Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change

Funafuti Atoll
Tuvalu

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Brad Moore[1], Semese Alefaio[2] and Fulitua Siaosi[2]
[1]Coastal Fisheries Programme, Secretariat of the Pacific Community
[2]Tuvalu Department of Fisheries

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ACRONYMS

ANOVA	Analysis of Variance
AusAID	Australian Agency for International Development
CFP	Coastal Fisheries Programme
COTS	Crown-of-thorns starfish
CPC	Coral Point Count
CPUE	Catch-per-unit-effort
D-UVC	Distance-sampling Underwater Visual Census
EEZ	Exclusive Economic Zone
FCA	Funafuti Conservation Area
FL	Fork length
G	gram(s)
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
IUCN	International Union for Conservation of Nature
km	Kilometre(s)
MCRMP	Millennium Coral Reef Mapping Project
mm	millimeter(s)
MPA	Marine Protected Area
NASA	National Aeronautics and Space Administration
NGO	Non-Government Organisation
PCA	Principle Component Analysis
PCCSP	Pacific Climate Change Science Program
PERMANOVA	Permutational multivariate analysis of variance
PICTs	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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EXECUTIVE SUMMARY

Introduction

Considering the concerns of climate change and its impacts on coastal fisheries resources, the Secretariat of the Pacific Community (SPC) is implementing the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project with funding assistance from the Australian 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 could be attributed to climate change, as opposed to other causative factors. This report presents the results of the second round of monitoring conducted in Funafuti Atoll, Tuvalu, in April-May 2013. Collected data have been compared to that from the 2011 survey to examine changes in resource status over time.

Survey Design

Survey work at Funafuti Atoll covered six disciplines, including monitoring of water temperature, in-water assessments of finfish and invertebrate resources and the health of benthic habitats, creel surveys and biological monitoring of key reef fishes, and was conducted by staff from SPC's Coastal Fisheries Science and Management Section and Tuvalu's Department of Fisheries. In-water assessments were conducted in both the Funafuti Conservation Area (FCA) and locations open to fishing (hereafter termed 'Fongafale', allowing for both the effects of climate change to be decoupled from fishing effects, and an assessment on the current condition of the FCA. The fieldwork included capacity development of local counterparts by providing training in survey design and methodologies, data collection and entry, and data analysis.

Finfish Surveys

Finfish resources of Funafuti Atoll were surveyed using distance-sampling underwater visual census (D-UVC) methodology, and were conducted across reef flat, back reef, lagoon reef and outer habitats on the FCA and Fongafale sites. Reef flat, back reef and outer habitats were surveyed in 2011 and 2013, while lagoon reefs were surveyed for the first time in 2013.

Finfish diversity in both the FCA and Fongafale sites was generally higher in 2013 than 2011, with the lagoon and outer reefs of the FCA supporting the greatest diversity. In contrast, few differences were observed in mean total density or mean total biomass, or density and biomass of individual families and functional groups, amongst years for each site. Similarly, few consistent differences in finfish density or biomass were observed amongst the FCA and Fongafale sites, indicating the Conservation Area is having little effect on the protection of most finfish species.

Benthic Habitat Assessments

Benthic habitats of Funafuti Atoll were surveyed using two complementary approaches: a broad-scale method, using manta tows, and a fine-scale method, using a photoquadrat analysis. Manta tows were conducted along the back and outer reefs of the FCA and Fongafale sites. While little difference was evident in benthic habitat condition of the FCA, benthic habitats of the Fongafale site appeared in poor health in 2013, with a significant increase in macroalgae and an overall change from a coral-dominated system to and algae-dominated system evident at this site, particularly along the back reefs.

A total of 48 photoquadrat transects were conducted around Funafuti Atoll in 2013, with 24 transects established in each of the FCA and Fongafale sites, and 2,400 individual photos of the benthos analysed. Transects were positioned along the same reef flat, back reef, lagoon reef and outer reef habitats as the finfish assessments. Overall, benthic habitats appeared largely similar amongst 2011 and 2013 surveys. Outer reef habitats of both sites were in relatively good health, characterised by relatively high cover of live coral (reaching up to 77% cover for Fongafale transects, and 48% cover for FCA transects in 2013). In contrast, lagoon patch reefs, particularly at the Fongafale site, showed poor health, with high (up to 75% cover) cover of macro- and turf algae, and low live coral cover.

Invertebrate Surveys

Invertebrate resources of Funafuti Atoll were surveyed using two complementary approaches: a broad-scale method, using manta tows, and a fine-scale method, using reef-benthos transects (RBt). No significant differences were observed in density of any invertebrate species among the 2011 and 2013 surveys within either the FCA or Fongafale sites. Overall, densities of invertebrates observed during manta tow surveys were low, and few differences were observed between the FCA and Fongafale sites. Densities of the elongate giant clam (*Tridacna maxima*) were significantly higher at manta stations within the FCA than the Fongafale stations in both 2011 and 2013, yet well below the regional recommended healthy stock reference point of 750 individual/ha.

Invertebrate diversity at the RBt stations showed a slight decrease in 2013 relative to 2011 at both the FCA and Fongafale sites. The sea cucumber assemblage at the RBt stations was extremely depauperate with respect to both diversity and abundance, with no sea cucumbers observed at RBt stations in the FCA site and only three species (*Actinopyga mauritiana*, *Bohadschia argus* and *Holothuria atra*) observed at the Fongafale site (2011 and 2013 combined). None of these three species were observed in densities exceeding recommended minimum harvest densities. For other species, few consistent differences were seen amongst the 2011 and 2013 surveys for any species group. Densities of *Tridacna maxima* were similar amongst surveys at Fongafale, yet showed a large decrease within the FCA between 2011 and 2013. Densities of Diadematidae urchins were at the Fongafale site were slightly higher in 2013 than 2011.

Overall, few differences in invertebrate density were observed amongst the FCA and Fongafale sites, with densities of only the urchin families Diadematidae and Echinometridae higher in the FCA than the Fongafale stations, suggesting the Conservation Area is having little effect on the protection of invertebrate stocks.

Creel surveys

Creel surveys at Funafuti Atoll were conducted for the first time at Funafuti Atoll in 2013, and focused on commercial spear and handline fishers. Nine surveys of handline (bottom fishing) were completed, with the catches of 22 individuals fishers assessed. On average, handline trips involved 2.44fishers, and lasted 6.44 hours. The average catch per trip was 31.22 kg or 79.89 individual fish and was dominated by members of the families Lutjanidae (snappers), Lethrinidae (emperors), Serranidae (groupers) and Sphyraenidae (barracudas). The most commonly observed species in the handline catch were *Lutjanus gibbus* and *L. kasmira* (which combined represented almost 50% of the catch in terms of abundance. Average catch-per-unit-effort (CPUE) was 5.34 fish/fisher/hour, or 2.35 kg/fisher/hour.

Four surveys of night spearfishing were completed, with the catches of 20 individuals fishers assessed. On average, spearfishing trips involved 5.25 fishers and lasted on average 5.75 hours. The average catch per trip was 99.18 kg, or 129.25 individual fish, and the catch was dominated by acanthurids, in particular *Naso unicornis*, *N. lituratus* and *N. caesius*. Average CPUE was 4.66 fish/fisher/hour, or 3.50 kg/fisher/hour.

Perceptions of fishers on the status of resources were collected during six surveys. The majority of fishers surveyed indicated that they had seen changes in the fishery in the last few years, with 83% of respondents claiming they felt their catches had decreased compared to five years ago, and 67% of respondents claiming sizes of fish had decrease compared to five years ago.

Biological Monitoring

Biological monitoring of key reef fish species at Funafuti Atoll was included for the first time during the 2013 survey, and focused on five commercially harvested species: steephead parrotfish (*Chlorurus microrhinos*), honeycomb grouper (*Epinephelus merra*), humpback red snapper (*Lutjanus gibbus*), bluestripe snapper (*Lutjanus kasmira*) and orangespine unicornfish (*Naso lituratus*) and two ‘control’ species: redfin butterflyfish (*Chaetodon lunulatus*) and striated surgeonfish (*Ctenochaetus striatus*). Demographic parameters, including von Bertalanffy growth function parameters, total, natural and fishing mortality rates and lengths and ages at sex change (where applicable) were determined for each species to provide a baseline for Funafuti Atoll. Fishing mortality was found to exceed the reference point of 0.5 times the rate of natural mortality for *E. merra*. *L. gibbus* and *L. kasmira*, indicative of over-exploitation of these species.

Recommendations for Management and On-going Monitoring

Several key management recommendations are prescribed from observations during the current study that will help improve the resilience of the coastal fisheries of tFunafuti Atoll to both long-term (e.g. climate change) and short-term (e.g. overfishing) stressors. These include:

1) During the field survey a number of boats were observed extracting marine resources from the Funafuti Conservation Area. For the Conservation Area to be effective, greater enforcement of illegal fishing needs to occur.
2) Further to greater enforcement, awareness programs should be offered to the public Funafuti Atoll regarding coastal fisheries, the marine environment, the benefits of the Conservation Area, and climate change, in a effort to increase understanding and promote better management practices by stakeholders.

3) Sources of eutrophication into the lagoon need to be identified and restricted. Effort should also be made to monitor the nutrient inputs into the lagoon.

4) Fishing pressure on herbivorous fishes, in particular browsing and scraping species, should be reduced. Potential methods could include:
    - placing restrictions on destructive or highly efficient fishing practices that target these groups (e.g. night-time spearfishing);
    - the creation of education/awareness programs on the importance and value of herbivorous fishes; and
    - the creation of incentives to focus fishing pressure on pelagic species, such as small tunas, flying fish, mackerels and scads.

5) Protection should be offered to other ecologically significant and species, in particular sharks and the humphead wrasse, *Cheilinus undulatus*. Sharks, in particular, are apex predators that play a key role in maintaining healthily reef ecosystems. To conserve these iconic species we recommend that a regional moratorium be placed on shark fishing, particularly for the fin trade, and the sale of *C. undulatus*.

6) Due to the low densities, the sea cucumber fishery within Funafuti Atoll should be officially closed to allow recovery of stocks and the ecological functioning they perform. Similarly, there is no potential for commercial fishing of trochus at this time, and stocks are in need of on-going protection to build until recommended minimum harvest densities of 500–600 individuals/ha are achieved.

7) Given the over-exploitation observed for *E, merra*, *L. gibbus*, and *L. kasmira*, and large number of immature *L. gibbus* in the handline fishery, urgent management attention is required to reduce fishing pressure on these, and likely other, species. It is strongly recommended that a coastal fisheries management plan / regulations be developed that addresses various fishing activities (e.g. fishing gears and practices), restrictions on species' harvests (e.g. size limits, seasonal closures during spawning season), export of coastal resources, and community management practices.

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 (Table 1). 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 the second round of field surveys for the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project conducted in Funafuti Atoll, Tuvalu, between April and May 2013, by a team from SPC's Coastal Fisheries Science and Management Section and staff from Tuvalu's Department of Fisheries. Collected data are compared against those of the baseline survey at Funafuti Atoll conducted in 2011 (Siaosi et al. 2012). Recommendations for management and future monitoring events are also provided.

Table 1 Summary of activities and variables measured during the monitoring program in Funafuti Atoll, Tuvalu, 2013.

Task	Description	Variables measured
Monitoring of water temperate	Fine-scale monitoring of local water temperature within and outside lagoon	Water temperature (°C)
Benthic habitat assessments	Photoquadrat transects across outer, back, flat and lagoon reef habitats at selected sites	Percentage cover of benthic organisms and substrate types (with emphasis on hard corals and algae)
Finfish surveys	Distance-sampling underwater visual census surveys of finfish communities across outer, back, flat and lagoon reef habitats at selected sites	Counts and sizes of most non-cryptic fish species, habitat indices (topography, complexity, substrate type, cover of coral and algae), other incidental observations (e.g. coral bleaching)
Invertebrate surveys	Broad-scale (manta tow) and fine-scale (reef benthos transect) assessments of invertebrate communities	Counts of observed invertebrate species, habitat indices (relief, complexity, cover of coral and algae), other incidental observations (e.g. coral bleaching)
Creel surveys	Assessment of fishing activities and catch	Fisher demographics, catch composition, length and weight of individuals caught, fishing methods, catch-per-unit effort, fisher's perceptions
Biological sampling of finfish	Examination of key population characteristics of focal reef fish species	Age and growth relationships, mortality rates

Tuvalu

Background

Tuvalu is located in the western South Pacific Ocean between the 5.6 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.

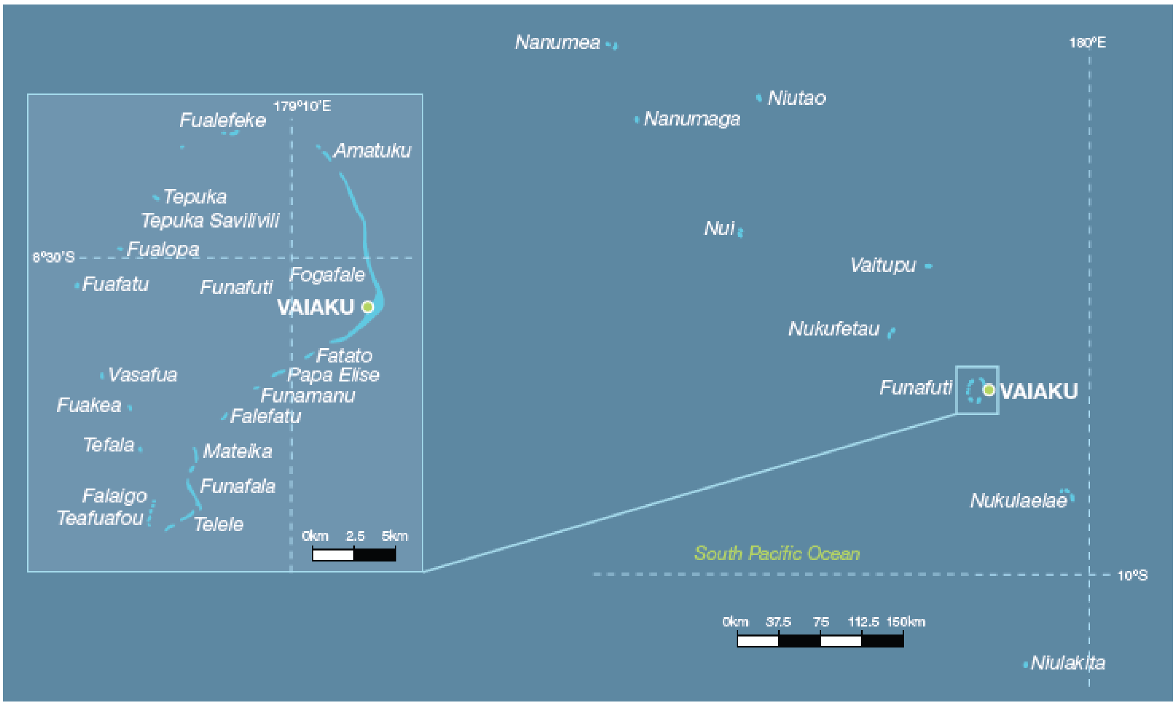

Figure 1 Map of Tuvalu (from PCCSP 2011).

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 2 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 3 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 Atoll 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 4).

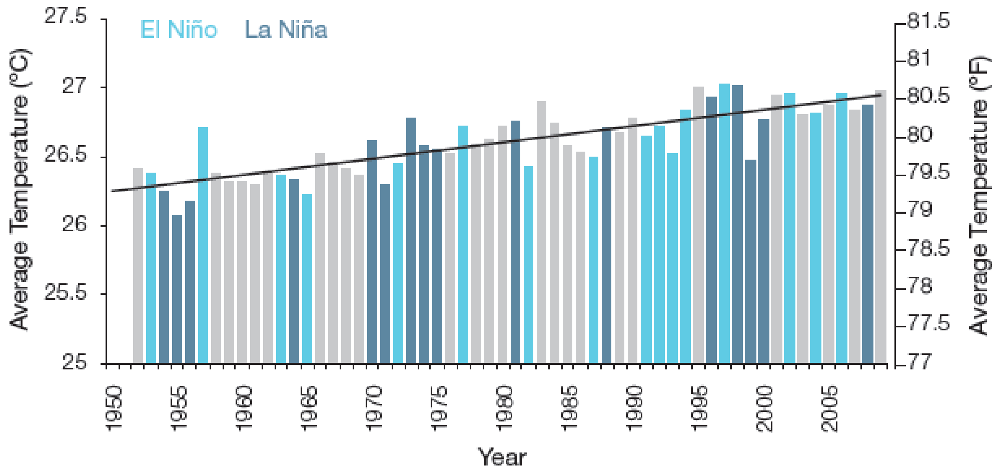

Figure 2 Annual mean air temperature at Funafuti Atoll (1950–2009) (from PCCSP 2011).

Table 4 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 5).

Table 5 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 6). 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 6 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 7 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. Implementation of the Project in Tuvalu

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;

- Funafuti Atoll represents a closed fishing system (people fish in well-defined fishing grounds);

- 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 33 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 33 km^2 of ocean area including six small islets (motu) that occupy a land area of approximately 8 ha (Figure 3). The FCA was established in 1996 with the aim of conserving the terrestrial and marine biodiversity resources of Funafuti Atoll. Management of the FCA currently falls under the jurisdiction of the Funafuti Town Council (Kapule).

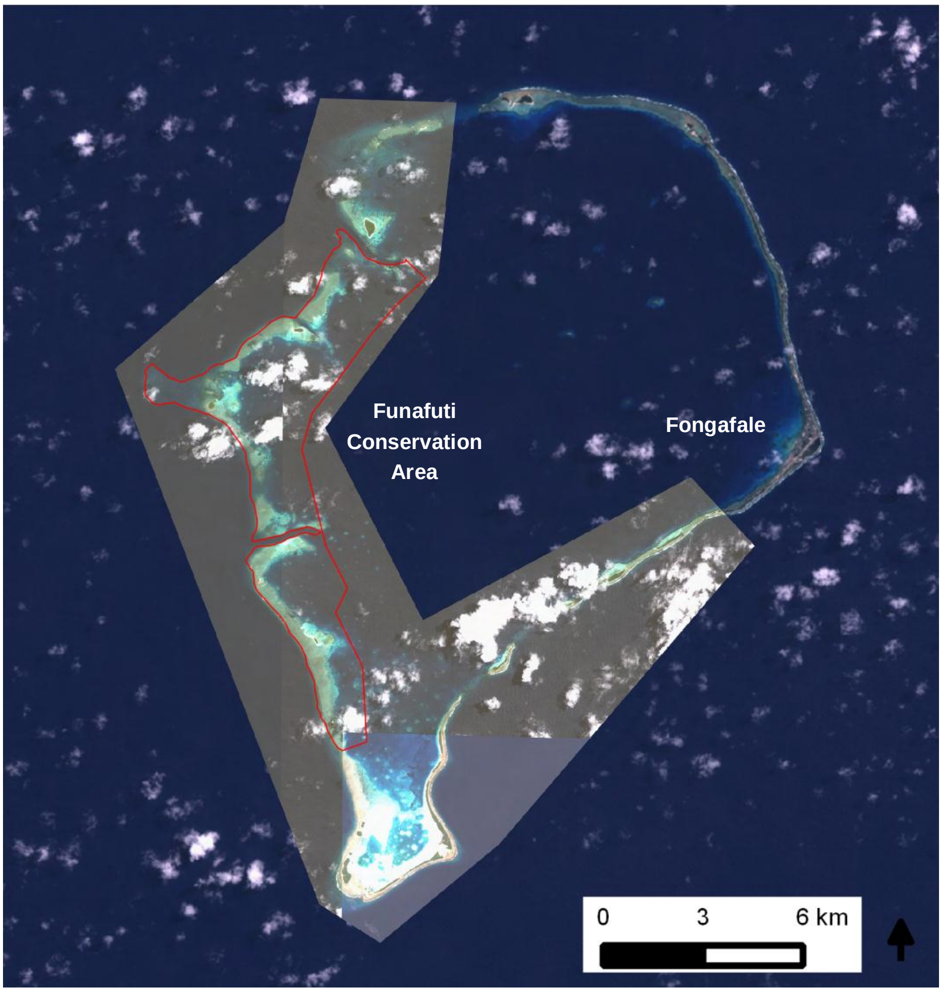

Figure 3 Map of Funafuti Atoll showing the Funafuti Conservation Area.

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. Spearfishing and handlining are the methods most commonly used for reef fishing (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 per household (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 spider conch (*Lambis* spp.). 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, four general reef types were categorised:

1) reef flat;
2) back-reef slope (inner/lagoon side of outer reef/main reef body);
3) lagoon-reef (patch reefs within the lagoon); and
4) outer-reef: ocean-side of barrier reef.

Capacity Building

One of the key objectives of the project is to train local Fisheries Officers in undertaking monitoring programs and resource assessments. The activities carried out under this project were conducted in a participatory manner, with staff from Tuvalu Department of Fisheries involved in the original design, implementation of survey activities and analysis of resulting data. This is to build local capacity and to provide staff with the skills so regular re-assessments of the pilot sites can be carried out in the future.

During the 2013 surveys a total of nine staff from Tuvalu Fisheries were trained in various monitoring components. 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 surveys.

A Comparative Approach Only

The collected data form part of a time-series 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. In general, these data should not be considered as indicative of the actual available fisheries resources.

3. Monitoring of Water Temperature

Methods

To monitor sea surface temperature at a local scale, two RBR TR1060 temperature loggers were deployed at Funafuti Atoll in August 2011, with one established on the outer reef and one inside the lagoon (Figure 4; Figure 5; Table 8). The loggers were calibrated to an accuracy of ±0.002ºC and programmed to record temperature every five minutes. Loggers were housed in a PVC tube with holes to allow flow of water and encased in a concrete block (Figure 5). These blocks were then secured to the sea floor using rebars.

Due to obvious battery life flaws in the RBR TR1060 loggers, both of these loggers were replaced with a superior model (Sea-Bird SBE 56) on the 1st June 2012. The Sea-Bird SBE 56 loggers were housed in the original housing system. Theses loggers were then retrieved, and a second set of Sea-Bird SBE 56 loggers deployed on the outer reef and in the lagoon, on the 20th and 25th April 2013, respectively.

