labridae	*Cheilinus undulatus*	0.0017	0.0010	1.9079	1.0766
Outer	Labridae	*Coris gaimard*	0.0003	0.0003	0.1390	0.1390
Outer	Labridae	*Epibulus insidiator*	0.0007	0.0004	0.4247	0.2706
Outer	Labridae	*Gomphosus varius*	0.0050	0.0029	0.3582	0.2265
Outer	Labridae	*Halichoeres hortulanus*	0.0033	0.0018	0.1764	0.0991
Outer	Labridae	*Hemigymnus fasciatus*	0.0007	0.0007	0.0432	0.0432
Outer	Labridae	*Labroides bicolor*	0.0013	0.0008	0.0138	0.0134
Outer	Labridae	*Labroides dimidiatus*	0.0033	0.0026	0.0031	0.0027
Outer	Labridae	*Thalassoma hardwicke*	0.0037	0.0023	0.2560	0.2002
Outer	Labridae	*Thalassoma purpureum*	0.0007	0.0004	0.0103	0.0065
Outer	Lethrinidae	*Lethrinus obsoletus*	0.0007	0.0007	0.2764	0.2764
Outer	Lethrinidae	*Lethrinus sp.*	0.0003	0.0003	0.1424	0.1424
Outer	Lethrinidae	*Monotaxis grandoculis*	0.0103	0.0055	6.6413	3.6923
Outer	Lutjanidae	*Lutjanus bohar*	0.0003	0.0003	0.0983	0.0983
Outer	Lutjanidae	*Lutjanus gibbus*	0.0217	0.0197	9.5808	6.4538
Outer	Lutjanidae	*Lutjanus kasmira*	0.0010	0.0010	0.5269	0.5269
Outer	Lutjanidae	*Lutjanus sebae*	0.0003	0.0003	0.2837	0.2837
Outer	Lutjanidae	*Macolor niger*	0.0037	0.0027	1.8599	1.5476
Outer	Mullidae	*Mulloidichthys flavolineatus*	0.0007	0.0007	0.0286	0.0286
Outer	Mullidae	*Parupeneus bifasciatus*	0.0013	0.0008	0.1534	0.1019
Outer	Mullidae	*Parupeneus multifasciatus*	0.0070	0.0026	0.7651	0.4111
Outer	Mullidae	*Parupeneus pleurostigma*	0.0023	0.0023	0.3432	0.3432
Outer	Nemipteridae	*Pentapodus caninus*	0.0142	0.0142	0.4160	0.4160
Outer	Pomacanthidae	*Centropyge flavissimus*	0.0083	0.0038	0.2141	0.1016
Outer	Pomacanthidae	*Centropyge loriculus*	0.0003	0.0003	0.0094	0.0094
Outer	Pomacanthidae	*Pygoplites diacanthus*	0.0010	0.0007	0.1304	0.1078
Outer	Pomacentridae	*Amphiprion chrysopterus*	0.0007	0.0007	0.0010	0.0010
Outer	Pomacentridae	*Chromis margaritifer*	0.0373	0.0258	0.2124	0.1174
Outer	Pomacentridae	*Chromis xanthura*	0.2261	0.0956	4.2062	2.6252