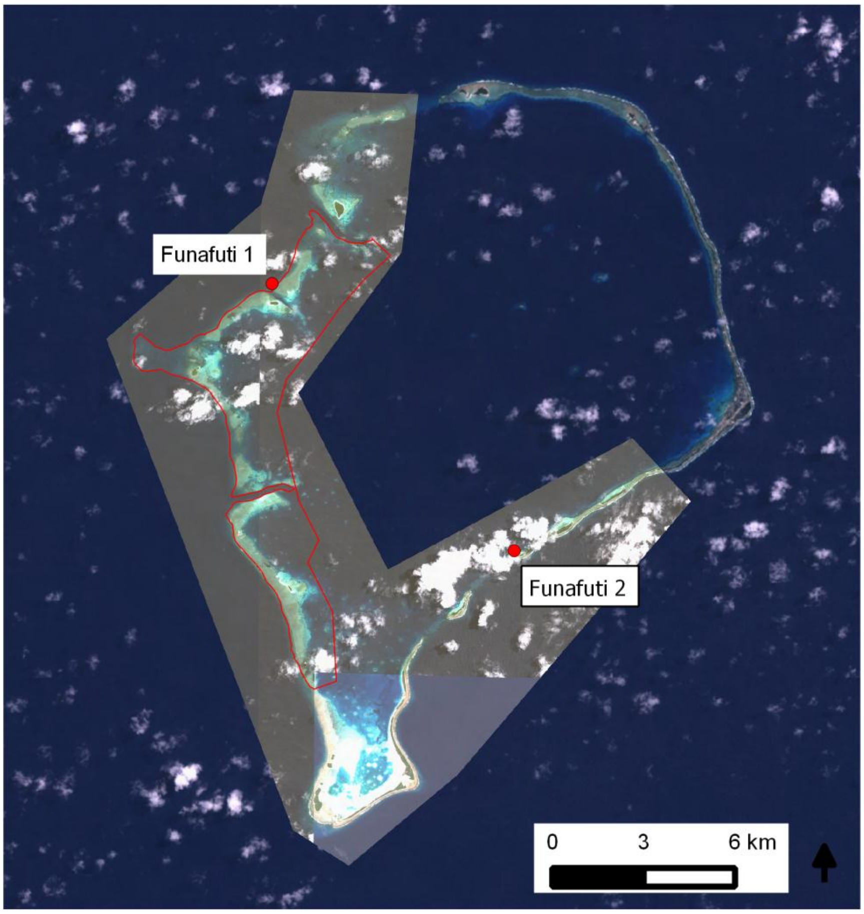

Figure 4 Locations of water temperature loggers deployed in Funafuti Atoll.

Figure 5 Deployment of temperature loggers in Funafuti, 2011.

Table 8 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 inside lagoon
Longitude (E)	179.050169	179.132789
Latitude (S)	8.483362	8.563798
Depth	12 m	11 m

Results

Both RBR TR1060 loggers collected temperature data for approximately 4-6 months before failing. These loggers have subsequently been removed. In contrast, the Seabird SBE 56 loggers collected water temperature data continuously on both the outer reef and within the lagoon from their deployment in early June 2012 to their retrieval in late April 2013.

On the outer reef, a maximum average daily temperature of 30.39°C was recorded on the 10th January 2013; while a minimum average daily water temperature of 28.36°C was recorded on the 17th July 2012. The maximum temperature recorded over the collection period was 30.57°C, reached on 9th January 2013. The minimum temperature recorded over the collection period was 27.81°C, reached on 2nd September 2011. Where data were collected for comparable months over the different years, average daily SSTs recorded on the outer reef were generally higher in 2012 and 2013 than 2011 (Figure 6).

In the Funafuti lagoon, a maximum average daily temperature of 30.43°C was recorded on the 9th January 2013; while a minimum average daily water temperature of 28.34°C was recorded on the 27th August 2011. The maximum temperature recorded over the collection period was 30.67°C, reached on 8th November 2012. The minimum temperature recorded over the collection period was 28.05°C, reached on 25th August 2011. Where data were collected for comparable months over the different years, average daily SSTs recorded in the lagoon reef were generally higher in 2013 than 2011 (Figure 6). For example, average daily temperatures in the lagoon were 29.00±0.06°C in October 2011 and 29.69±0.02°C in October 2013.

Loggers will be continuously retrieved and re-deployed to maintain water temperature monitoring within Funafuti Atoll.

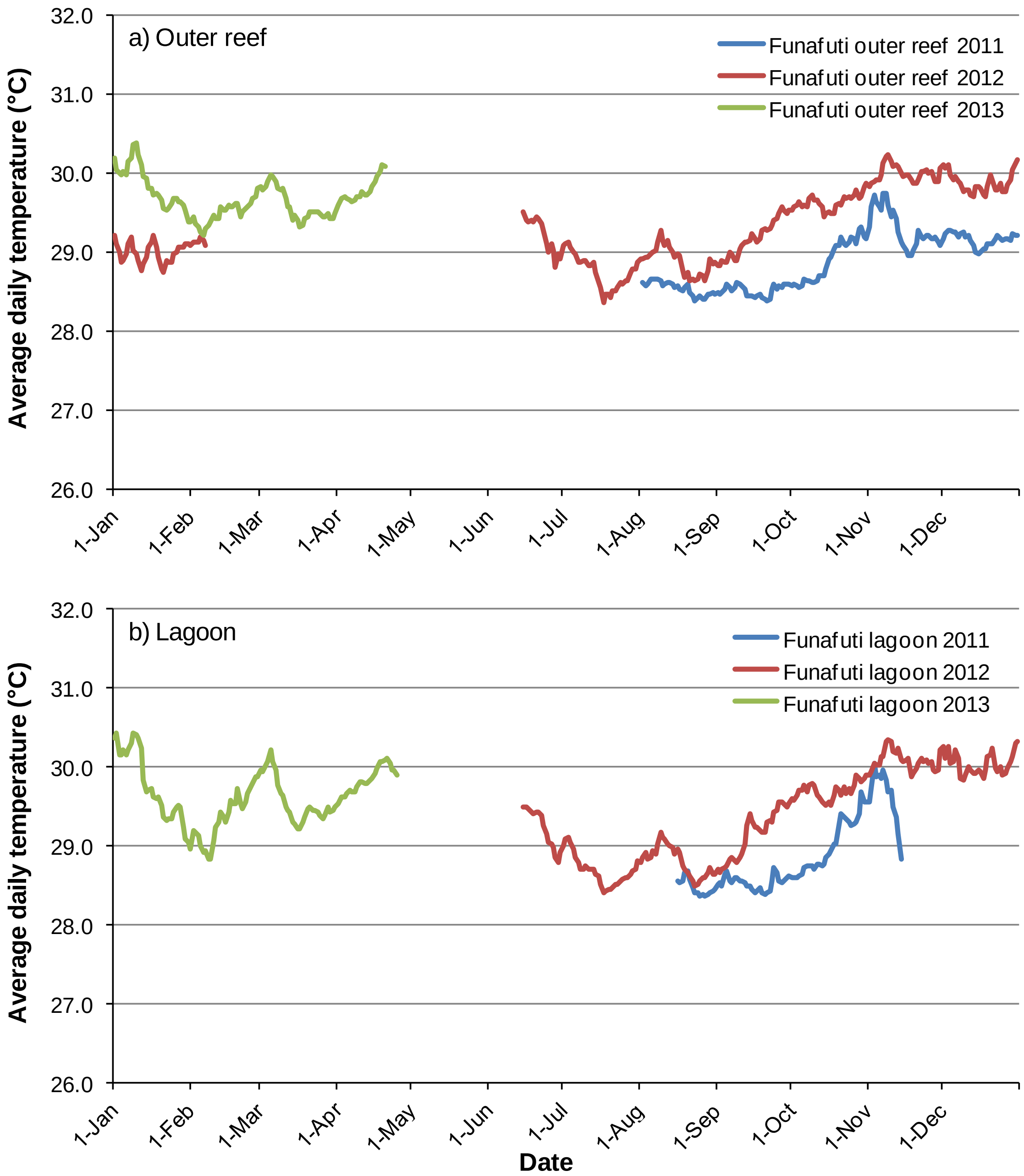

Figure 6 Mean daily water temperature in the a) outer-reef and b) lagoon at Funafuti Atoll. See Figure 4 for logger locations.

4. Finfish Assessments

Methods

Data collection

Fish on reef habitats were surveyed using distance-sampling underwater visual census (D-UVC) methodology. Finfish assessments were conducted at two sites around Funafuti Atoll: Fongafale and the Funafuti Conservation Area, with two stations established in each site (Figure 8). Within each station, finfish assessments typically focused on up to four habitats (reef flat, back reef, lagoon reefs and outer reefs), with up to three replicate 50 m transects surveyed in each habitat at each station. Each transect was completed by two SCUBA divers who recorded the species name, abundance and length of all fish observed (Appendix 2). The distance of the fish from the transect line was also recorded (Figure 9). Two distance measurements were recorded for a school of fish belonging to the same species and size (D1 and D2; Figure 9), while for individual fish only one distance was recorded (D1). Every effort was made to ensure that the survey took place under the same tidal state and moon phase as the baseline survey. Regular review of identification books and cross-checks between divers after the dive ensured that accurate and consistent data were collected. Following collection, all data were reviewed. Data considered unreliable were removed from the dataset prior to analysis.

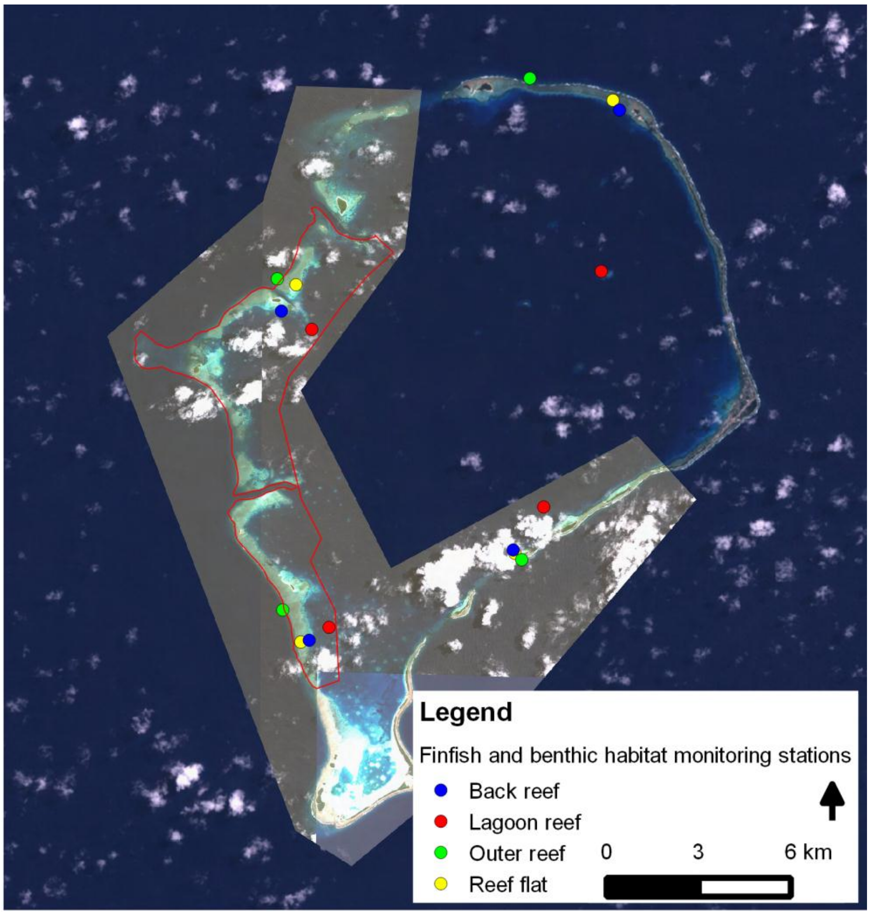

Figure 7 Location of finfish assessment stations at Funafuti Atoll. Note three replicate transects were surveyed in the vicinity of each point. A list of GPS coordinates for each transect is presented as Appendix 1.

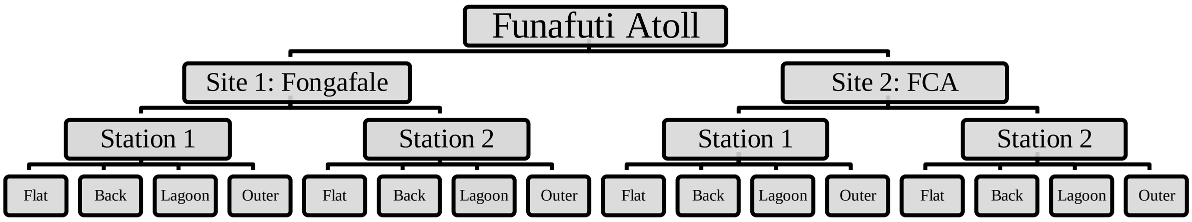

Figure 8 Survey design of the benthic habitat and finfish assessments in Funafuti Atoll, Tuvalu. Up to three replicate 50 m transects were planned in each reef flat, back-reef, lagoon-reef and outer-reef habitat for each station (= 6 transects per habitat per site).

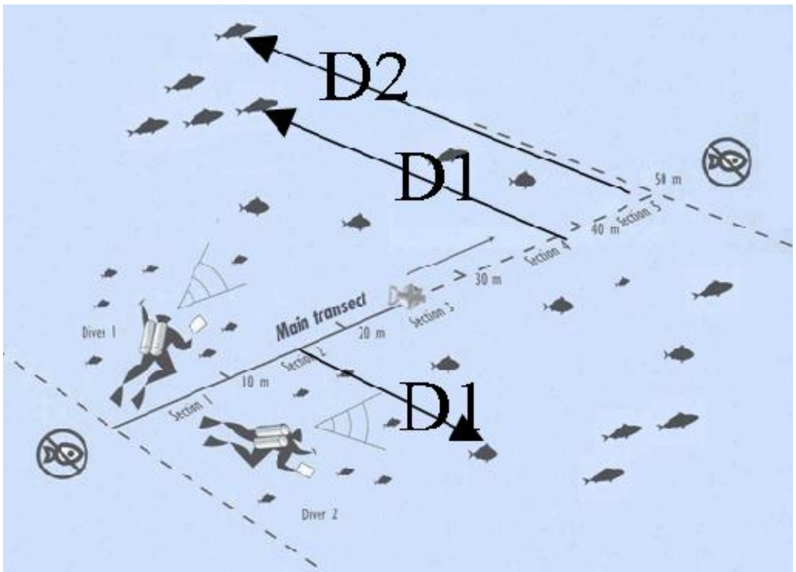

Figure 9 Diagrammatic portrayal of the D-UVC method.

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 *macroalgae, turf algae, calcareous algae, encrusting algae* (crustose coralline algae) and *seagrass* components.

(Note: for purposes of brevity, medium-scale habitat data has not been presented in this report.)

Data processing and 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 – mean number of species observed per transect (± SE);
3) mean density (fish/100 m^2) and mean biomass (g/m^2)– estimated from fish abundance in D-UVC, calculated at a total, functional group, family and individual species level.

Indicator families and assignment of functional groups

While all observed finfish species were recorded, including both commercial and non-commercial species, for the purposes of this report analyses at a family level are 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 Blennidae and Gobiidae, were not analysed due to the difficulties in enumerating these cryptic species.

For analyses by functional group, each species identified during the D-UVC surveys was classified into one of eight broad functional groups, adapted from Bellwood et al 2004; Pratchett 2005; Green and Bellwood 2009:

1) Macro-carnivores / Piscivores (feed predominantly on mobile benthic organisms and fish) (e.g. some members of the Lethrinidae, Lutjanidae, Serranidae);
2) Micro-carnivores (feed predominantly on small benthic organisms and ecto-parasites) (e.g. some members of the Labridae, Chaetodontidae);

3) Corallivores (feed predominantly on coral polyps) (e.g. some members of the Chaetodontidae);
4) Planktivores (feed predominantly on macro- and micro-zooplankton, including both diurnal and nocturnal species) (e.g. some members of the families Acanthuridae, Apogonidae, Chaetodontidae, Holocentridae, Pomacentridae and Serranidae);
5) Scraping / excavating herbivores (roving herbivores that feed on turf algae, and remove reef substratum as they feed. Members of this group play a key role in coral reef resilience by limiting the establishment of macroalgae, intensely grazing turf algae and providing areas of clean substratum for coral recruitment) (e.g. members of the Scaridae);
6) Detritivores / Grazing herbivores (roving herbivores that feed on turf algae, but do not scrape or excavate the reef substrate as they feed) (e.g. some members of the families Acanthuridae, all Siganidae except *Siganus canaliculatus*);
7) Browsing herbivores (roving herbivore that tends to bite or 'crop' algae leaving the basal portions and substrate intact. Browsers play a important role in reef resilience by reducing coral overgrowth and shading by macroalgae, and can play a key role in reversing coral-algal regime shifts) (e.g. some members of the Acanthuridae, *Siganus canaliculatus*); and
8) Territorial / farming herbivores (feed predominantly on algae within small territories. Considered to have a negative influence on coral recruitment by allowing algae to grow and out-compete coral recruits for space) (e.g. some members of the Pomacentridae).

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. Summary graphs of mean density and mean biomass (± SE) for each site were generated to further explore patterns in total mean density and mean density of the 18 indicator families and eight functional groups by habitat and survey year. To test for differences among surveys, sites and habitats, total, family-specific and functional group-specific density and biomass data for each individual transect were ln(x+1) transformed to reduce heterogeneity of variances and analysed by a series of two-way permutational multivariate analysis of variance (PERMANOVA) at $P = 0.05$, using Primer 6.1.13, with site+survey year (e.g. FCA 2013) and habitat (reef flat, back reef, lagoon reef and outer reef) as fixed factors in the analysis. This procedure uses permutations to test for significant differences among factors and therefore does not assume data normality or homogeneity of variances (Anderson et al. 2008). PERMANOVA analyses were based on Euclidean distances and 999 permutations of the data.

Results

Funafuti Conservation Area

Finfish assemblages within the Funafuti Conservation Area (FCA) site have been monitored at four habitats during the project. Reef flat, back reef and outer reef habitats were surveyed in both 2011 and 2013, while the finfish assemblages of lagoon reef habitats were surveyed for the first time in 2013 (Appendix 1).

Finfish diversity within the FCA was higher during the 2013 survey relative to 2011 for all habitats examined (Table 9). All habitats showed high functional group diversity, with all functional groups represented in both the 2011 and 2013 surveys (Table 9).

Table 9 Total number of families, genera and species, and diversity of finfish observed at reef flat, back, lagoon and outer reef habitats of the FCA site, 2011 and 2013.

Parameter	Reef-flat		Back-reef		Lagoon-reef		Outer-reef	
	2011	2013	2011	2013	2011	2013	2011	2013
No. of families	10	10	21	18	-	21	17	22
No. of genera	24	27	46	47	-	60	47	57
No. of species	52	60	91	98	-	127	94	114
Diversity	19.0±3.3	22.2±1.8	26.5±3.6	38.2±2.4	-	51.0±6.4	32.3±3.6	43.0±4.4
Functional groups	8/8	8/8	8/8	8/8	-	8/8	8/8	8/8

Reef flat

No significant differences were observed in mean total density or mean total biomass of finfish resources on reef flat habitats among the 2011 and 2013 surveys (Figure 10; Figure 11). Of the 18 indicator families, the mean density and biomass of Labridae and mean density of Pomacentridae appeared slightly, yet significantly higher in 2013 relative to 2011, while the mean density and mean biomass of Mullidae appeared significantly lower in 2013 relative to 2011 (Figure 12; Figure 13). In terms on functional groups, mean density of only territorial / farming herbivores was slightly, yet significantly, higher in 2013 compared to 211 (Figure 14; Figure 15) (Appendix 4).

Back reef

As with reef flat habitats, no significant differences were observed in mean total density or mean total biomass of finfish resources on back reef habitats among the 2011 and 2013 surveys (Figure 10; Figure 11). Mean density of Pomacentridae, and mean biomass of Serranidae, appeared significantly higher in 2013 relative to 2011 (Figure 12; Figure 13). No other differences in any other family or any functional group were observed amongst surveys (Figure 12–Figure 15) (Appendix 4).

Lagoon reefs

Finfish communities of the lagoon reefs of the FCA were dominated by planktivores, grazing herbivores / detritivores and macro-carnivores / piscivores, particularly of the families

Pomacentridae, Acanthuridae, Siganidae, Lutjanidae, Serranidae and Lethrinidae (Figure 12–Figure 15).

Outer reefs

As with other habitats, no significant differences were observed in mean total density or mean total biomass of finfish resources on outer reef habitats among the 2011 and 2013 surveys (Figure 10; Figure 11). Mean densities of Balistidae, Labridae and Scaridae on outer reef transects appeared significantly higher in the 2013 survey compared to 2011, while mean density and mean biomass of Mullidae decreased amongst surveys (Figure 12; Figure 13). In terms of functional groups, mean densities of scraping herbivores and territorial / farming herbivores increased in 2013 relative to 2011. No significant difference was apparent in mean biomass of any functional group amongst surveys (Figure 14; Figure 15) (Appendix 4).

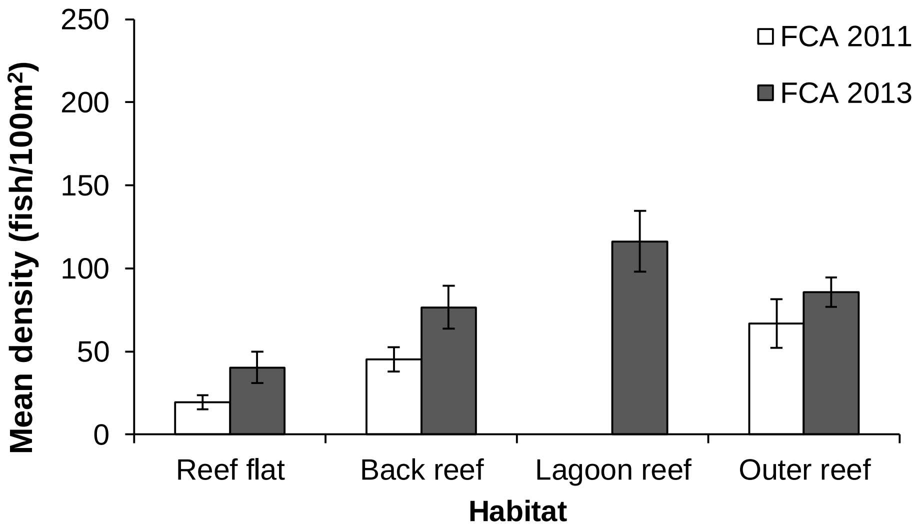

Figure 10 Mean total density of finfish (± SE) on reef flat, back, lagoon and outer reef transects within the FCA monitoring site, 2011 and 2013.

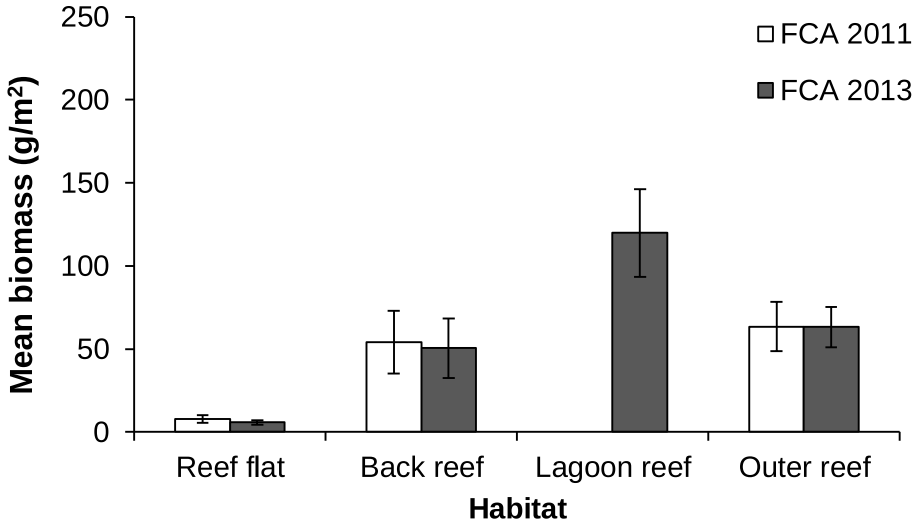

Figure 11 Mean total biomass of finfish (± SE) on reef flat, back, lagoon and outer reef transects within the FCA monitoring site, 2011 and 2013.

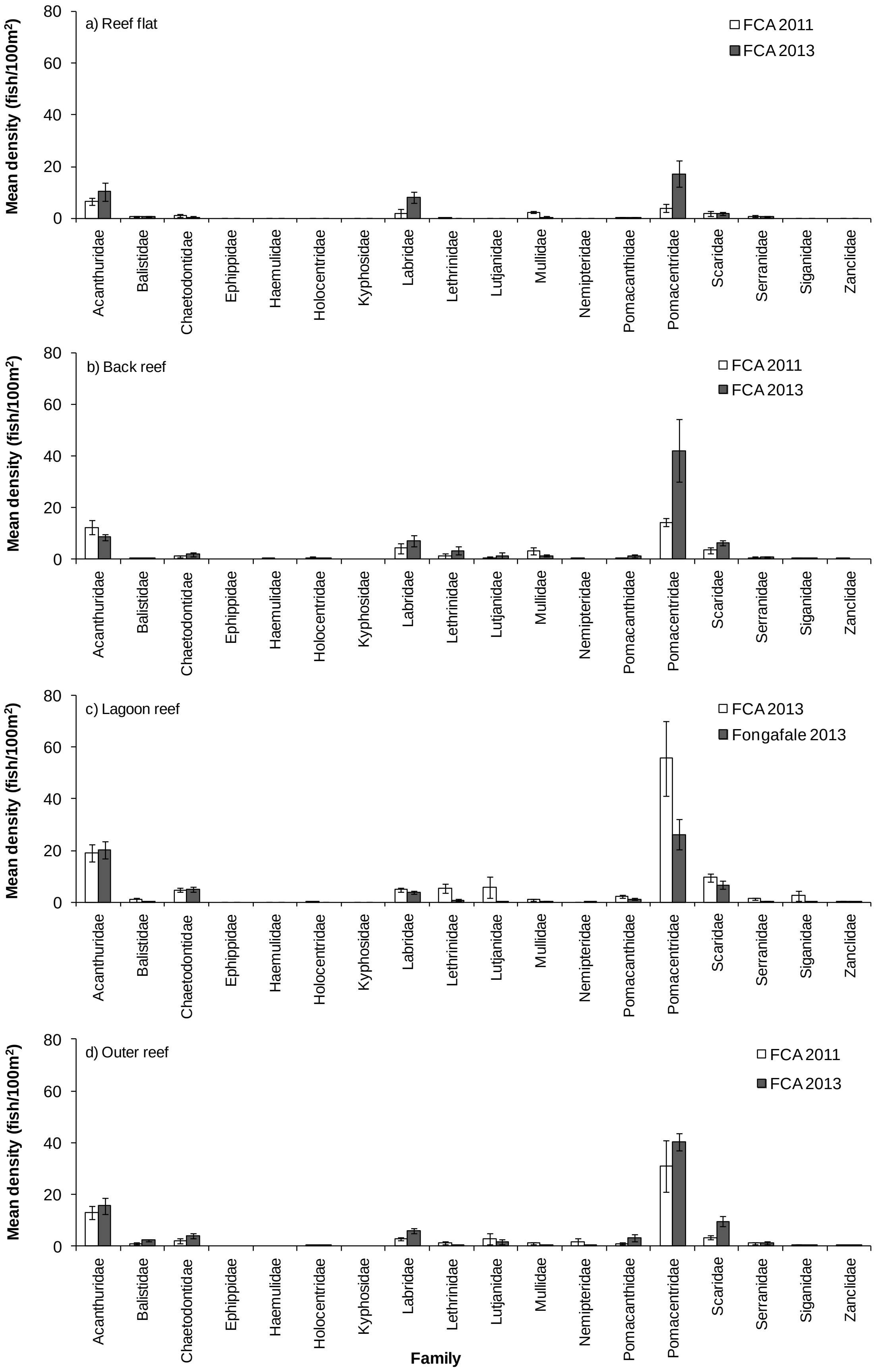

Figure 12 Mean density (± SE) of 18 indicator finfish families among a) reef flat, b) back, c) lagoon and d) outer reef habitats of the FCA site during the 2011 and 2013 surveys.

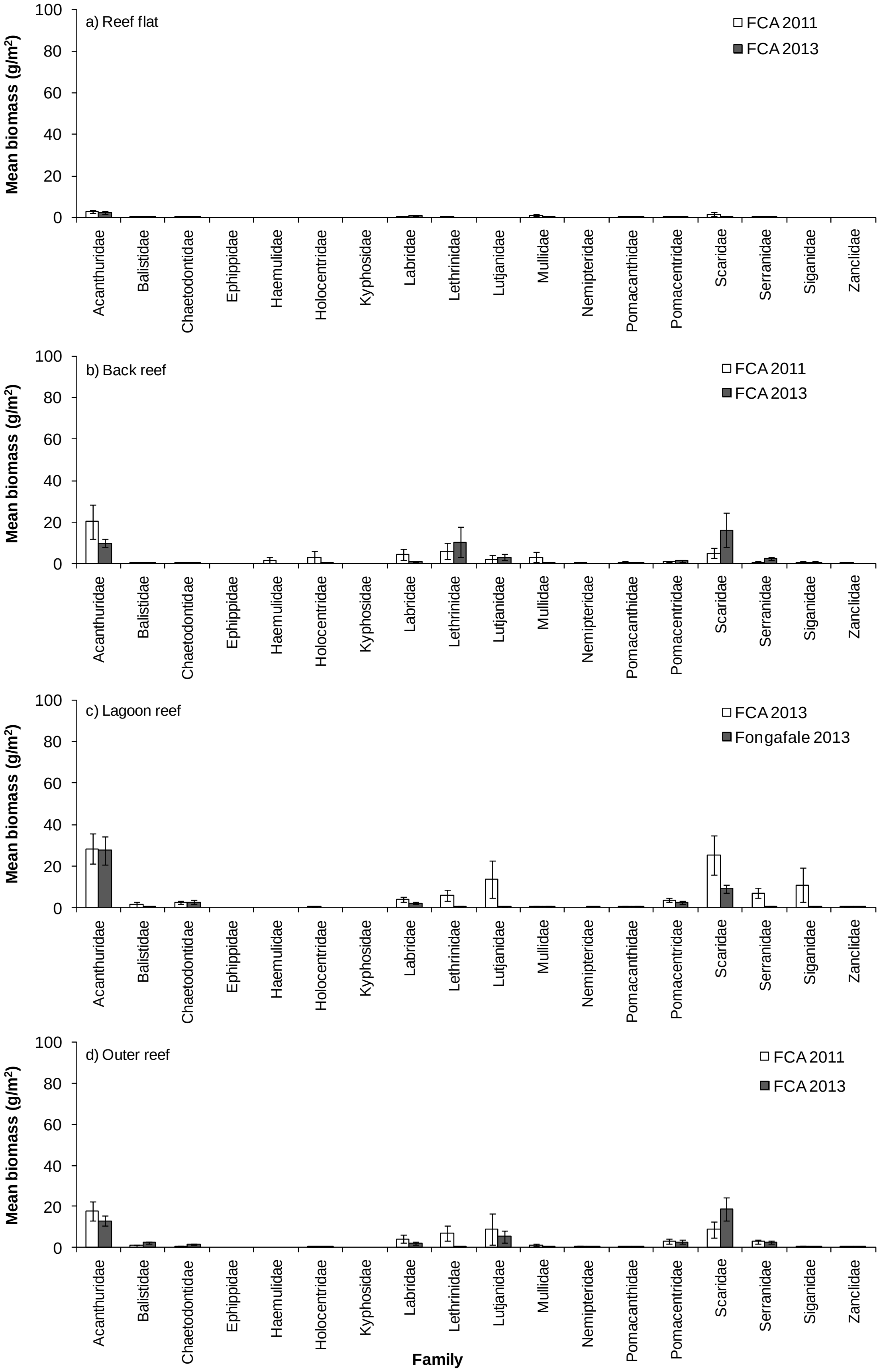

Figure 13 Mean biomass (± SE) of 18 indicator finfish families among a) reef flat, b) back, c) lagoon and d) outer reef habitats of the FCA site during the 2011 and 2013 surveys.

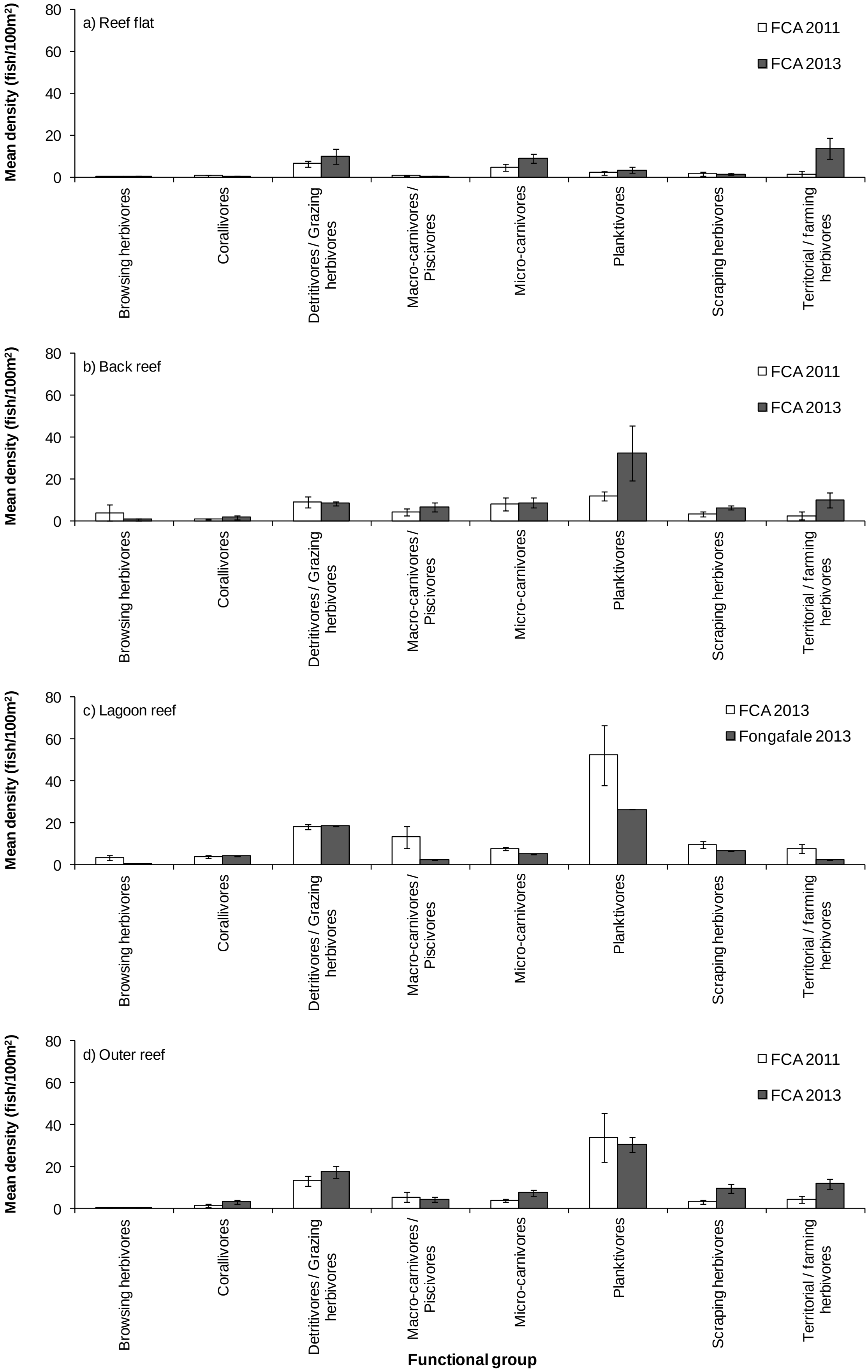

Figure 14 Mean density (± SE) of eight functional groups among a) reef flat, b) back, c) lagoon and d) outer reef habitats of the FCA site during the 2011 and 2013 surveys.

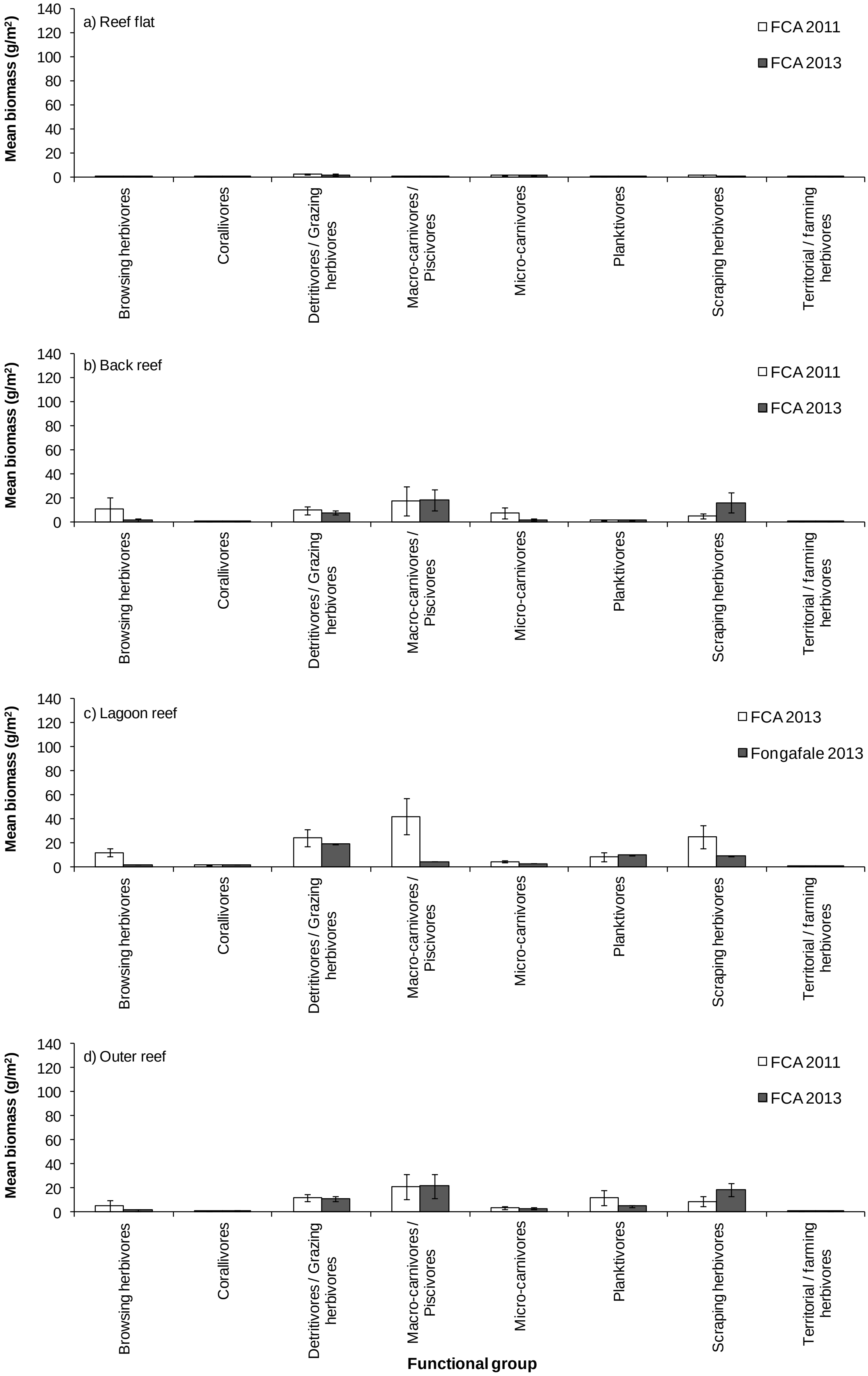

Figure 15 Mean biomass (± SE) of eight functional groups among a) reef flat, b) back, c) lagoon and d) outer reef habitats of the FCA site during the 2011 and 2013 surveys.

Fongafale

As with the FCA site, finfish assemblages of the Fongafale site have been monitored at four habitats during the project. Reef flat, back reef and outer reef habitats were surveyed in both 2011 and 2013, while the finfish assemblages of lagoon reef habitats were surveyed for the first time in 2013 (Appendix 1).

Finfish diversity on back and outer reef transects of the Fongafale site was slightly higher in 2013 than 2011, while no differences in diversity were evident on the reef flat (Table 10). All habitats showed high functional group diversity, with all functional groups represented in both the 2011 and 2013 surveys (Table 9).

Table 10 Total number of families, genera and species, and diversity of finfish observed at reef flat, back, lagoon and outer reef habitats of the Fongafale monitoring site, 2011 and 2013.

Parameter	Reef-flat		Back-reef		Lagoon-reef		Outer-reef	
	2011	2013	2011	2013	2011	2013	2011	2013
No. of families	15	13	17	20	-	20	16	21
No. of genera	38	39	37	48	-	49	40	58
No. of species	79	69	82	96	-	95	84	103
Diversity	28.5±2.4	27.8±0.5	32.0±1.7	42.5±1.8	-	40.2±3.0	31.2±1.2	37.3±3.5
Functional groups	8/8	8/8	8/8	8/8	-	8/8	8/8	8/8

Reef flat

No significant differences were observed in mean total density or mean total biomass of finfish on reef flat transects within the Fongafale site amongst the 2011 and 2013 surveys (Figure 16; Figure 17). Similarly, no significant differences were observed in mean density or mean biomass of any of the 18 indicator families or eight functional groups among surveys (Figure 18–Figure 21) (Appendix 4).

Back reefs

Mean total density of finfish on back reefs transects of the Fongafale site in 2013 appeared slightly, yet significantly, higher than in 2011 (Figure 16). These differences were largely due to increases in densities of the families Labridae, Pomacanthidae and Pomacentridae, all of which appeared higher in 2013 relative to 2011 (Figure 18). In contrast, no significant differences in mean total density or mean density of any of the 18 indicator families were observed amongst surveys (Figure 17; Figure 19). In terms of functional groups, mean density and mean biomass of territorial / farming herbivores appeared significantly higher in 2013 relative to 2011 (Figure 20; Figure 21) (Appendix 4).

Lagoon reefs

Lagoon reefs were dominated by members of the Acanthuridae and Pomacentridae in terms of both mean density and mean biomass (Figure 18; Figure 19).

Outer reefs

No significant differences were observed in mean total density or mean total biomass of finfish on outer reef transects within the Fongafale site (Figure 16; Figure 17). Mean density of Chaetodontidae and mean biomass of Lutjanidae appeared slightly, yet significantly, higher in 2013 relative to 2011 (Figure 18; Figure 19). Mean density and mean biomass of Scaridae appeared slightly lower in 2013, however these differences were not significant at P = 0.05 (Appendix 4).

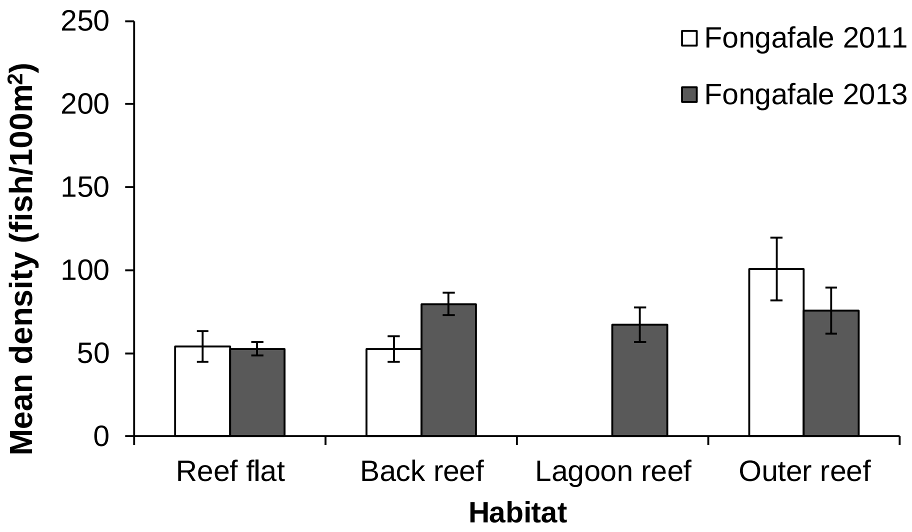

Figure 16 Overall mean density of finfish (± SE) within reef flat, back, lagoon and outer reef habitats within the Fongafale monitoring site, 2011 and 2013.