Habitat	Family	Species	Density (fish/m²)	SE density	Biomass (g/m²)	SE biomass
Outer	Pomacentridae	*Plectroglyphidodon dickii*	0.0013	0.0010	0.0586	0.0435
Outer	Pomacentridae	*Plectroglyphidodon johnstonianus*	0.0010	0.0010	0.0324	0.0324
Outer	Pomacentridae	*Pomacentrus brachialis*	0.0017	0.0017	0.0651	0.0651
Outer	Pomacentridae	*Pomacentrus coelestis*	0.0027	0.0027	0.0574	0.0574
Outer	Pomacentridae	*Pomacentrus moluccensis*	0.0007	0.0007	0.0088	0.0088
Outer	Pomacentridae	*Pomacentrus vaiuli*	0.0373	0.0158	0.1804	0.0801
Outer	Pomacentridae	*Stegastes lividus*	0.0010	0.0010	0.0013	0.0013
Outer	Pomacentridae	*Stegastes nigricans*	0.0133	0.0133	0.0091	0.0091
Outer	Scaridae	*Cetoscarus bicolor*	0.0007	0.0007	0.5727	0.5727
Outer	Scaridae	*Chlorurus sordidus*	0.0080	0.0045	1.4905	0.9558
Outer	Scaridae	*Hipposcarus longiceps*	0.0037	0.0023	1.9179	1.2322
Outer	Scaridae	*Scarus altipinnis*	0.0003	0.0003	0.1651	0.1651
Outer	Scaridae	*Scarus chameleon*	0.0007	0.0007	0.3998	0.3998
Outer	Scaridae	*Scarus ghobban*	0.0083	0.0017	1.9358	0.5397
Outer	Scaridae	*Scarus globiceps*	0.0010	0.0007	0.2682	0.2652
Outer	Scaridae	*Scarus oviceps*	0.0053	0.0025	0.5203	0.2477
Outer	Scaridae	*Scarus rubroviolaceus*	0.0007	0.0007	0.0467	0.0467
Outer	Scaridae	*Scarus schlegeli*	0.0017	0.0017	0.7683	0.7683
Outer	Scaridae	*Scarus sp.*	0.0007	0.0007	0.4625	0.4625
Outer	Scaridae	*Scarus tricolor*	0.0007	0.0007	0.0467	0.0467
Outer	Serranidae	*Cephalopholis argus*	0.0047	0.0015	2.9339	0.9381
Outer	Serranidae	*Cephalopholis leopardus*	0.0010	0.0007	0.0754	0.0725
Outer	Serranidae	*Cephalopholis urodeta*	0.0027	0.0014	0.2926	0.2528
Outer	Serranidae	*Epinephelus merra*	0.0007	0.0007	0.0168	0.0168
Outer	Serranidae	*Epinephelus espilotoceps*	0.0010	0.0007	0.1777	0.1143
Outer	Siganidae	*Siganus argenteus*	0.0027	0.0018	0.9606	0.8307
Outer	Siganidae	*Siganus vulpinus*	0.0007	0.0007	0.0453	0.0453

Appendix 9 Invertebrate survey form

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 /	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/

Appendix 10 GPS positions of manta tow surveys conducted at the Fongafale and FCA monitoring sites, 2011

Site	Station ID	Replicate	Start Latitide (S)	Start Longitude (E)
Fongafale	Manta 1	1	8.49312	179.19217
Fongafale	Manta 1	2	8.49105	179.19178
Fongafale	Manta 1	3	8.48830	179.19117
Fongafale	Manta 1	4	8.48502	179.19057
Fongafale	Manta 1	5	8.48215	179.19015
Fongafale	Manta 1	6	8.47922	179.18975
Fongafale	Manta 2	1	8.47172	179.18775
Fongafale	Manta 2	2	8.46908	179.18627
Fongafale	Manta 2	3	8.46622	179.18522
Fongafale	Manta 2	4	8.46363	179.18402
Fongafale	Manta 2	5	8.45958	179.18253
Fongafale	Manta 2	6	8.45780	179.18165
Fongafale	Manta 3	1	8.43752	179.16530
Fongafale	Manta 3	2	8.43563	179.16313
Fongafale	Manta 3	3	8.43417	179.16073
Fongafale	Manta 3	4	8.43275	179.15830
Fongafale	Manta 3	5	8.43117	179.15537
Fongafale	Manta 3	6	8.43032	179.15247
Fongafale	Manta 4	1	8.43150	179.12327
Fongafale	Manta 4	2	8.43270	179.12008
Fongafale	Manta 4	3	8.43135	179.11710
Fongafale	Manta 4	4	8.43128	179.11388
Fongafale	Manta 4	5	8.43678	179.09555
Fongafale	Manta 4	6	8.43715	179.09210
Fongafale	Manta 7	1	8.54005	179.17203
Fongafale	Manta 7	2	8.54120	179.16868
Fongafale	Manta 7	3	8.54323	179.16573
Fongafale	Manta 7	4	8.54448	179.16237
Fongafale	Manta 7	5	8.54943	179.15665
Fongafale	Manta 7	6	8.55103	179.15373
Fongafale	Manta 8	1	8.55160	179.15305
Fongafale	Manta 8	2	8.55302	179.14968
Fongafale	Manta 8	3	8.55323	179.14618
Fongafale	Manta 8	4	8.55587	179.14380
Fongafale	Manta 8	5	8.55828	179.14137
Fongafale	Manta 8	6	8.56007	179.13850
FCA	Manta 10	1	8.53653	179.05222
FCA	Manta 10	2	8.53807	179.05420
FCA	Manta 10	3	8.53985	179.05505
FCA	Manta 10	4	8.54085	179.05730