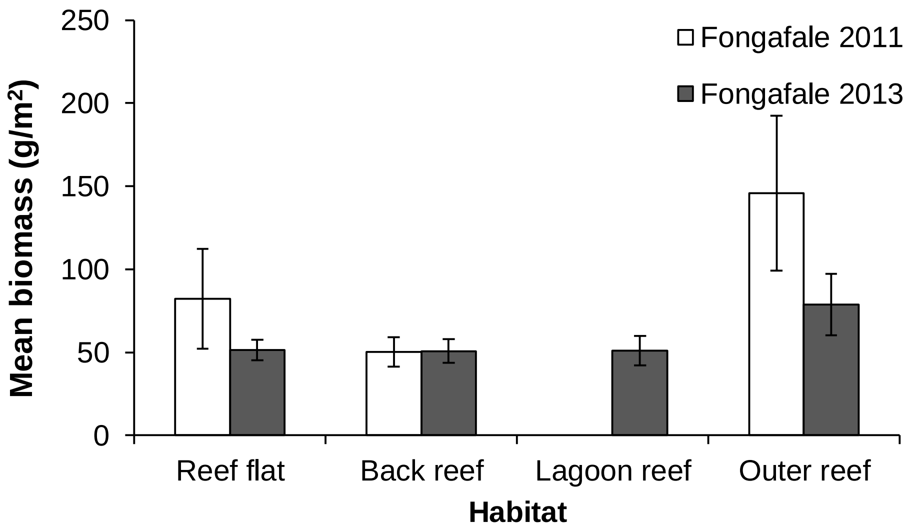

Figure 17 Overall mean biomass of finfish (± SE) within reef flat, back, lagoon and outer reef habitats within the Fongafale monitoring site, 2011 and 2013.

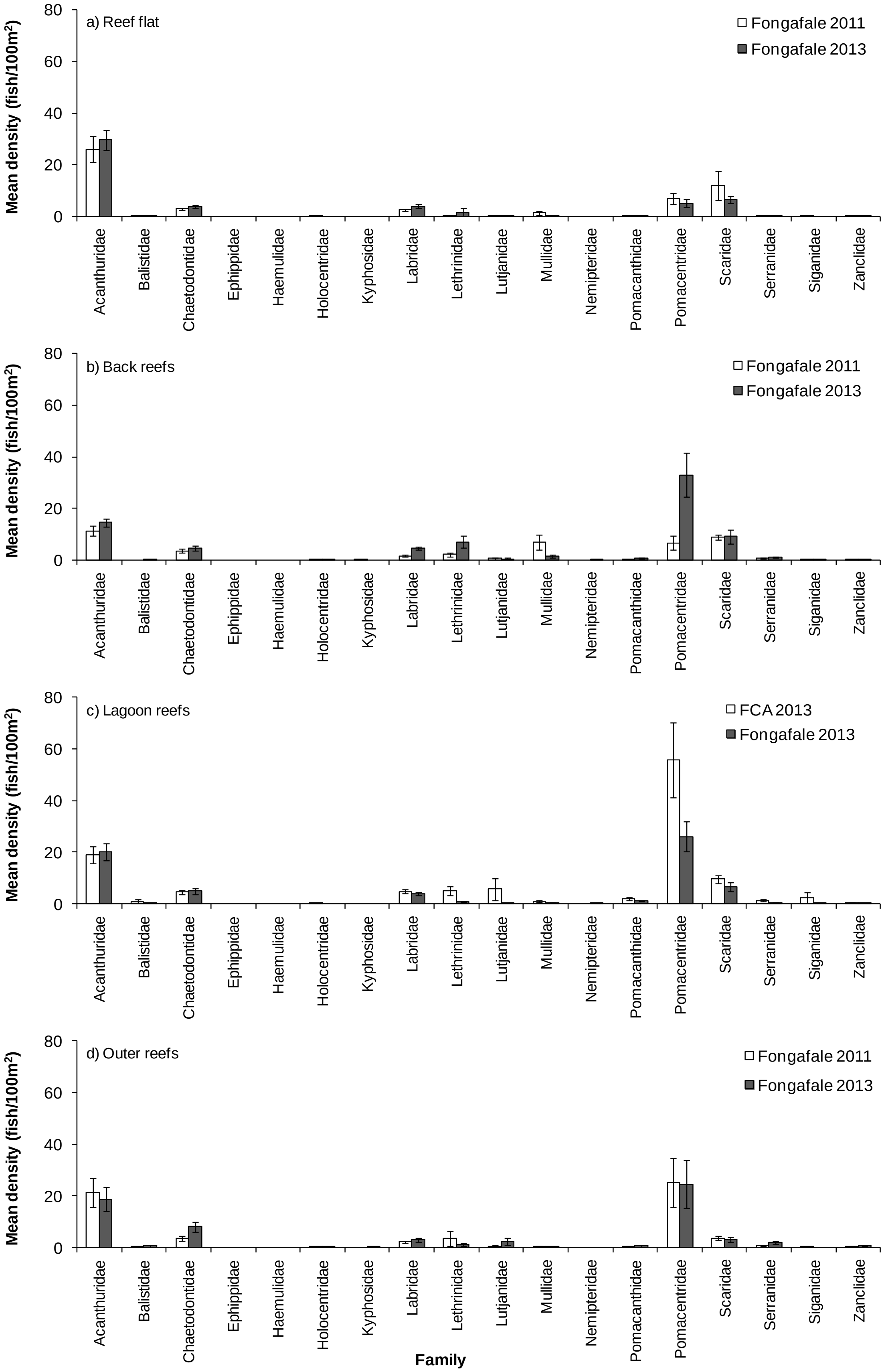

Figure 18 Mean density (± SE) of 18 indicator finfish families among a) reef flat, b) back, c) lagoon and d) outer reef habitats of the Fongafale site during the 2011 and 2013 surveys**.**

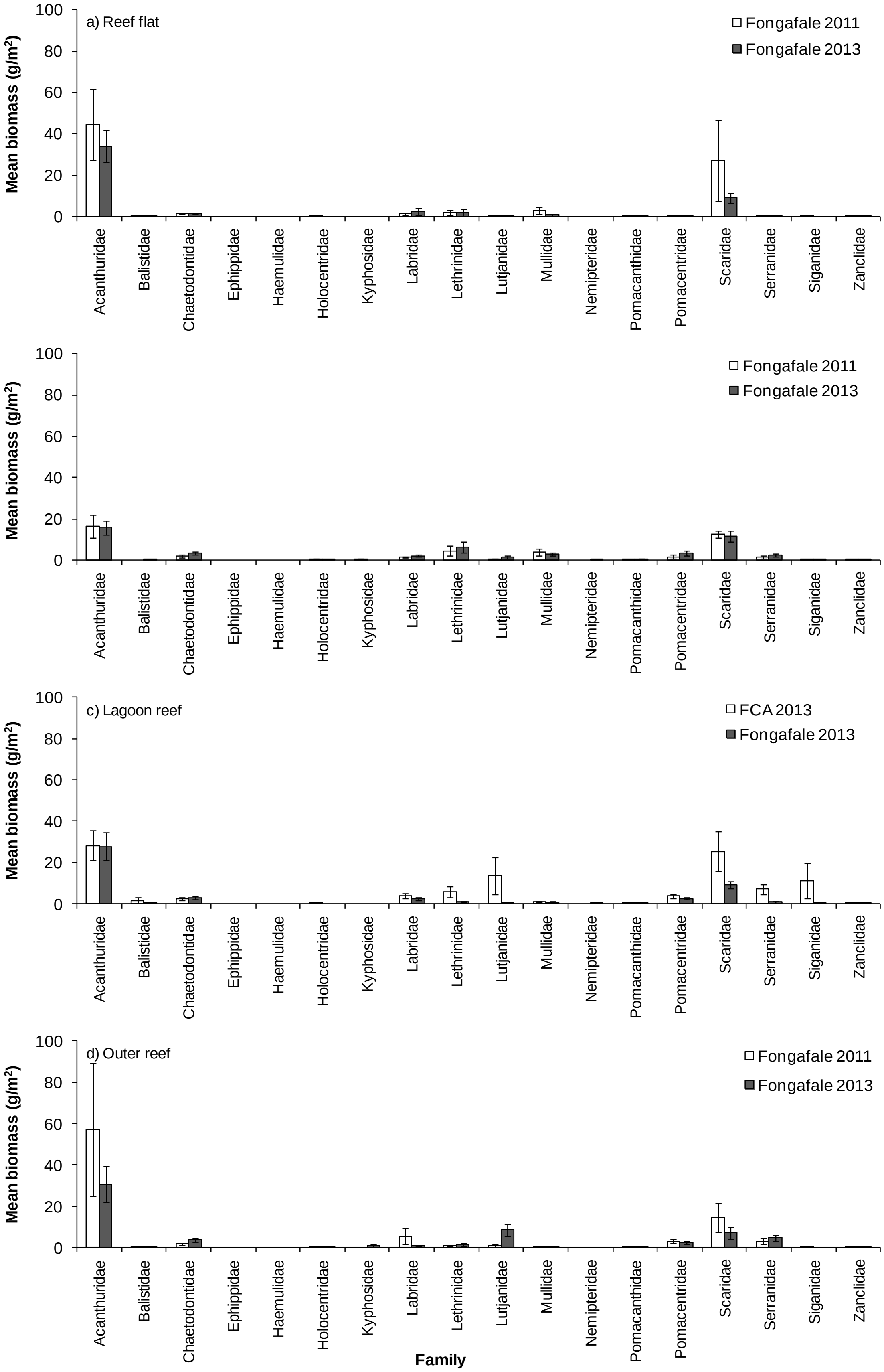

Figure 19 Mean biomass (± SE) of 18 indicator finfish families among a) reef flat, b) back, c) lagoon and d) outer reef habitats of the Fongafale site during the 2011 and 2013 surveys**.**

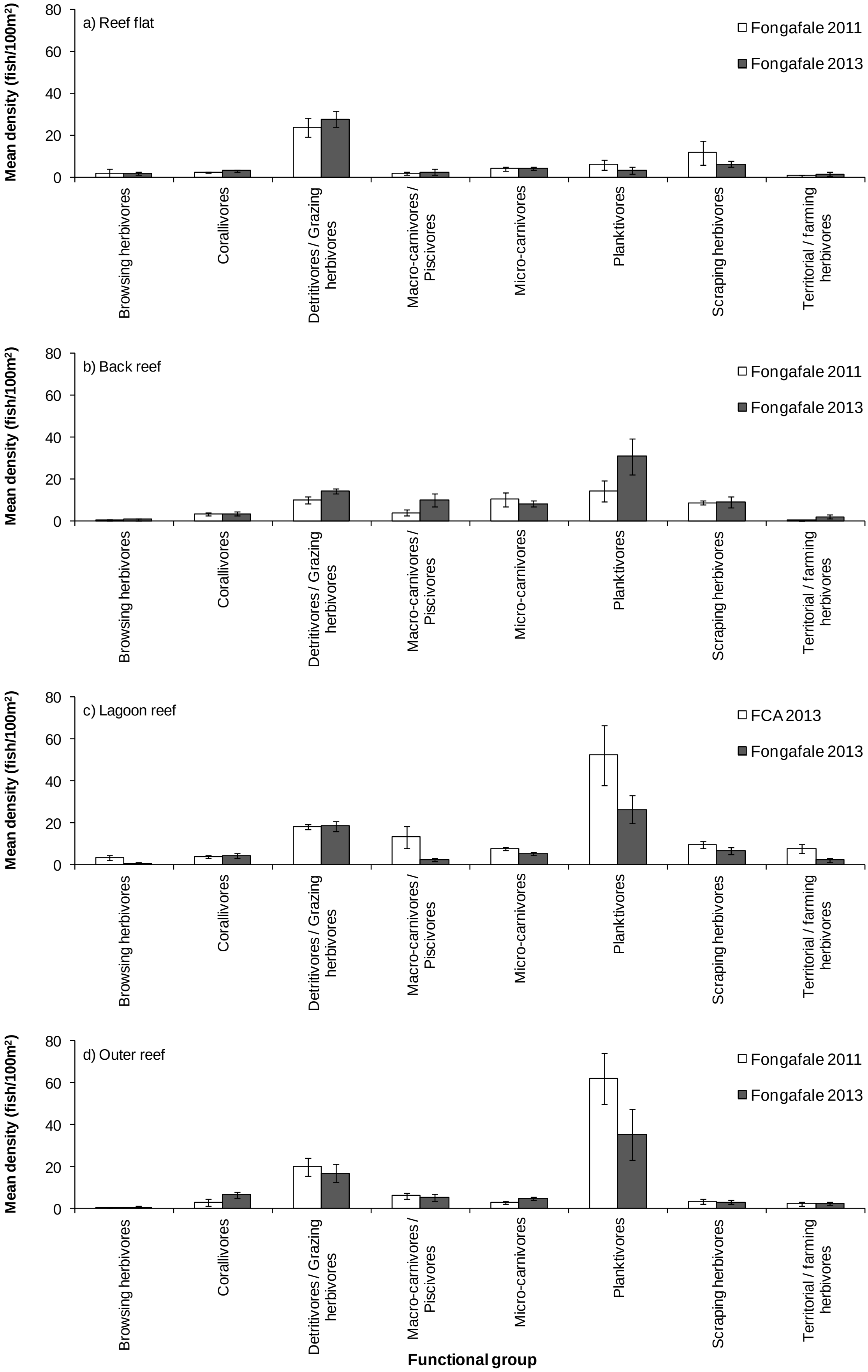

Figure 20 Mean density (± SE) of eight functional groups among a) reef flat, b) back, c) lagoon and d) outer reef habitats of the Fongafale site during the 2011 and 2013 surveys.

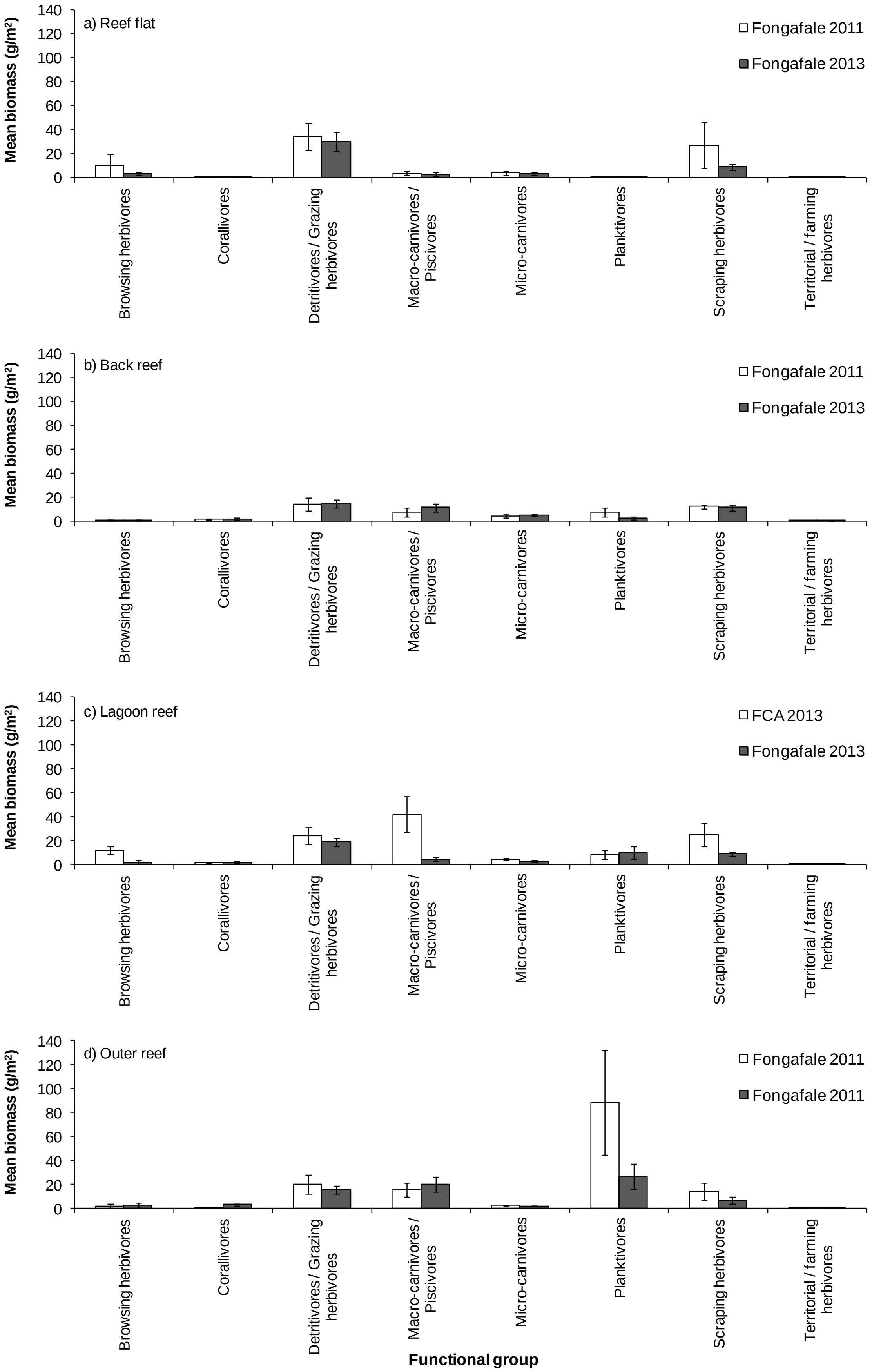

Figure 21 Mean biomass (± SE) of eight functional groups among a) reef flat, b) back, c) lagoon and d) outer reef habitats of the Fongafale site during the 2011 and 2013 surveys.

Performance of the FCA in 2014

When compared against the Fongafale site, several differences were observed. Most notably:

- For reef flat habitats, mean total biomass and mean densities and mean biomass of Acanthuridae, Chaetodontidae and Scaridae were all higher at the Fongafale site than the FCA, while mean densities of Pomacentridae were higher in the FCA;
- Fewer differences were evident on the back reef, with only mean density of Acanthuridae and mean biomass of Mullidae appearing higher for Fongafale transects than those at the FCA;
- For lagoon reefs, mean total biomass and mean density and biomass of Lethrinidae, Lutjanidae and Serranidae were all significantly higher within the FCA than the Fongafale site;
- For transects on the outer reef, mean densities of Balistidae, Pomacanthidae and Scaridae, and mean biomass of Balistidae were higher for FCA transects, while mean densities and mean biomass of Chaetodontidae and Lethrinidae were higher for Fongafale transects (Appendix 4).

5. Benthic Habitat Assessments

Methods

Broad-scale assessments

Data collection

Broad-scale assessments of the benthic habitat of the FCA and Funafuti sites were assessed using manta tow. Here, a surveyor was towed on a manta board behind a boat at a speed of approximately 3-4 km/h. Manta tows were conducted along the back and outer reefs of the FCA and Fongafale sites. The surveyor recorded percent cover of substrate types, including live coral, dead coral, bleached coral, rubble, coralline algae (e.g. *Halimeda*) and other macroalgae within a 300 m long x 2 m wide transect. Transect lengths were determined using the odometer function within the trip computer option of a Garmin Etrex GPS, and transects were typically conducted at depths of 1–6 metres. Six 300 m manta tow replicates were conducted within each site, with GPS positions recorded at the start and end of each transect to an accuracy of within ten meters.

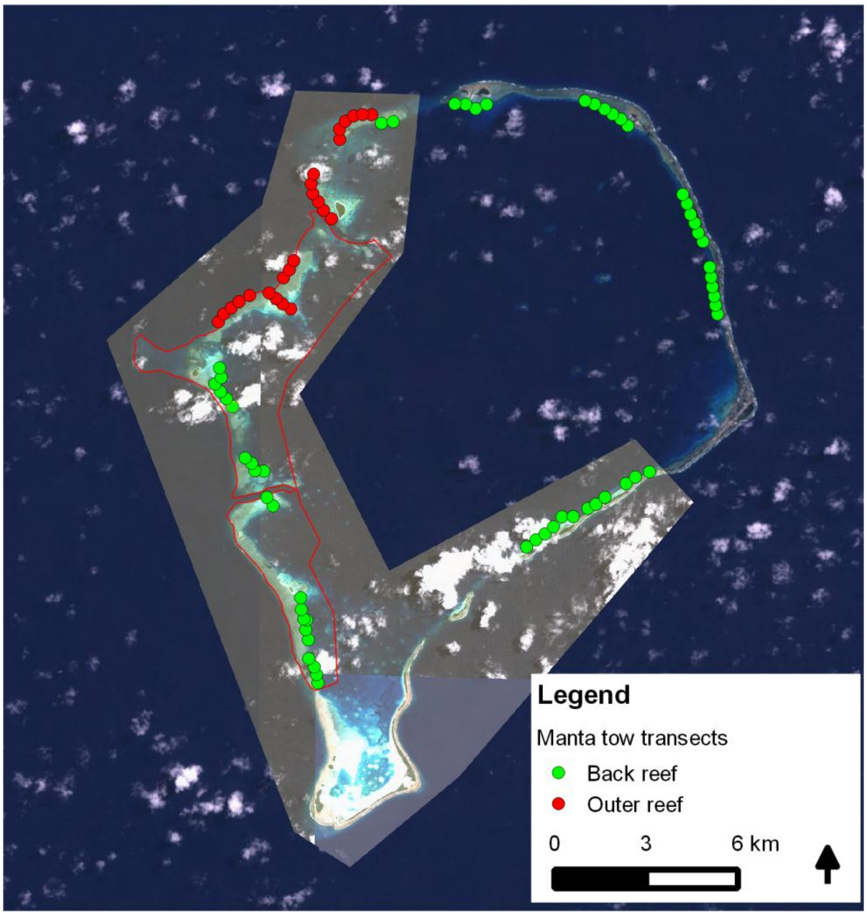

Figure 22 Location of broad-scale (manta tow) benthic habitat monitoring regions at Funafuti Atoll. Each point represents a single 300 m replicate within each station.

Data analysis

Summary graphs of mean percentage cover (± SE) of each substrate type, based on cover of each individual 300 m x 2m transect, were generated for each site (Fongafale, FCA), habitat (back reef, outer reef) and survey year (2011 and 2013) to explore differences amongst site and surveys.

Fine-scale assessments

Fine-scale benthic habitat assessments were conducted using a photoquadrat approach at the same locations and transects as the finfish assessments (Figure 7), and were conducted immediately after the finfish surveys. 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. Transects were laid parallel to the reef. A GPS position was recorded at the beginning of each transect.