Site	Station ID	Replicate	Start Latitide (S)	Start Longitude (E)
FCA	Manta 10	5	8.54817	179.05857
FCA	Manta 10	6	8.55050	179.06020
FCA	Manta 11	1	8.57778	179.06878
FCA	Manta 11	2	8.58107	179.06887
FCA	Manta 11	3	8.58373	179.06978
FCA	Manta 11	4	8.58722	179.07018
FCA	Manta 11	5	8.59005	179.07135
FCA	Manta 11	6	8.59292	179.07060
FCA	Manta 12	1	8.59638	179.07162
FCA	Manta 12	2	8.59858	179.07270
FCA	Manta 12	3	8.60075	179.07328
FCA	Manta 12	4	8.60348	179.07300
FCA	Manta 12	5	8.60642	179.07410
FCA	Manta 12	6	8.60755	179.07622
FCA	Manta 5	1	8.47805	179.06638
FCA	Manta 5	2	8.48078	179.06532
FCA	Manta 5	3	8.48295	179.06357
FCA	Manta 5	4	8.48923	179.06103
FCA	Manta 5	5	8.49062	179.06297
FCA	Manta 5	6	8.49242	179.06532
FCA	Manta 6	1	8.48790	179.05887
FCA	Manta 6	2	8.48752	179.05590
FCA	Manta 6	3	8.49013	179.05043
FCA	Manta 6	4	8.49083	179.04950
FCA	Manta 9	1	8.50982	179.04448
FCA	Manta 9	2	8.51267	179.04500
FCA	Manta 9	3	8.51457	179.04302
FCA	Manta 9	4	8.51677	179.04463
FCA	Manta 9	5	8.51893	179.04653
FCA	Manta 9	6	8.51987	179.04758

Appendix 11 Mean category score or percent cover (± SE) of each habitat category at the manta tow and reef-benthos transect (RBT) stations of the Fongafale and FCA monitoring sites, 2011

Habitat category	Manta tow		RBT	
	Fongafale	FCA	Fongafale	FCA
Depth (m)	4.67±0.19	4.38±0.28	2.03±0.12	1.46±0.16
Relief	2.97±0.23	3.50±0.15	2.68±0.06	2.39±0.17
Complexity	2.94±0.25	3.58±0.19	2.87±0.04	2.61±0.15
Oceanic Influence	3.69±0.37	4.50±0.22	4.17±0.10	4.03±0.17
Mud	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Sand	38.19±10.06	15.14±4.51	5.55±1.04	13.89±1.89
Coarse sand	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Rubble	4.58±0.67	12.92±4.11	11.08±2.70	6.94±1.11
Boulders	1.39±0.70	0.00±0.00	4.25±1.71	1.94±0.57
Consolidated rubble	3.61±1.41	8.06±3.06	2.00±0.97	4.86±1.61
Pavement	1.39±1.39	0.00±0.00	0.58±0.27	22.64±5.56
Live coral	24.17±7.60	28.47±6.35	26.67±2.77	13.06±1.67
Dead coral	26.67±8.48	35.42±11.61	49.87±3.82	36.67±4.78
Bleaching coral	0.14±0.14	0.00±0.00	0.00±0.00	0.00±0.00
Crustose coralline algae	4.17±2.42	23.61±3.41	5.55±0.64	15.97±2.17
Coralline algae	5.28±2.17	11.81±2.00	6.68±0.50	8.75±1.40
Other algae	8.11±2.99	8.75±2.09	2.08±0.42	11.25±2.65
Seagrass	0.00±0.00	0.00±0.00	0.50±0.26	0.00±0.00
Soft coral	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Sponge	0.00±0.00	2.22±1.41	0.58±0.21	0.83±0.31
Fungids	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Appendix 12 Mean density (± SE) of individual invertebrate species recorded during manta tow surveys at the Fongafale and FCA monitoring sites, 2011