The habitat photographs were analyzed using SPC software (available online: http://www.spc.int/CoastalFisheries/CPC/BrowseCPC). 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 including *Asparagopsis*, *Blue-green algae*, *Boodlea*, *Bryopsis*, *Chlorodesmis*, *Caulerpa*, *Dictyota*, *Dictosphyrea*, *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 (growing on fixed substrate);
6. Fleshy coralline algae (growing on fixed substrate, e.g. *Peyssonnelia*);
7. Turf algae (growing on fixed substrate);
8. Seagrass – sum of seagrass genera *Enhalus*, *Halodule*, *Halophila*, *Syringodium*, *Thalassia*, *Thalassodendron*;
9. Sand/silt – 0.1 mm < hard particles < 30 mm;
10. Rubble – carbonated structures of heterogeneous sizes, broken and removed from their original locations; and
11. 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. All data processing and identifications were checked by an experienced surveyor. Resulting data were extracted to MS Excel and summarized as percentages. Summary graphs of mean percentage cover (± SE) for each site were generated to further explore patterns of each major substrate category by habitat and survey year. To explore whether significant differences in cover occurred among sites and habitats, coverage data of each major benthic category in each individual transect were log(x+1) transformed to reduce heterogeneity of variances and analysed by a two-way permutational multivariate analysis of variance

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

(PERMANOVA) at P = 0.05, using Primer 6.1.13, with site+survey year (e.g. FCA 2013) and habitat (reef flat, back reef, lagoon reef and outer reef) as fixed factors in the analysis. PERMANOVA analyses were based on Euclidean distances and 999 permutations of the data.

Results

Broad-scale assessments

Back reefs

While little difference was observed in man cover of live coral and dead coral among surveys, mean cover of rubble ($P < 0.01$), coralline algae ($P < 0.01$) and other algae ($P < 0.027$) increased significantly on back-reefs of the Fongafale site between the 2011 and 2013 surveys (Figure 23). At Fongafale, the benthic composition changed from an overall coral-dominated state in 2011 to an algae-dominated state in 2013, with the cover of algae (coralline algae and other macro-algae categories combined) exceeding that of live coral in 2013 (Figure 31). In contrast, few differences were observed on back-reefs at the FCA site among the 2011 and 2013 surveys, with only a small, yet significant, increase in the cover of bleached coral observed among surveys ($P = 0.016$) (Figure 23). Mean cover of live hard coral showed little difference amongst the Fongafale and FCA sites during either survey year (Figure 23).

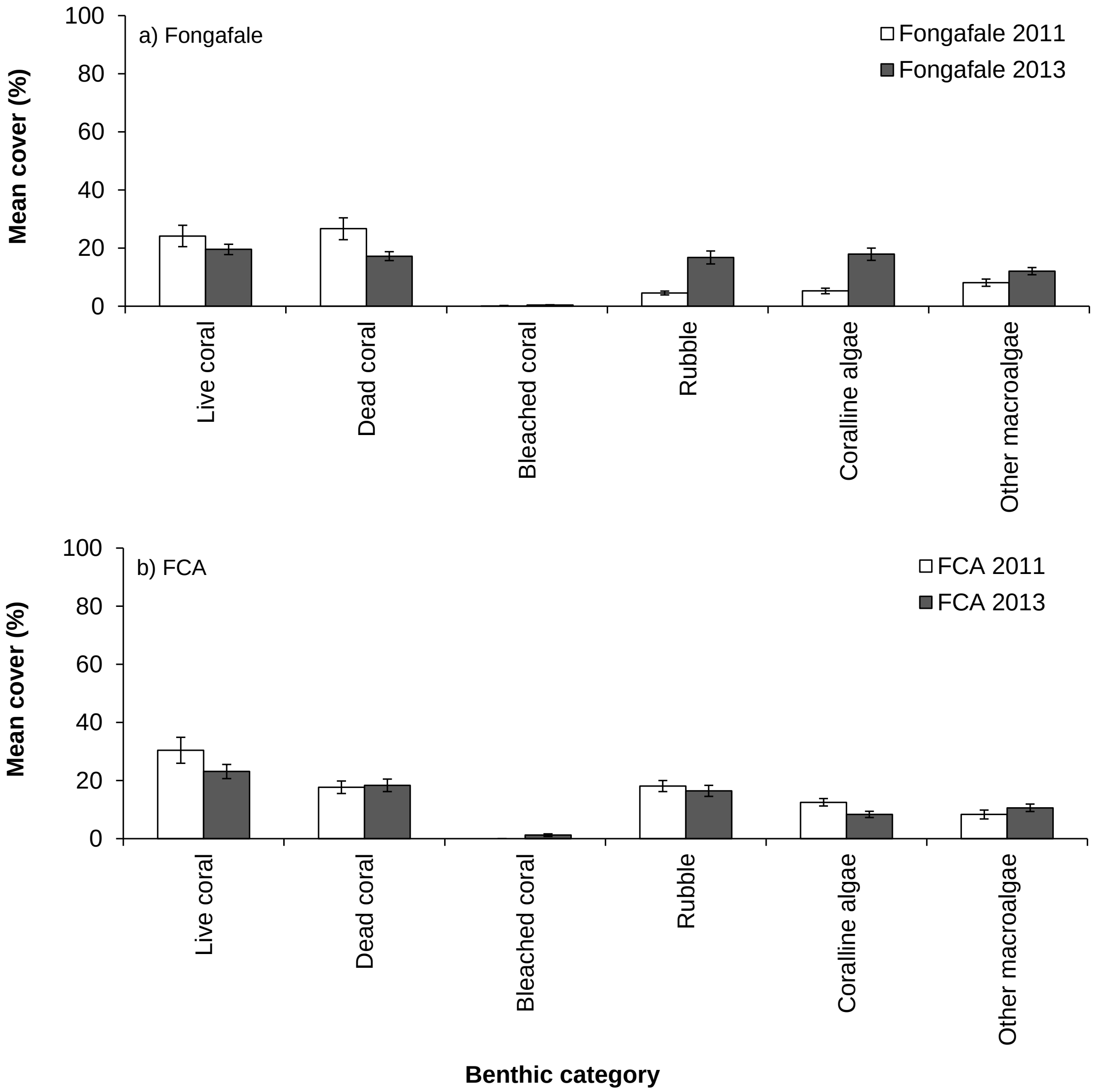

Figure 23 Mean percent cover (±SE) of coral, rubble and algae categories observed on back reef habitats of the a) Fongafale and b) FCA sites during broadscale assessments by manta tow.

Outer reefs

A broadscale assessment of the outer reefs of the Fongafale site was conducted for the first time in 2013. A relatively high percent cover of live hard coral was observed at this site, with cover comparable to that observed within the FCA (Figure 24).

Outer reefs of the FCA were assessed in both 2011 and 2013. As with back-reef habitats, few changes were evident among outer reef habitat categories between the 2011 and 2013 surveys at the FCA site, with only a slight, yet significant, increase in mean cover of bleached coral observed in 2013 relative to 2011 ($P < 0.01$) (Figure 24).

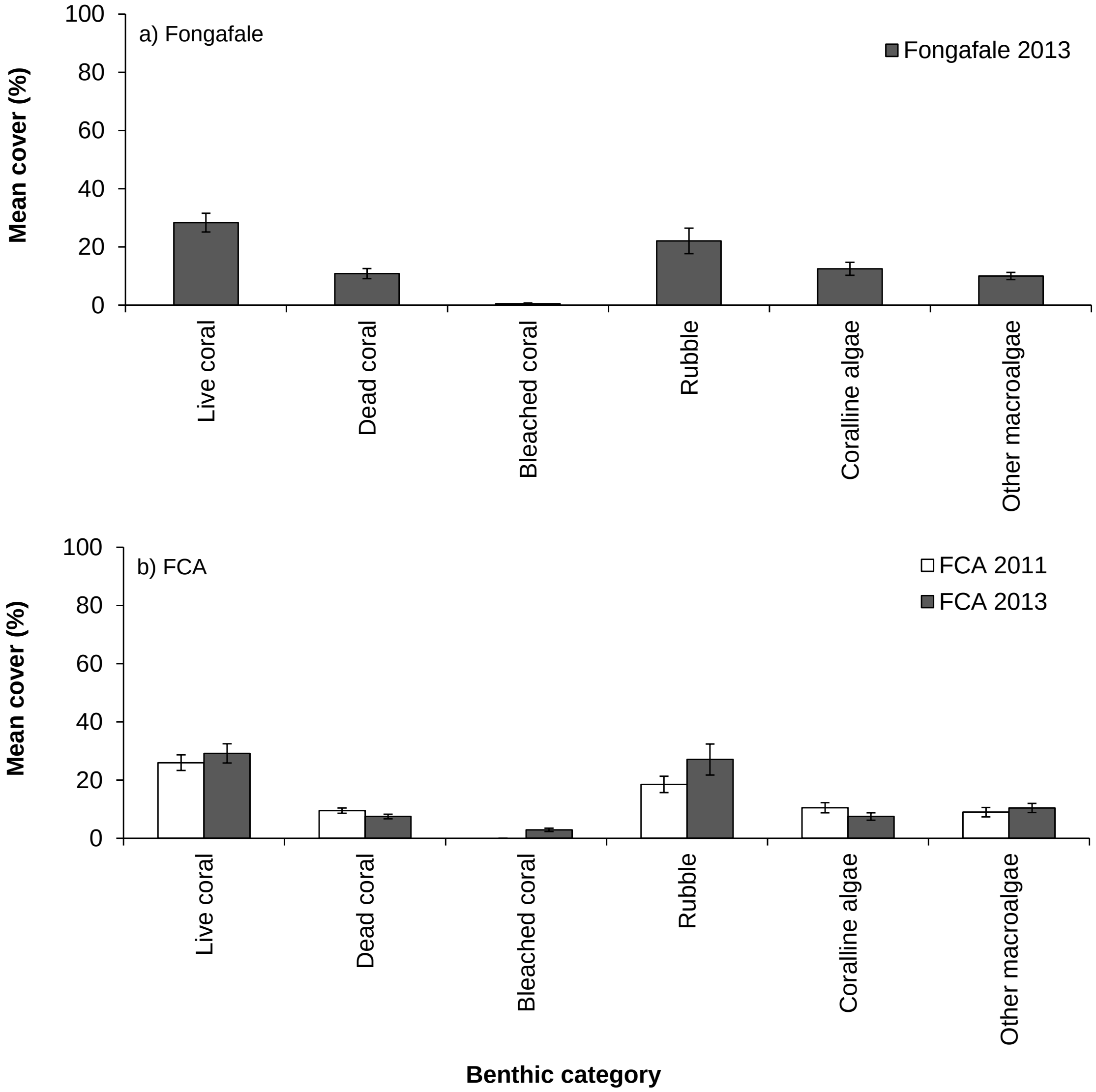

Figure 24 Mean percent cover (±SE) of coral, rubble and algae categories observed on outer reef habitats of the a) Fongafale and b) FCA sites during broadscale assessments by manta tow.

Fine-scale assessments

Funafuti Conservation Area

Benthic habitats of the FCA site have been monitored at four habitats during the project. Reef flat, back reef and outer reef habitats were surveyed in both 2011 and 2013, while benthic habitats of lagoon reef habitats were surveyed in 2013 only (Appendix 1).

No significant differences observed in any of the major benthic categories amongst the 2011 and 2013 surveys for transects on the reef flat at the FCA site (Figure 25). On the back reef, the cover of pavement appeared slightly yet significantly higher in 2013 relative to 2011 (Figure 25). When compared to the Fongafale site, the cover of live hard coral and crustose coralline algae was significantly lower for reef flat transects in the FCA in 2013 (1.2±1.0% vs. 47.6±10.8%), while the cover of sand and rubble was higher (Appendix 5). Back reef transects within the FCA had a significantly higher cover of crustose coralline algae (8.5±3.4% vs. 0.2±0.2%), and a significantly lower cover of turf algae (3.8±1.3% vs. 13.8±1.8%) than those at the Fongafale site (Appendix 5).

Lagoon reef habitats at the FCA site were surveyed for the first time in 2013. These habitats were characterised by a relatively high cover of live hard coral (35.6±5.1%), which was dominated by *Acropora* spp.), and moderate cover of macroalgae (primarily *Microdictyon* and *Halimeda* spp.) (Figure 25; Figure 28). As with back reef habitats, lagoon reef transects within the FCA had a significantly higher cover of live hard coral (36.7±5.1% vs. 19.2±7.5%) and crustose coralline algae (8.5±3.4% vs. 0.2±0.2%) than those at the Fongafale site (Appendix 5).

Consistent with other habitats, few changes were evident in benthic community composition of outer reef habitats of the FCA among the 2011 and 2013 surveys. While no changes were evident in the cover of live hard coral, macroalgae, crustose coralline algae bleached coral or recently dead coral, cover of turf algae and other invertebrates on outer reefs decreased slightly, yet significantly between 2011 and 2013 (Figure 25). In 2013, the cover of macroalgae and turf algae was significantly higher, and cover of live hard coral significantly lower, on the outer reef transects at the FCA site than those at the Fongafale site (Figure 25; Figure 30; Appendix 5).

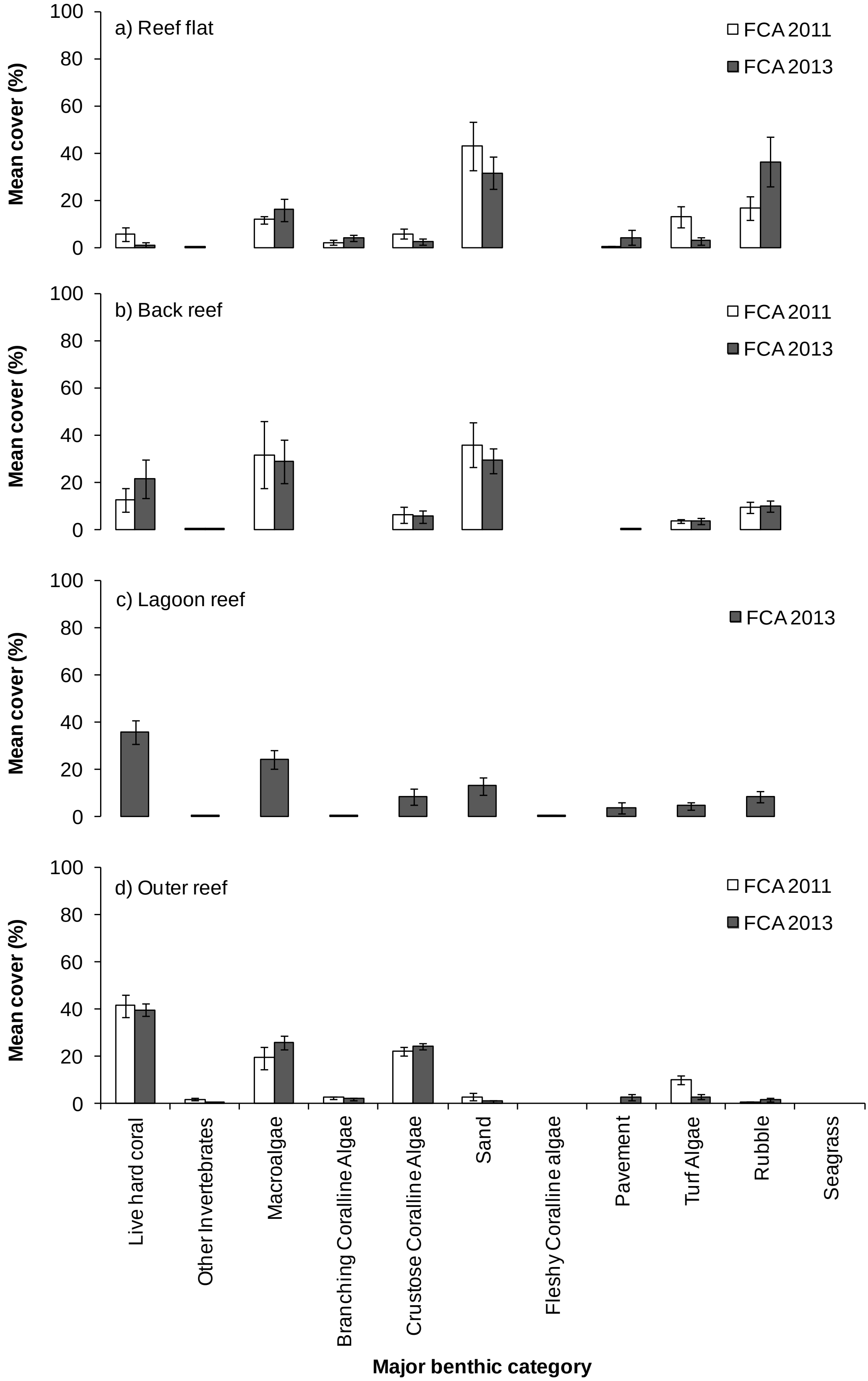

Figure 25 Percent cover of major benthic categories at a) reef flat, b) back reef, c) lagoon reef and d) outer reef transects of the FCA monitoring site among 2011 and 2013 surveys.

Figure 26 Reef flat reef habitats of the FCA monitoring site were characterised by low coral cover and high cover of macroalgae (typically *Microdictyon* sp.), sand and rubble.

Figure 27 Back reef habitats of the Fongafale monitoring site were characterised by moderate cover of live coral, macroalgae (typically *Microdictyon* sp. and sand.

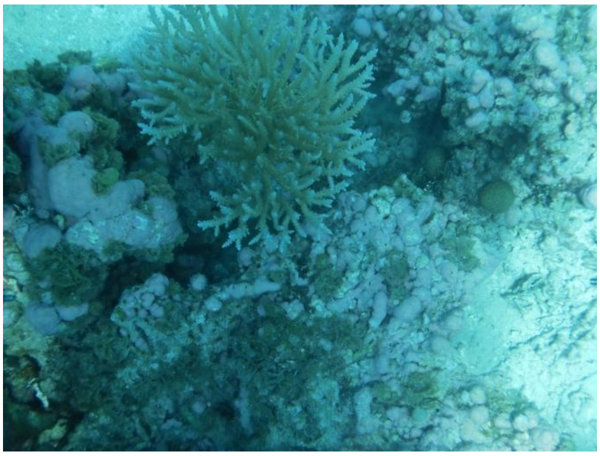

Figure 28 Lagoon reef habitats of the FCA monitoring site had a high cover of live hard coral, in particular *Acropora spp.* and moderate cover of macroalgae (predominantly *Microdictyon* and *Halimeda*).

Figure 29 Outer reef habitats of the FCA monitoring site had a high cover of live coral (in particular *Acropora*, *Montipora* and *Pocillopora*), and moderate cover of crustose coralline algae and macroalgae (predominantly *Microdictyon* and *Halimeda).*

Fongafale

Benthic habitats of the Fongafale site have been monitored at four habitats during the project. Reef flat, back reef and outer reef habitats were surveyed in both 2011 and 2013, while benthic habitats of lagoon reef habitats were surveyed in 2013 only (Appendix 1).

At Fongafale, no significant differences were observed in the cover of any benthic community category on reef flat and outer reefs amongst the 2011 and 2013 surveys (Figure 30). Cover of turf algae on back reef habitats decreased significantly between 2011 and 2013 (32.8±3.4 vs. 13.8±1.8%, Appendix 5), which likely reflects uncertainty of the exact positioning transects resulting from uncertainty around the 2011 GPS waypoints. In 2013, cover of live hard coral was higher at the Fongafale site than the FCA site for outer reef habitats, largely due to a higher cover of *Acropora* (48.2±9.9% at the Fongafale site vs. 6.9±1.7% at the FCA site) (Appendix 5).

Lagoon reef habitats at the Fongafale site were surveyed for the first time in 2013. These habitats were in poor condition, characterised by a high cover of macroalgae (46.3±8.6%), and moderate cover of live hard coral (17.9±7.4%) and turf algae (14.8±3.4%) (Figure 30; Figure 33). The dominant macroalgae genera observed on these transects were *Halimeda* (23.0±3.1% cover), *Padina* (12.8±8.2% cover), *Asparagopsis* (5.4±3.6% cover) and *Dictyota* (4.5±2.1% cover). The dominant coral genus at this site was *Acropora*. Cover of turf algae on lagoon reef transects in 2013 was significantly higher at Fongafale than the FCA (14.8±3.4% vs. 4.6±1.7%), while coral cover on the lagoon reefs or the Fongafale site was significantly lower than that observed within the FCA (Figure 25 vs. Figure 30; Appendix 5).

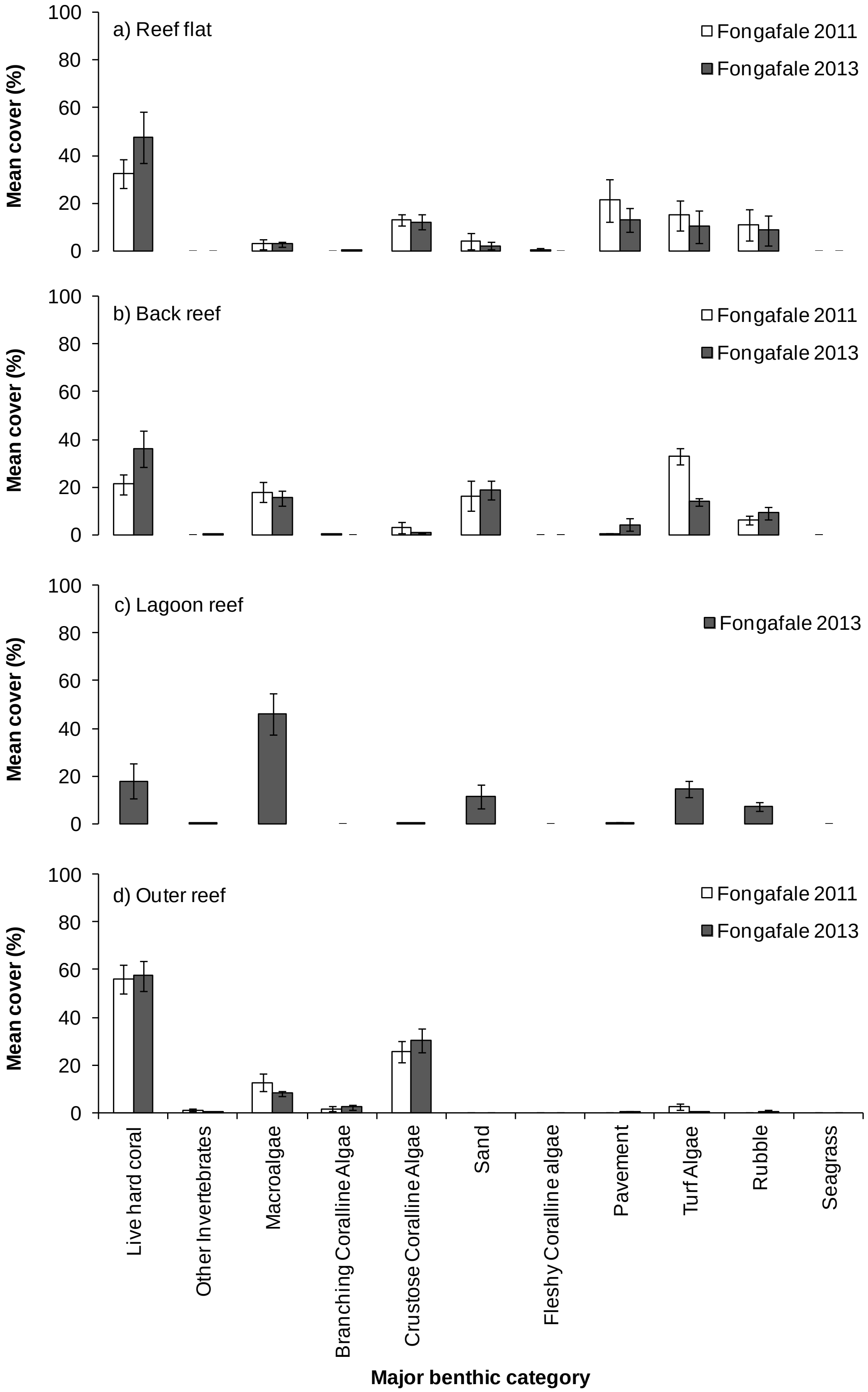

Figure 30 Percent cover of major benthic categories at a) reef flat, b) back reef, c) lagoon reef and d) outer reef transects of the Fongafale monitoring site among 2011 & 2013 surveys.