Group	Species	Density (individuals/ha)	
		Fongafale	FCA
Sea cucumber	*Actinopyga mauritiana*	-	0.69±0.69
	Bohadschia argus	3.70±2.75	2.31±1.82
	Bohadschia vitiensis	2.31±1.33	0.93±0.93
	Stichopus hermanni	0.46±0.46	-
	Thelenota anax	2.31±1.82	2.78±2.78
Bivalve	*Pinctada margaritifera*	0.46±0.46	-
	Tridacna maxima	-	23.84±3.94
	Tridacna squamosa	-	4.63±1.71
Gastropod	*Conomurex luhuanus*	1.39±1.39	-
	Conus sp.	-	0.46±0.46
	Dendropoma maximum	-	20.37±13.35
	Lambis sp.	-	4.63±3.26
	Lambis truncata	-	5.09±3.24
	Turbo sp.	-	0.46±0.46
Urchin	*Diadema savignyi*	-	3.24±3.24

Appendix 13 GPS positions of reef-benthos transects conducted at the Fongafale and FCA monitoring sites, 2011

Site	Station ID	Latitude (S)	Longitude (E)
Fongafale	RBt 1	8.43670	179.16462
Fongafale	RBt 2	8.44227	179.17192
Fongafale	RBt 3	8.47548	179.18950
Fongafale	RBt 4	8.43122	179.15552
Fongafale	RBt 5	8.42930	179.14402
Fongafale	RBt 6	8.42927	179.12753
Fongafale	RBt 7	8.43143	179.11020
Fongafale	RBt 8	8.43775	179.08920
Fongafale	RBt 9	8.45917	179.08410
Fongafale	RBt 12	8.56557	179.12907
FCA	RBt 10	8.48477	179.06178
FCA	RBt 11	8.48830	179.05920
FCA	RBt 13	8.52633	179.05243
FCA	RBt 14	8.57493	179.06357
FCA	RBt 15	8.57362	179.06712
FCA	RBt 16	8.59263	179.06695

Appendix 14 Mean density (± SE) of individual invertebrate species recorded during reef-benthos transects at the Fongafale and FCA monitoring sites, 2011

Family	Species	Density (individuals/ha)	
		Fongafale	FCA
Sea cucumber	*Actinopyga mauritiana*	4.17±4.17	-
	Bohadschia argus	12.50±12.50	-
	Holothuria atra	50.00±45.56	-
Bivalve	*Pinctada margaritifera*	4.17±4.17	-
	Tridacna maxima	50.00±18.43	125.00±90.01
	Tridacna squamosa	16.67±12.73	-
Crustacean	*Dardanus* sp.	8.33±8.33	-
	Parribacus antarcticus	-	13.89±13.89
Gastropod	*Astralium* sp.	12.50±12.50	-
	Cerithium nodulosum	8.33±5.56	-
	Charonia tritonis	4.17±4.17	-
	Conus flavidus	4.17±4.17	-
	Conus miles	-	20.83±20.83
	Conus sp.	62.50±33.59	173.61±82.93
	Conus vexillum	-	69.44±46.48
	Cymatium sp.	254.17±249.57	-
	Cypraea sp.	29.17±29.17	20.83±20.83
	Cypraea tigris	4.17±4.17	13.89±13.89
	Dendropoma maximum	1362.50±927.50	555.56±466.43
	Drupa morum	-	13.89±8.78
	Drupa sp.	483.33±455.72	6.94±6.94
	Filifuscus filamentosa[2]	-	6.94±6.94
	Harpago chiragra[3]	41.67±41.67	6.94±6.94
	Lambis crocata	4.17±4.17	-
	Mitra mitra	-	13.89±13.89
	Monetaria annulus[4]	16.67±16.67	-
	Monetaria caputserpensis[5]	-	6.94±6.94
	Monetaria moneta[6]	13.89±13.89	-
	Morula sp.	12.50±6.36	-
	Reishia armigera[7]	4.17±4.17	13.89±13.89
	Conomurexluhuanus	-	13.89±13.89
	Tectus pyramis	50.00±22.22	76.39±44.90