Figure 31 Reef flat reef habitats of the Fongafale monitoring site were characterised by high cover of live coral, in particular *Acropora* spp.

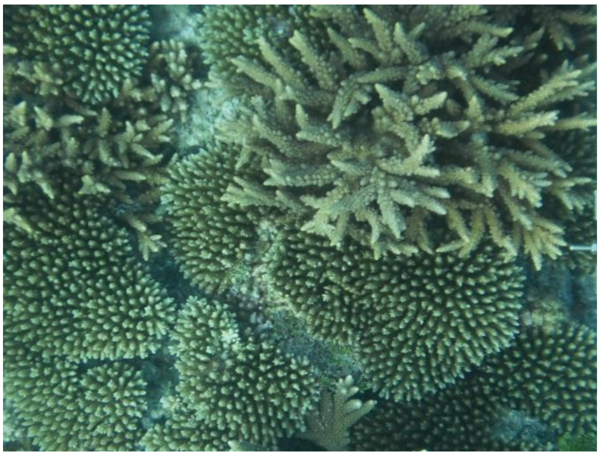

Figure 32 Back reef habitats of the Fongafale monitoring site were characterised by moderate cover of live coral, macroalgae and turf algae growing over coral.

Figure 33 Lagoon reef habitats of the Fongafale monitoring site exhibited poor health, with a high cover of macroalgae, in particular *Halimeda* and *Asparagopsis*.

Figure 34 Outer reef habitats of the Fongafale monitoring site had a high cover of live coral (in particular *Acropora* spp.), *Halimeda* spp. and crustose coralline algae.

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6. Invertebrate Surveys

Methods

Data collection

Invertebrates

Two survey methods were used to assess the abundance, size and condition of reef-associated invertebrate resources of Funafuti Atoll. Manta tows were used to provide a broad-scale assessment of invertebrate resources associated with reef areas, and followed the same path used in the broadscale habitat assessments (Figure 22). In this assessment, a snorkeler 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 35; Table 11). 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.

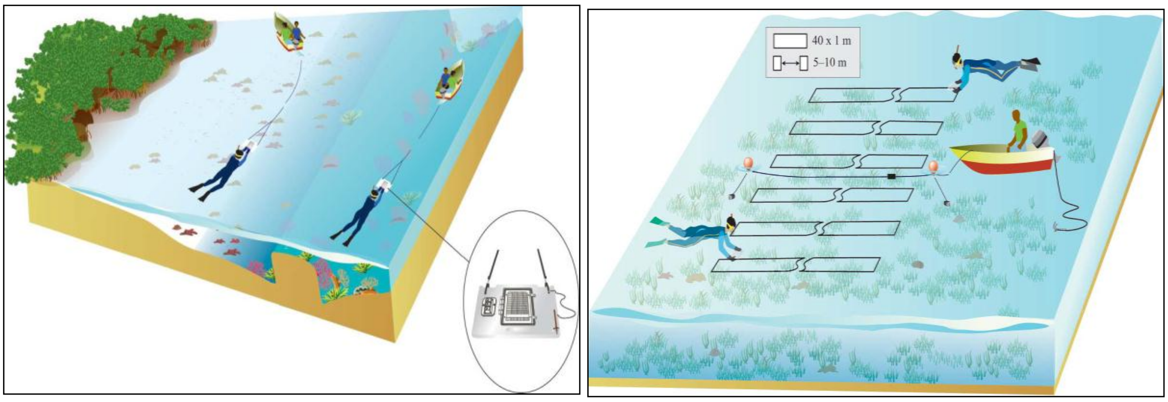


Figure 35 Diagrammatic representation of the two invertebrate survey methods used at Funafuti Atoll during the 2011 and 2013 surveys: manta tow (left) and reef benthos transects (right).

To assess the abundance, size and condition of invertebrate resources 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, 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 x 1 m transects for each station (Figure 35). The GPS position of each station was recorded in the centre of the station.

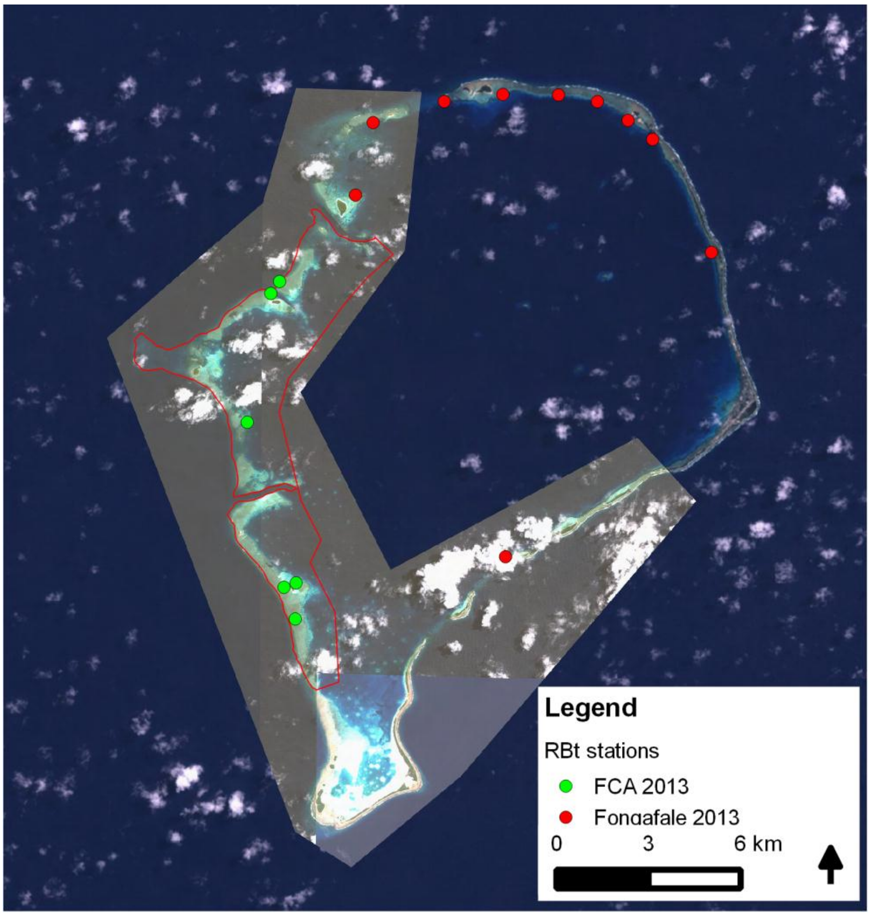


Figure 36 Map of Tuvalu showing approximate positions of reef benthos transect (RBt) stations at the FCA and Fongafale monitoring sites. A list of GPS waypoints for the RBt stations is included as Appendix 5.

Data analysis

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

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

Summary graphs of mean density by site and survey year were generated to explore spatial and temporal patterns in invertebrate assemblages. Data was analysed on an individual species level except for gastropods, which were pooled at a genus level, and urchins, which were pooled to the family level, due to uncertainties in species identification of these organisms, particularly during the baseline assessment. To test for differences in invertebrate densities observed during manta tows and RBts amongst surveys and sites, density data within each station were ln(x+1) transformed to reduce heterogeneity of variances and analysed by a series of one-way PERMANOVAs at P = 0.05, using Primer 6.1.13, with site+survey year (e.g. FCA 2013) as a fixed factors in the analysis. PERMANOVA analyses were based on Euclidean distances and an unrestricted number of permutations of the data. Due to low numbers of invertebrates observed on the outer reefs, only back reef transects were used in the analyses of manta tow data.

Table 11 Species analysed in manta tow assessments (where present).

Species group	Species analysed
Sea cucumbers	All species
Bivalves	All *Tridacna* species, *Hippopus hippopus*, *Hippopus porcellanus*
Gastropods	*Cassis cornuta*, *Charonia tritonis*, All *Lambis* species, *Tectus niloticus*, *Tectus pyramis*, *Trochus maculatus*, *Turbo marmoratus*
Starfish	*Acanthaster planci*, *Anchitosia queenslandensis*, *Choriaster granulatus*, *Cornaster nobilis*, *Culcita novaeguineae*, *Fromia monilis*, All *Linckia* species, *Protoreaster nodosus*, *Tropiometra afra*, *Valvaster striatus*

Results

Manta tow

No significant differences were observed in density of any invertebrate species amongst the 2011 and 2013 surveys within either the FCA or Fongafale sites. Overall, densities of invertebrates were low, and few differences were observed between the FCA and Fongafale sites. Densities of the elongate giant clam (*Tridacna maxima*) were significantly higher at manta stations within the FCA than the Fongafale stations in both 2011 and 2013 (Figure 37; Appendix 9), yet well below the healthy stock reference point of 750 individual/ha recommended by Pakoa et al. (2014).

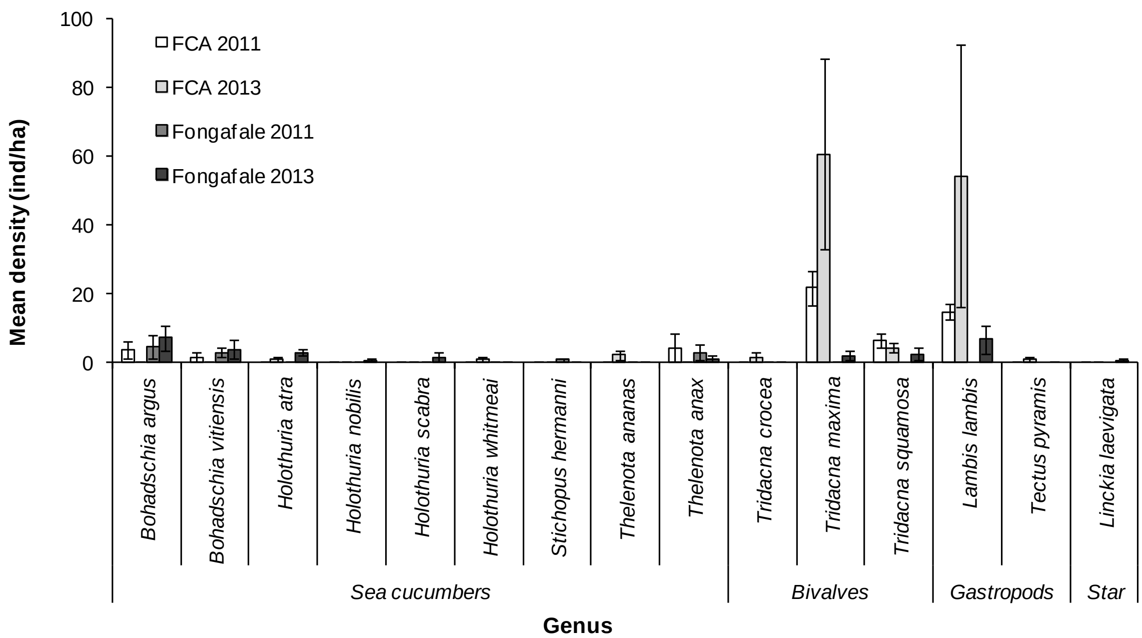


Figure 37 Overall mean densities (±SE) of invertebrate species (± SE) observed during manta tow surveys at the Fongafale and FCA monitoring sites, 2011 and 2013.

Reef-benthos transects

Invertebrate diversity at the RBt stations was slightly higher in 2011 than 2013 for both the FCA and Fongafale sites (Table 12). The sea cucumber assemblage at the RBt stations was extremely depauperate in terms of both diversity and abundance, with no sea cucumbers observed at RBt stations in the FCA site and only three species observed at the Fongafale site (2011 and 2013 combined) (Figure 38; Table 13). None of these three species were observed in densities exceeding minimum harvest densities proposed by Pakoa et al. (2014) (Table 13). For other species, few consistent differences were seen amongst the 2011 and 2013 surveys for any species group (Figure 38). Densities of *Tridacna maxima* were similar amongst surveys at Fongafale, yet showed a large (yet not significant) decrease within the FCA between 2011 and 2013 (Figure 38). Densities of Diadematidae urchins were at the Fongafale site were slightly higher in 2013 than 2011 (Figure 38; Appendix 9). No crown-of-thorns starfish (*Acanthaster planci*) were observed during the 2013 surveys at RBt stations in either the FCA or Fongafale sites.

In 2013, few differences in invertebrate density were observed amongst the FCA and Fongafale sites, with densities of only the urchin families Diadematidae and Echinometridae higher in the FCA than the Fongafale stations (Figure 38; Appendix 9).

Table 12 Number of genera and species, and diversity of invertebrates observed during reef-benthos transects at the Fongafale and FCA monitoring sites during the 2011 and 2013 surveys.

Parameter	Site and year			
	FCA 2011	FCA 2013	Fongafale 2011	Fongafale 2013
Number of genera	17	17	23	18
Number of species	29	24	31	23
Diversity	4.8	4.0	3.1	2.3

Table 13 Densities of sea cucumber species at RBt stations in 2011 and 2013. The regional reference density for healthily stocks (RBt sites) is provided in the last column (from Pakoa et al. 2014).

Species	FCA 2011 (ind/ha)	FCA 2013 (ind/ha)	Fongafale 2011 (ind/ha)	Fongafale 2013 (ind/ha)	Ref. density (ind/ha)
Actinopyga mauritiana	-	-	4.17±4.17	-	200
Bohadschia argus	-	-	12.5±12.5	20.83±14.23	120
Holothuria atra	-	-	50.00±45.56	229.17±194.96	5,600

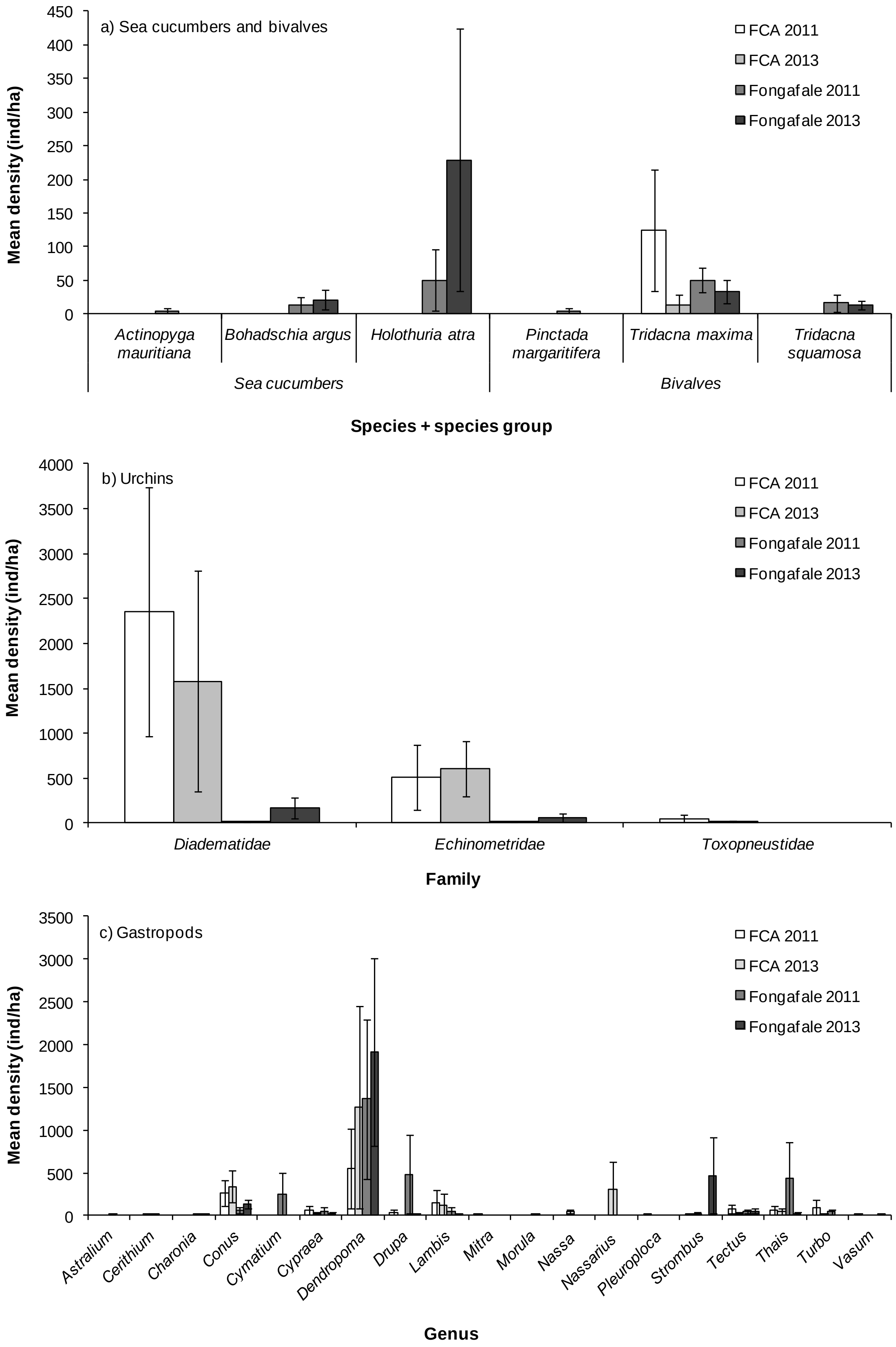


Figure 38 Overall mean densities (±SE) of a) sea cucumbers and bivalves, b) urchins and c) gastropods at the FCA and Fongafale sites, 2011 and 2013.

7. Creel surveys

Methods

Creel surveys at Funafuti Atoll focused on commercial spear and handline fishers. The creel surveys had the following objectives:

1) Document fisher demographics and fishing behavior (e.g. locations fished, distances travelled);
2) Provide a 'snapshot' of species composition of each fishery;
3) Document catch (including length and weight of all individuals caught) and catch-per-unit-effort for monitoring purposes.
4) Document fisher's perceptions of the status of fisheries resources.

Due to the lack of a centralized landing point or central market, fishers were contacted directly or by telephone to determine when they were going fishing and arrange a suitable meeting time and place to conduct the surveys.

During the survey the lead fisher was asked questions relating to the fishing trip, including the number of fishers that took part in the fishing trip, the fishing method(s) used, locations fished, distance travelled, and costs involved. Their historical fishing patterns, and perceptions of the state of resources, were also documented. Perceptions were documented once only for each lead fisher, regardless of how many times that fisher was surveyed. All fish caught were identified to species, measured to the nearest mm, and weighed to the nearest 10 g, unless damaged. A copy of the survey form used in the creel surveys is included as Appendix 6.

Data analysis

Summary statistics, including mean number of fishers, mean trip duration, mean catch (individual fish and kg) were compiled for each fishing method. Analyses of catch were performed on both taxonomic (family, species) and functional group (browsing herbivore, macro-carnivore / piscivore etc) levels, with functional groups consistent with those used in the D-UVC surveys (Chapter 4). Where weight data were not recorded (i.e. when a fish was damaged), location-specific length-weight relationships were used to estimate weight. In cases where no suitable location-specific length-weight relationship could be established, length-weight relationships were taken from published records in FishBase (Froese and Pauly 2013). Length-frequency plots were established for the main target species, and were compared against lengths-at-maturity (where known) to estimate the percentage of immature individuals in the catch. Catch-per-unit effort was calculated for each fishing method, and was based on number of fish and weight of fish caught per fisher per hour. The number of surveys required to detect a change in CPUE by abundance at a level of precision of 0.2 was calculated for each fishing method using the formula:

$$n = (SD / (P*avg))^2$$

where n = number of replicates required, SD = standard deviation, P = level of precision, and avg = average CPUE of each fishing method.

Results

Fishing behavior and catch details

Handline

Nine surveys of handline (bottom fishing) were completed. On average, handline trips involved 2.44±0.24 fishers, and lasted 6.44±0.8 hours (Table 14). The average catch per trip was 31.22±4.04 kg, or 79.89±15.03 individual fish. Catch-per-unit-effort (CPUE) was 5.34±0.77 fish/fisher/hour, or 2.35±0.40 kg/fisher/hour (Table 14). Handlining trips were largely conducted around the lagoon patch reefs at the eastern, western and southern areas of the lagoon.

The handline catch was dominated by members of the families Lutjanidae (snappers), Lethrinidae (emperors), Serranidae (groupers) and Sphyraenidae (barracudas) in terms of both individuals and weight (Figure 40). Forty-three species were observed in the handline catch (Appendix 11), with 719 individuals, weighing an estimated 281 kg, recorded. The most common species observed in the handline catch were *Lutjanus gibbus* (representing 36% of the total catch by abundance and 26% of the total catch by weight), *Lutjanus kasmira* (11% of the total catch by abundance and 4% of the total catch by weight), *Lethrinus obsoletus* (6% of the total catch by abundance and 5% of the total catch by weight) and *Sphyraena forsteri* (5% of the total catch by abundance and 12% of the total catch by weight) (Appendix 11).

Night Spearfishing

Four surveys of night spearfishing were completed. On average, spearfishing trips involved 5.25±0.25 fishers and lasted a mean duration of 5.75±0.85 hours (Table 14). The average catch per trip was 99.18±10.37 kg, or 129.25±13.42 individual fish. Catch-per-unit effort (CPUE) was 4.66±0.92 fish/fisher/hour, or 3.50±0.63 kg/fisher/hour (Table 14). Spearfishing trips took place mainly along the back and outer reefs of the western and southern atoll.

A total of 517 individual fishes were observed from the night spearfishing catch. Spearfishing largely targeted browsing herbivores, macro-carnivores / piscivores planktivores and scraping herbivores (Figure 41). Thirty-nine species from 11 families were observed (Appendix 12), with members of the Acanthuridae dominating the total catch by both abundance (254 individuals, representing 49.1% of the total catch by abundance) and weight (220.85 kg, representing 55.7% of the total catch by weight) (Figure 42). The most common finfish species caught were the browsing herbivores *Naso unicornis* (representing 16% of the total catch by abundance and 26% of the total catch by weight) and *Naso lituratus* (15% of the total catch by abundance and 6% of the total catch by weight) and the planktivore *Naso caesius* (9% of the total catch by abundance and 17% of the total catch by weight) (Appendix 12).

Figure 39 Members of the Tuvalu Fisheries Department undertaking a creel survey on Funafuti Atoll.

Table 14 Data summary of creel surveys conducted at Funafuti Atoll, 2013.

Fishing method	**Handline**	**Spear**
No. surveys where method observed	9	4
Total number of fishers surveyed	22	20
Mean trip duration (hrs)	6.44±0.80	5.75±0.85
Mean no. of fishers per trip	2.44±0.24	5.25±0.25
Average catch (number of fish) per trip	79.89±15.03	129.25±13.42
Average catch (kg) per trip	31.22±4.04	99.18±10.37
Average CPUE by abundance (no. fish / fisher / hour)	5.34±0.77	4.66±0.92
Average CPUE by weight (kg / fisher / hour)	2.35±0.40	3.50±0.63
No. of landings needed to survey to detect change in CPUE by abundance at precision of 0.2 (to 1 sig. fig.)	5	4
No. of landings needed to survey to detect change in CPUE by weight at precision of 0.2 (to 1 sig. fig.)	6	3

Length frequency plots for eight of the most commonly observed species for handline and spearfishing are presented as Figure 43. For *Epinephelus polyphekadion* and *Lutjanus gibbus*, spearfishing appeared to targeted slightly larger individuals than handlining, while no difference in length frequencies amongst methods was observed for *Lutjanus kasmira* or *Sphyraena forsteri* (Figure 43). Approximately 56% of the *E. polyphekadion* caught by handlining, and 50% caught by spearfishing, were under the median length at maturity of 352 mm proposed by Rhodes et al. (2011). Similarly, 66% of the *L. gibbus* caught by handlining, and 13% caught by spearfishing, were under the regional estimated median length of maturity of 25 cm FL (SPC unpublished data). All *N. lituratus* and 95% of *N. unicornis* were larger than the median lengths of maturity estimated for populations in Micronesia (Taylor et al. 2014).

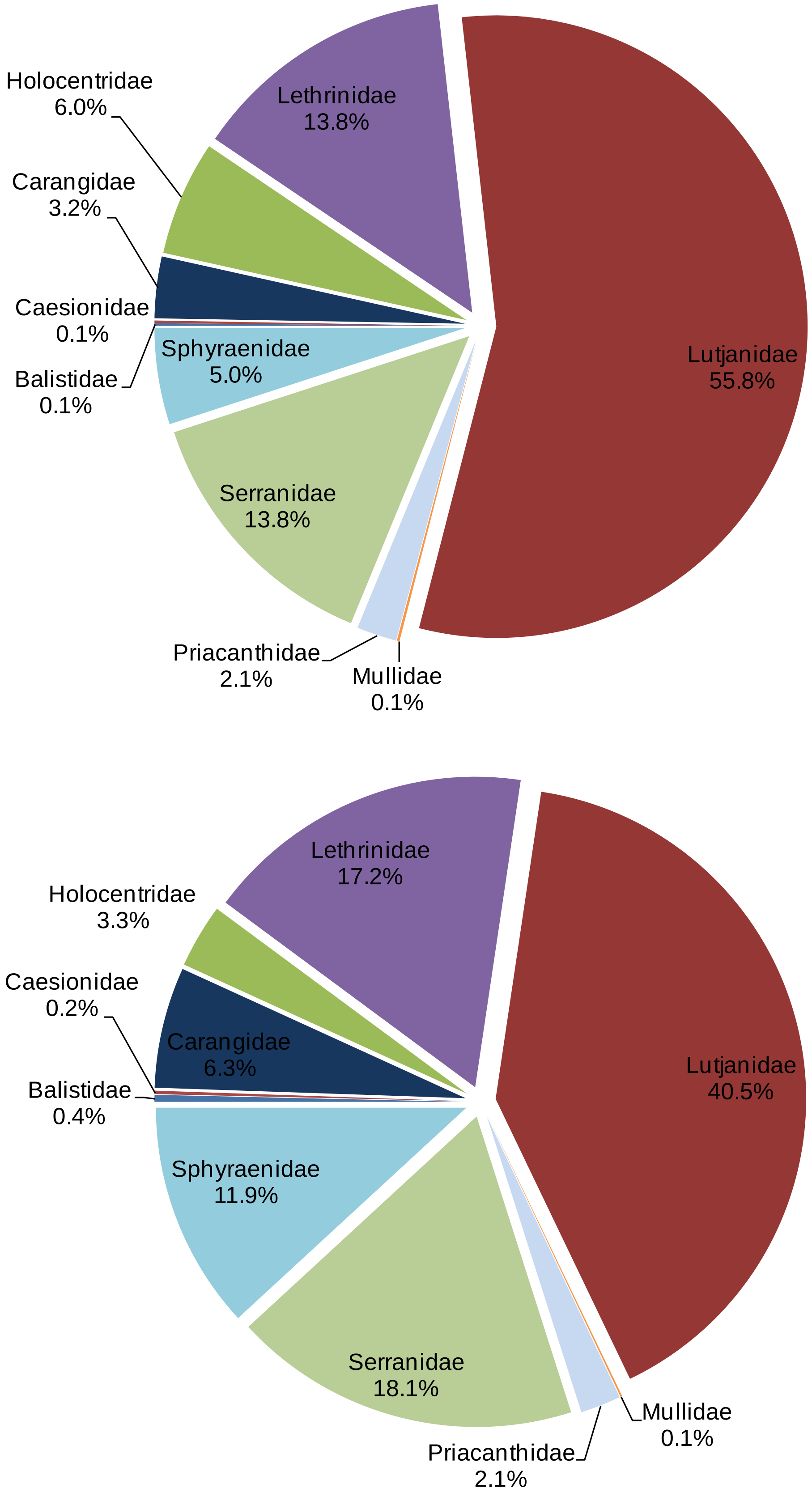


Figure 40 Percent contribution by abundance (top) and weight (bottom) of families caught by handlining, Funafuti Atoll, May 2013.

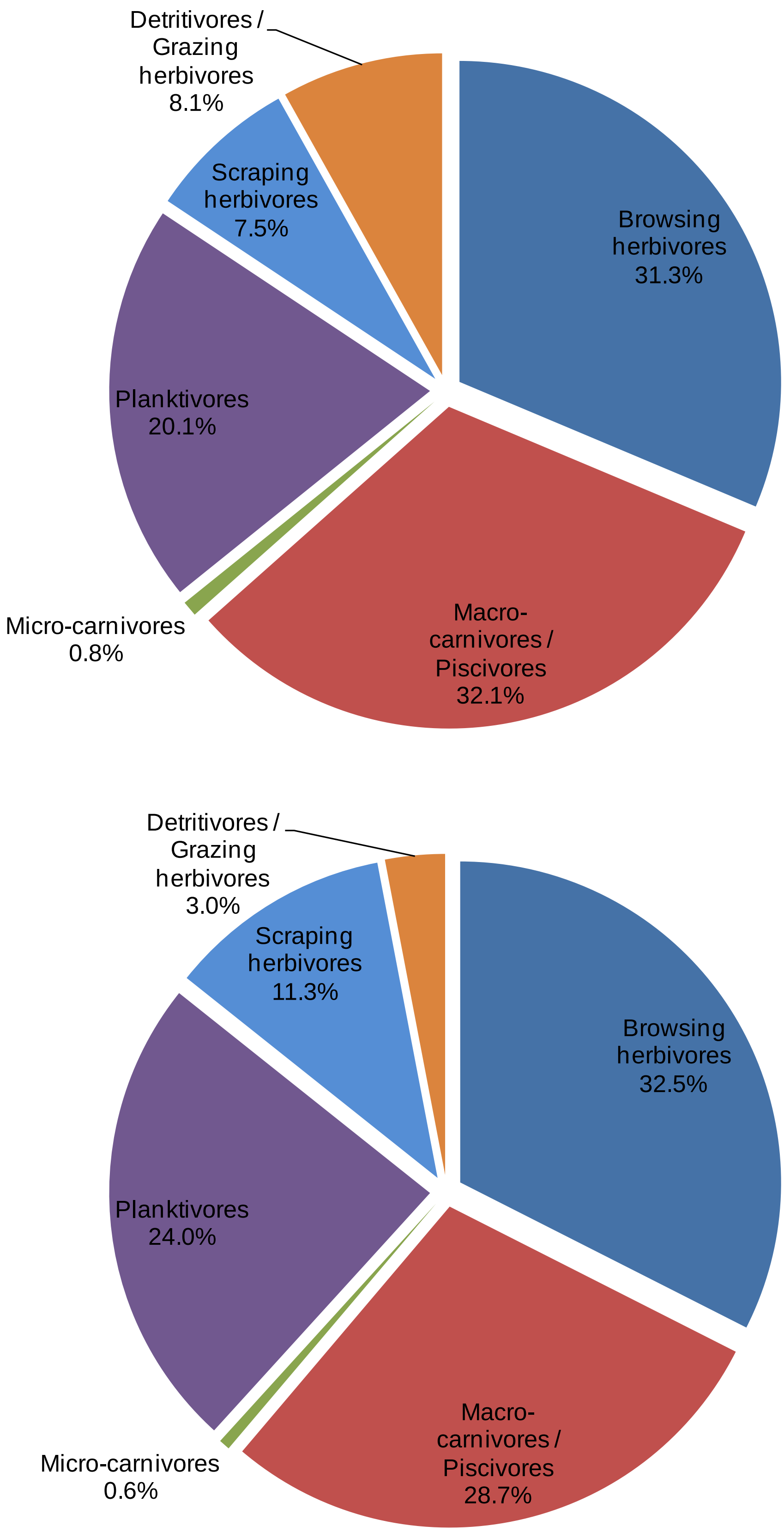
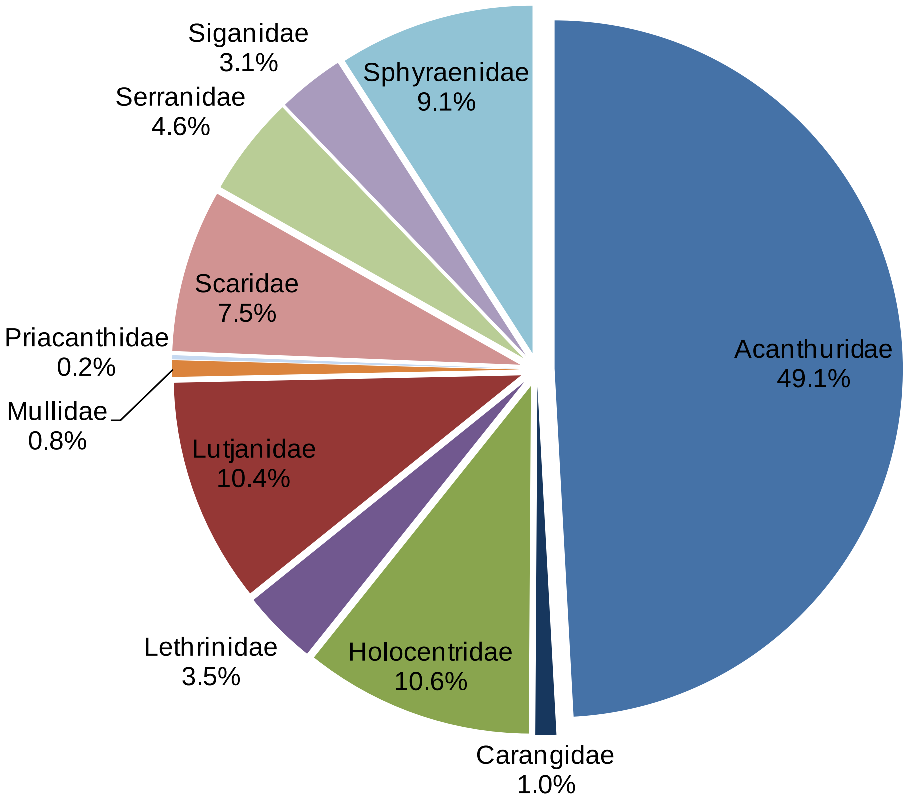


Figure 41 Percent contribution by abundance (top) and weight (bottom) of functional groups caught by night spearfishing, Funafuti Atoll, May 2013.



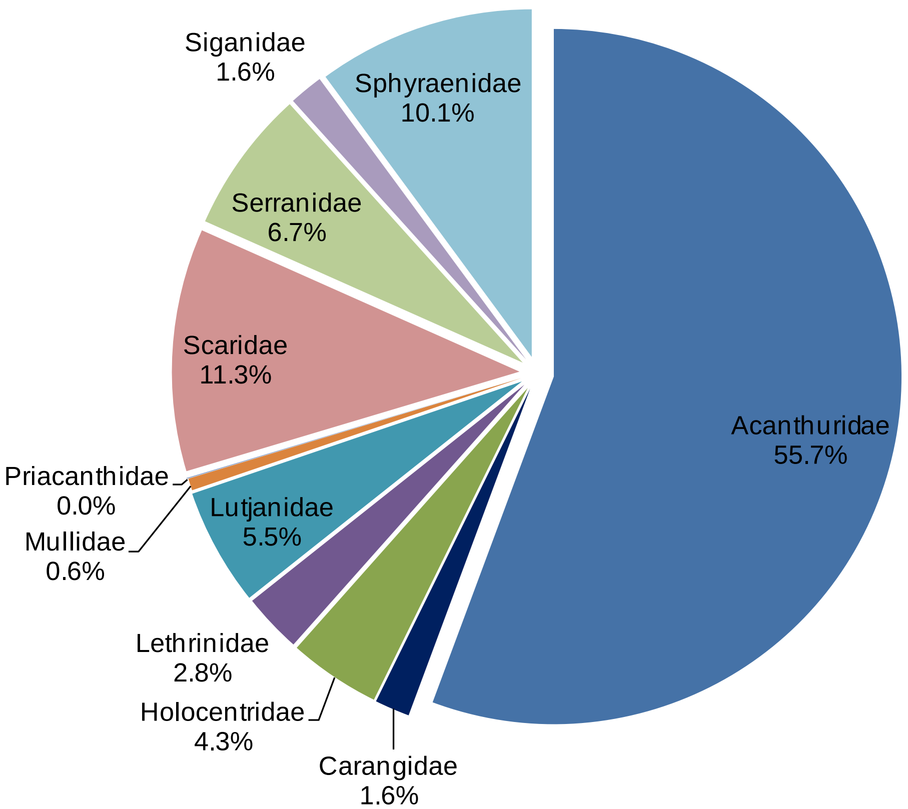


Figure 42 Percent contribution by abundance (top) and weight (bottom) of families caught by night spearfishing, Funafuti Atoll, May 2013.

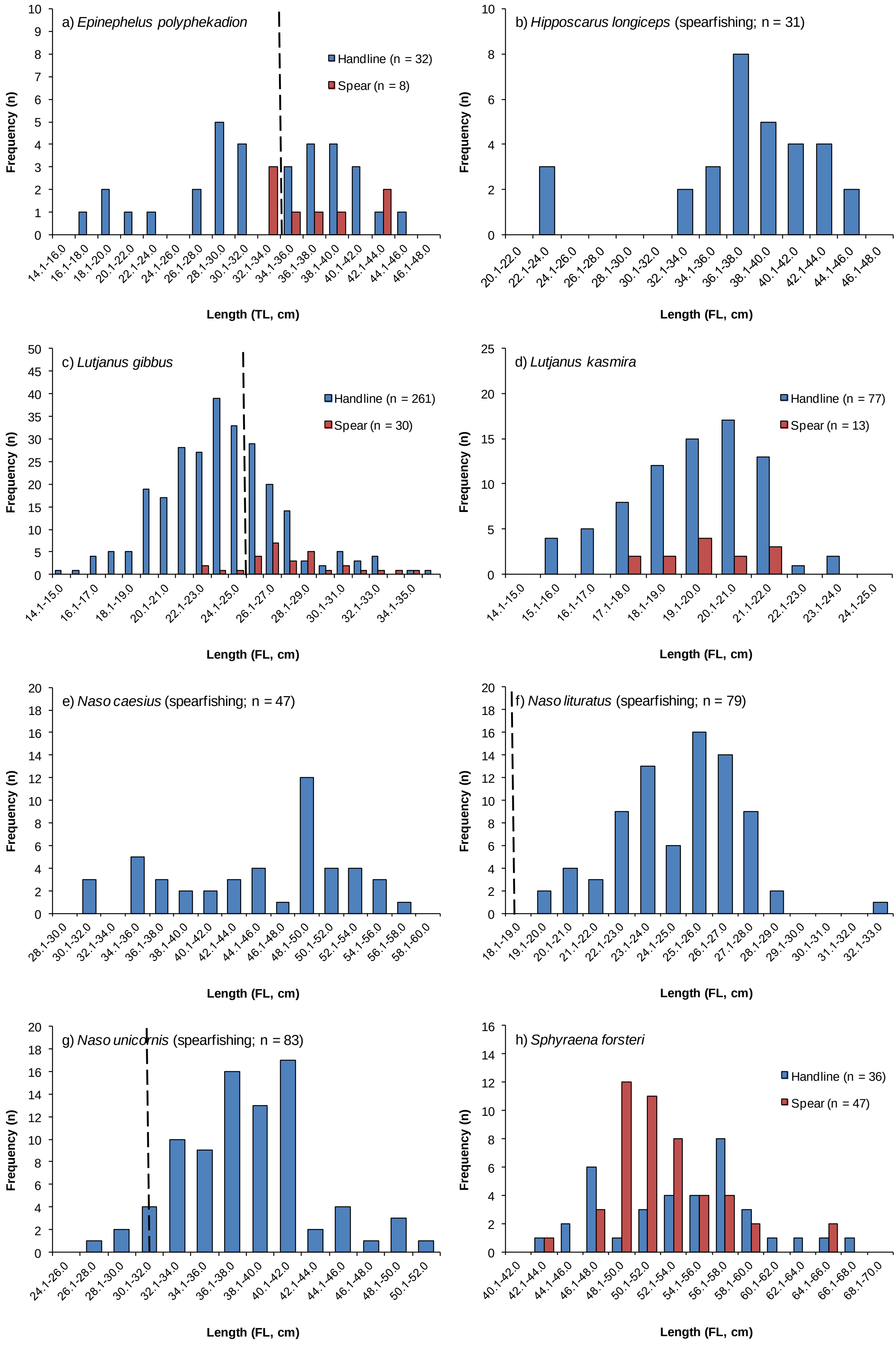


Figure 43 Length frequencies for eight of the most commonly observed finfish species during creel surveys. Dashed lines indicate estimated lengths at 50% maturity from: a) Rhodes et al. 2011; c) SPC unpublished data; f) & g) Taylor et al. 2014.

Fisher perceptions

Fisher perceptions were collected during six surveys[2]. The majority of fishers surveyed indicated that they had seen changes in the fishery in the last few years, with 83% of respondents claiming they felt their catches had decreased compared to five years ago, and 67% of respondents claiming sizes of fish had decrease compared to five years ago (Figure 44).

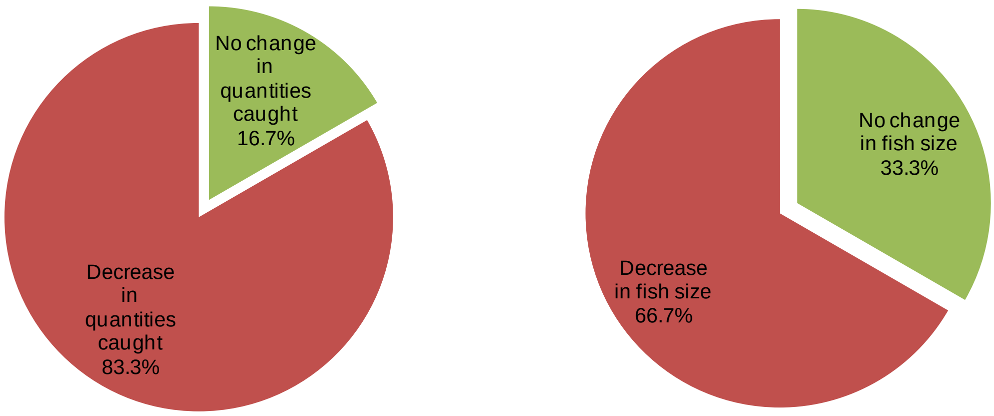


Figure 44 Responses of lead fishers to questions on perceptions on whether catch quantities (left) or fish sizes (right) have changed over the last five years.

[2] Perception data were only collected once for each lead fisher, irrespective of how many times they were surveyed.

8. Biological Monitoring of Selected Reef Fish Species

Methods

Sample collection

Biological monitoring of key reef fish species at Funafuti Atoll focused on five commercially harvested species: steephead parrotfish (*Chlorurus microrhinos*), honeycomb grouper (*Epinephelus merra*), humpback red snapper (*Lutjanus gibbus*), bluestripe snapper (*Lutjanus kasmira*) and orangespine unicornfish (*Naso lituratus*) and two 'control' species: redfin butterflyfish (*Chaetodon lunulatus*) and striated surgeonfish (*Ctenochaetus striatus*), which were included to control for fishing effects. Fish were collected from commercial fishers, by fisheries-independent spearfishing, or from roadside fish markets where the location, date and method of capture were known. The fork length (FL) and total length (TL) were measured to the nearest millimetre for each fish collected, unless damaged. Each individual was weighed to the nearest 10 g unless damaged or eviscerated. Sex was determined from a macroscopic examination of the gonads. Sagittal otoliths (hereafter referred to as otoliths) were removed from all specimens for ageing purposes, cleaned, dried and stored in plastic vials until processing in the laboratory.