[2] This species was formerly known as *Pleuroploca filamentosa*
[3] This species was formerly known as *Lambis chiragra*
[4] This species was formerly known as *Cypraea annulus*
[5] This species was formerly known as *Cypraea caputserpentis*
[6] This species was formerly known as *Cypraea moneta*
[7] This species was formerly known as *Thais armigera*

Family	**Species**	**Density (individuals/ha)**	
		Fongafale	**FCA**
	Thais aculeata	-	13.89±8.78
	Thais armigera	4.17±4.17	13.89±13.89
	Thais sp.	433.33±415.15	20.83±20.83
	Thais tuberosa	-	13.89±8.78
	Turbo argyrostomus	41.67±29.13	97.22±89.15
	Vasum ceramicum	-	6.94±6.94
Starfish	*Acanthaster planci*	4.17±4.17	-
	Linckia guildingi	8.33±8.33	-
	Linckia laevigata	4.17±4.17	-
	Linckia sp.	8.33±8.33	-
Urchin	*Diadema savignyi*	4.17±4.17	2354.17±1391.47
	Echinometra mathaei	4.17±4.17	513.89±364.78
	Tripneustes gratilla	-	48.61±48.61

Appendix 15 Comparison of mean density (± SE) of invertebrate species recorded on Funafuti Atoll during RBT surveys in the current study (Fongafale and FCA sites combined) and during PROCFish surveys in 2004–2005

Family	Species	Density (individuals/ha)	
		Fongafale	FCA
Sea cucumber	*Actinopyga mauritiana*	2.60±2.60	-
	Bohadschia argus	7.81±7.81	-
	Holothuria atra	31.25±28.59	-
Bivalve	*Pinctada margaritifera*	2.60±2.60	-
	Tridacna maxima	78.13±35.04	118.06±33.56
	Tridacna squamosa	10.42±8.07	25.46±10.73
Crustacean	*Dardanus* sp.	5.21±5.21	-
	Parribacus antarcticus	5.21±5.21	-
Gastropod	*Astralium* sp.	7.81±7.81	-
	Cerithium nodulosum	5.21±3.56	6.94±5.05
	Charonia tritonis	2.60±2.60	-
	Chicoreus ramosus	-	2.31±2.31
	Conomurex luhuanus	5.21±5.21	39.35±27.26
	Conus flavidus	2.60±2.60	-
	Conus miles	7.81±7.81	2.31±2.31
	Conus sp.	104.17±38.41	18.52±10.23
	Conus vexillum	26.04±18.59	-
	Cymatium sp.	158.85±156.10	-
	Cypraea tigris	7.81±5.67	-
	Dendropoma maximum	1059.90±599.97	-
	Drupa morum	5.21±3.56	-
	Drupa rubusidaeus	5.21±5.21	-
	Drupa sp.	304.69±285.37	-
	Drupella sp.	-	254.63±187.22
	Filifuscus filamentosa	2.60±2.60	-
	Harpago chiragra	28.65±26.00	-
	Lambis crocata	2.60±2.60	-
	Lambis truncata	54.69±54.69	20.83±6.07
	Mitra mitra	5.21±5.21	-
	Monetaria annulus	10.42±10-.42	-
	Monetaria caputserpensis	2.60±2.60	-
	Monetaria moneta	5.21±5.21	2.31±2.31
	Morula sp.	7.81±4.20	-
	Talparia talpa[8]	-	4.63±3.18
	Tectus pyramis	59.90±21.17	57.87±16.89
	Turbo argyrostomus	62.50±36.88	4.63±3.18

[8] This species was formerly known as *Cypraea talpa*

Family	**Species**	**Density (individuals/ha)**	
		Fongafale	**FCA**
	Vasum ceramicum	2.60±2.60	-
	Vasum turbinellus	2.60±2.60	-
Starfish	*Acanthaster planci*	2.60±2.60	-
	Linckia guildingi	5.21±5.21	-
	Linckia laevigata	2.60±2.60	-
	Linckia sp.	5.21±5.21	-
Urchin	*Diadema savignyi*	885.42±572.99	-
	Echinometra mathaei	195.31±143.87	370.37±156.88
	Echinothrix diadema	-	11.57±5.64
	Tripneustes gratilla	18.23±18.23	-