Sample processing

A single otolith from each fish was weighed to the nearest 0.001g using an electronic balance, unless broken. Otoliths were used to estimate fish age. Otoliths from *C. microrhinos*, *C. striatus*, *E. merra*, *L. gibbus*, *L. kasmira* and *N. lituratus* were processed using standard sectioning protocols. Here, a single otolith from each individual was embedded in resin and sectioned on the transverse axis using a slow-speed diamond edge saw. Sections were approximately 300µm thick, and care was taken to ensure the primordium of the otolith was included in the sections. Sections were cleaned, dried and mounted onto clear glass microscope slides under glass coverslips using resin.

Otoliths from *C. lunulatus* were prepared using the single ground transverse sectioning method, following the method described in Krusic-Golub and Robertson (2014). Here, a single otolith from each fish is fixed on the edge of a slide using thermoplastic mounting media (CrystalBond), with the anterior of the otolith hanging over the edge of the slide, and the primordium just inside the slide's edge. The otolith was then ground down to the edge of the slide using 400 and 800 grit wet and dry paper. The slide was then reheated and the otolith removed and placed on a separate slide with CrystalBond, with the ground surface facing down. Once cooled, the otolith was ground horizontally to the grinding surface using varying grades (1500, 1200, 800 and 400 grit) of wet and dry paper and polished with lapping film.

Mounted otolith sections were examined under a stereo microscope with reflected light. Opaque increments observed in the otolith were assumed to be annuli for the seven species examined. Supportive evidence for annual periodicity in opaque increment formation in otoliths has been demonstrated in the majority of cases for tropical reef fish, including both *Lutjanus gibbus* (Nanami et al. 2010) and *Naso lituratus* (Taylor et al. 2014) and many other closely related species to those examined here (e.g. Choat and Axe 1996, Newman et al. 2000, Pilling et al. 2000). The annuli count was accepted as the final age of the individual, with no adjustment made of birth date or date of capture.

Data analysis

Length and age frequency distributions were constructed to examine population structures of each species. To examine growth, the von Bertalanffy growth function (VBGF) was fitted by nonlinear least-squares regression of length (FL or TL) on age. The form of the VBGF used to model length-at-age data was as follows:

$$L_t = L_\infty[1 - e^{-K(t-t_0)}]$$

where L_t is the length of fish at age t, L_∞ is the hypothetical asymptotic length, K is the growth coefficient or rate at which L_∞ is approached, and t_0 is the hypothetical age at which fish would have a length of zero. Due to a lack of smaller, younger fish in the samples, t_0 was constrained to zero. A single VBGF was fitted for hermaphroditic species (*E. merra* and *C. microrhinos*), while sex-specific VBGFs were initially fitted for gonochoristic (*C. lunulatus*, *C. striatus*, *L. gibbus*, *L. kasmira* and *N. lituratus*). Preliminary results indicated little significant difference in growth of males and females of *C. lunulatus* and *C. striatus*; hence a combined growth curve was fitted for males and females of each of these species.

Age-based catch curves (Ricker 1975) were used to estimate the instantaneous rate of total mortality (Z) for each species with samples sizes > 45. Catch curves were generated by fitting a linear regression to the natural log-transformed number of fish in each age class against fish age. The slope of this regression is an estimate of the rate of annual mortality. Regressions were fitted from the first modal age class, presumed to be the first age class fully selected by the sampling gear, to the oldest age class that was preceded by no more than two consecutive zero frequencies. Instantaneous natural mortality rates (M) were derived using the general regression equation of Hoenig (1983) for fish:

$$\ln(M) = 1.46 - 1.01 \times \ln t_{max}$$

where t_{max} is the maximum known age, in years. The harvest strategy of $F_{opt} = 0.5M$ (Walters 2000) was adopted in this study as the optimum fishing mortality rate for sustainable exploitation (sensu Newman and Dunk 2002).

The length and age at which the hermaphroditic species *C. microrhinos* and *E. merra* changed sex was determined by logistic regression analysis, using the equation:

$$Ps = 1/[1 + \exp(-\ln(19)\,(s - s_{50})(s_{95} - s_{50}))]$$

where Ps = the proportion of males in each 50 mm length or age class s, s_{50} and s_{95} are the ages or lengths at which 50% and 95% of the population have changed to males, respectively. Due to low numbers, transitional individuals were excluded from the analysis. The data (male or female) for individual fish were randomly re-sampled and analysed to create 10 sets of bootstrap estimates for the parameters of the logistic equation and estimates of the probability of sex change within the recorded lengths and ages. Approximate 95% confidence limits of the parameters were calculated as the 2.5 and 97.5 percentiles of the parameter estimates obtained from the re-sampling technique. The point estimates for each parameter and of the probability of fish being male at each specified length or age were taken as the medians of the bootstrap estimates.

Results

Eighteen redfin butterflyfish (*C. lunulatus*) were collected by spearfishing at Funafuti Atoll, with 17 of these successfully aged to date. Estimated ages ranged from 2–11 years, with a modal age of 8 years (Figure 45; Table 15). Growth was similar amongst sexes, and little difference was evident between unconstrained and constrained (t_0 = 0) VGBF curves (Figure 46). Due to low sample sizes, no mortality estimates were calculated for this species.

Twenty-two steephead parrotfish (*C. microrhinos*) were collected from the spearfishing catch of Funafuti Atoll, with 20 of these successfully aged to date. Estimated ages ranged from 3–11 years, with modal ages of 4 and 7 years (Figure 45; Table 15). Little difference was evident between unconstrained and constrained (t_0 = 0) VGBF curves (Figure 46). The length and age at which 50% of the population changed sex was estimated as 42.5 cm FL (95% CL = 41.7–43.3 cm FL) and 5.6 years (95% CL = 3.3–7.2 years), respectively. Due to low sample sizes, no mortality estimates were calculated for this species.

Forty-nine striated surgeonfish (*C. striatus*) were collected by spearfishing at Funafuti Atoll, with 41 of these successfully aged to date. Estimated ages ranged from 1-19 years, with a modal age of 5 years (Figure 45; Table 15). Little difference in growth was evident among sexes (Figure 46).

Sixty-one honeycomb grouper (*E. merra*) were collected from Funafuti Atoll, with 47 of these successfully aged to date. Estimated ages ranged from 1–6 years, with a modal age of 2 years (Table 15). The length at which 50% of the population changed sex was estimated as 17.7 cm TL (95% CL = 16.7–19.3 cm TL). Due to the low number of males aged, no estimates of the age at 50% sex change were possible. Total (Z) and natural (M) rates of mortality for *E. merra* were estimated as 0.734 and 0.279, respectively, while fishing mortality was estimated as 0.454, exceeding the reference point of 0.5 times the rate of M (Table 16).

Forty-nine humpback red snapper (*L. gibbus*) were collected from the commercial catch from Funafuti Atoll, all of which were aged successfully. Estimated ages for this species ranged from 1–21 years, with a modal age of 3 years (Figure 45; Table 15). Growth differed markedly among sexes, with males growing at a faster rate and reaching a greater length at a given age than females (Figure 46). Total (Z) and natural (M) rates of mortality were estimated as 0.189 and 0.115, respectively (Table 15). Fishing mortality was estimated as 0.074, exceeding the reference point of 0.5 times the rate of M (= 0.058; Table 16).

Forty-six bluestripe snapper (*L. kasmira*) were collected from the handline catch from Funafuti Atoll, with 43 of these successfully aged to date. Estimated ages ranged from 2–6 years, with a modal age of 3 years (Figure 45; Table 15). As with *L. gibbus*, growth differed markedly among sexes, with males growing at a faster rate and reaching a greater length-at-age than females (Figure 46). Total (Z) and natural (M) rates of mortality were estimated as 1.128 and 0.705, respectively, while fishing mortality was estimated as 0.423, exceeding the reference point of 0.5 times the rate of M (= 0.35; Table 16).

Forty-three orangespine unicornfish (*N. lituratus*) were collected from the spearfishing catch from Funafuti Atoll, with 39 of these aged successfully to date. Estimated ages ranged from 1–20 years, with a modal age of 5 years (Figure 45; Table 15). Growth differed among sexes, with males growing at a faster rate and reaching a greater length at a given age than females (Figure 46). Due to low sample sizes, no mortality estimates were calculated for this species.

Table 15 Demographic parameter estimates for selected reef fish species from Funafuti Atoll, Tuvalu, April–May 2013. VBGF parameters are based on constrained (t_0=0) estimates[3].

Species	No. collected	No. aged	Size range (cm)	Age range	L_∞ (males / females)	K (males / females)
Chaetodon lunulatus	18	17	9.0–11.7 (TL)	2–11	11.00	0.77
Chlorurus microrhinos	22	20	32.4–45.8 (FL)	3–11	47.38	0.41
Ctenochaetus striatus	49	41	11.9–20.2 (TL)	1-19	16.92	0.63
Epinephelus merra	62	47	10.5–20.8 (TL)	1–6	16.46	1.01
Lutjanus gibbus	49	49	15.5–35.7 (FL)	1–21	34.00 / 29.35	0.38 / 0.44
Lutjanus kasmira	46	43	15.6–23.4 (FL)	2–6	22.37 / 19.75	0.60 / 0.91
Naso lituratus	43	39	19.5–30.1 (FL)	1–20	27.05 / 23.22	0.92 / 1.05

Table 16 Estimates of mortality for monitored species (where n > 40 individuals aged) using catch curve and Hoenig (1983) estimators. Maximum ages used in the equation of Hoenig (1983) and age ranges used for total mortality (Z) calculations are indicated. Red faces indicate where estimated fishing mortality exceeds the reference point of 0.5 M, green faces indicate where fishing mortality is lower than 0.5 M.

Species	Maximum age (yr)	Age range	Catch curve (Z)	Hoenig (1983)	Fishing mortality (F)	Fopt
Epinephelus merra	15 (SPC unpublished data	2–6	0.734	0.279	0.454	0.140 
Lutjanus gibbus	36 (SPC unpublished data)	3–14	0.189	0.115	0.074	0.058 
Lutjanus kasmira	6 (this study, Morales-Nin and Ralston 1990)	3–6	1.128	0.705	0.423	0.352 

3 VBGF parameters are presented for each sex separately where growth differed amongst sexes, or for the entire population where no difference was observed among sexes.

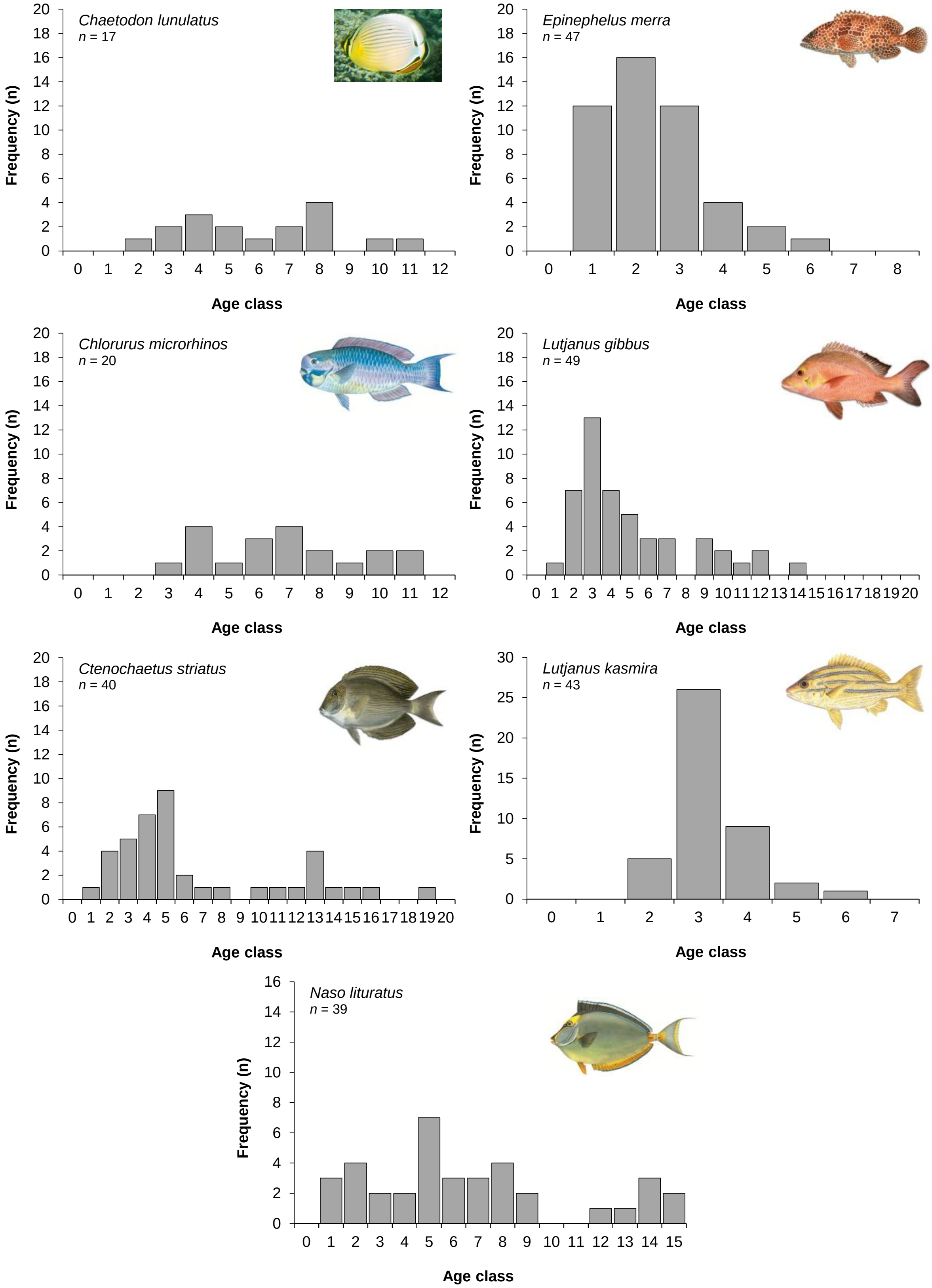


Figure 45 Age frequency distributions for the seven monitored finfish species at Funafuti Atoll, April-May 2013.

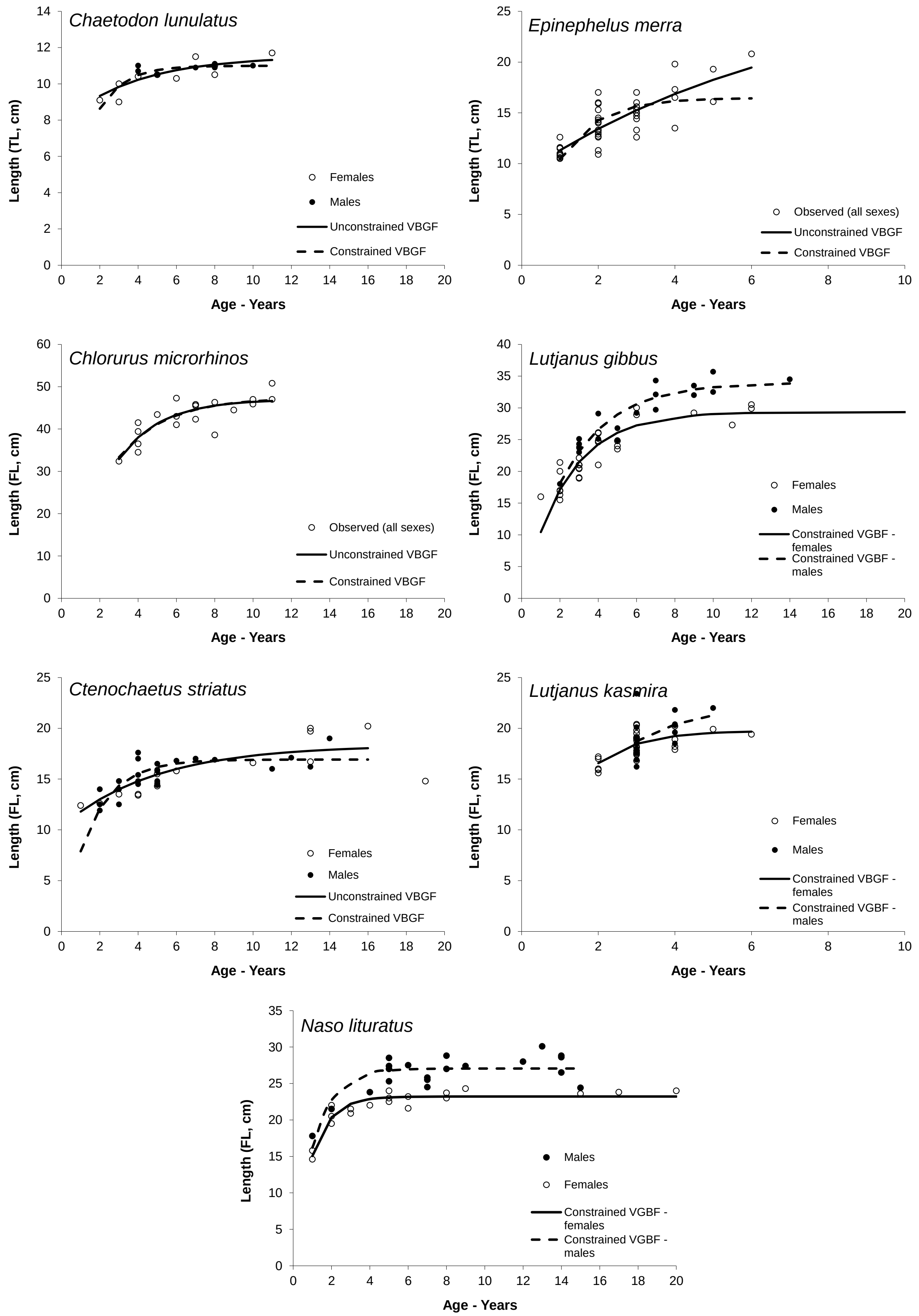


Figure 46 Length-at-age data and von Bertalanffy growth function curves of seven monitored finfish species at Funafuti Atoll.

9. Discussion and Recommendations for Improving the Resilience of Coastal Fisheries of Funafuti Atoll

Monitoring potential effects of chronic disturbances such as climate change is a challenging prospect that requires the generation of an extensive time series of data and regional cooperation and comparison amongst standardised datasets and indicators. Nevertheless, several key management recommendations, outlined below, are prescribed from the current study that will help improve the resilience of the coastal fisheries of Funafuti Atoll to both long-term (e.g. climate change) and short-term (e.g. overfishing) stressors. Many of the approaches recommended here will also be of relevance to other islands of Tuvalu. This list is by no means intended to be exhaustive; rather it provides salient information on the key recommendations.

1) **Provide greater enforcement of the Funafuti Conservation Area.** Overall, few consistent differences were observed in resource abundance or habitat health between the FCA and sites open to fishing. It is highly likely that illegal fishing is the main reason behind these patterns. During the field survey, boats were observed extracting marine resources from the Funafuti Conservation Area almost daily, while no enforcement was observed in the Area during the five weeks of fieldwork. For the Conservation Area to be effective, greater enforcement of illegal fishing needs to occur. Parties caught fishing in the Conservation Area should be fined, with the revenue generated from such fines used on enforcement expenses (e.g. fuel). Alternately, a departure tax could be imposed for visitors to Funafuti, with the revenue generated from this activity put into financing enforcement programs, similar to the 'Green fee' departure tax in Palau. Ultimately, in the event that the town council (Kapule) has limited capacity to monitor the Conservation Area, responsibility for its enforcement (and potentially management) should be handed over to other suitable organisations/government departments.

2) **Strengthen stakeholder awareness programs and exchange of information on coastal fisheries, the marine environment and climate change.** Education and awareness programs promoting responsible reef management practices and incorporating relevant scientific information should be provided to communities. Understanding the processes and effects of climate change will assist the communities to better integrate local and scientific knowledge in management processes and strategies to mitigate their impacts. Tuvalu Fisheries should play a central role in facilitating these programs.

3) Poor overall health and considerable overgrowth of corals by macroalgae is apparent along the back- and lagoon reefs of the more densely populated eastern side of the Atoll. This finding is suggestive of a widespread coral-algae regime shift in this region. Given their pattern of occurrence towards the eastern side of the atoll, these regime-shifts likely result from a combination of anthropogenic stressors, including heavy fishing pressure on herbivorous fishes, and high levels of eutrophication, combined with relatively poor tidal flushing. To prevent further overgrowth, and to promote the re- growth of coral on damaged reefs, the following activities are recommended:

- **Remedy point sources of nutrient input.** Sources of eutrophication into the lagoon need to be restricted. This will require a concerted and collaborative effort by various government departments. Effort should also be made to monitor the nutrient concentrations within the lagoon.

- **Place restrictions on destructive or highly efficient fishing practices, in particular night-time spearfishing.** Fishing pressure on herbivorous fishes, in particular browsing and scraping species such as unicornfishes and parrotfishes, should be reduced. While few browsing herbivores were observed during the in-water assessments, this group in particular comprised a significant proportion of the spearfishing catch observed during the creel surveys. Any possible methods to reduce fishing effort on browsing and scraping herbivorous fishes should be undertaken to minimise the risk further coral-algae regime shifts in the Atoll. Potential methods could include:
    - Placing restrictions on destructive or highly efficient fishing practices that target these groups (e.g. night-time spearfishing);
    - the creation of education/awareness programs on the importance and value of herbivorous fishes; and
    - the creation of incentives to focus fishing pressure on pelagic species, such as small tunas, flying fish, mackerels and scads.

4) **Protect sharks and other iconic and ecologically-significant species.** In addition to reducing fishing pressure on herbivorous fish populations, protection should be offered to other ecologically significant and species, in particular sharks and the humphead wrasse, *Cheilinus undulatus*. Sharks are apex predators that play a key role in maintaining healthy reef ecosystems. Few sharks were observed during the surveys. Globally, reef shark populations are plummeting and at risk of ecological extinction over the coming decades as a result of fishing, primarily for the shark fin trade. Similarly, the humphead wrasse is listed as Endangered on the IUCN Red List in recognition of its slow population turnover (Choat et al. 2006) and vulnerability to fishing. To conserve these iconic species we recommend that a regional moratorium be placed on shark fishing, particularly for the fin trade, and the sale of *C. undulatus*.

5) **Maintain the national closure of sea cucumber fisheries.** Due to low densities, the sea cucumber fishery within Funafuti Atoll should be officially closed to allow recovery of stocks and the ecological functioning they perform. A national assessment into the health and status of sea cucumber stocks is recommended. Similarly, there is no potential for commercial fishing of trochus at this time, and stocks are in need of on-going protection to build until recommended minimum harvest densities of 500–600 individuals/ha are achieved (Pakoa et al. 2014).

6) **Develop and implement coastal fisheries management plan / regulations.** Fishing in Funafuti Atoll, and elsewhere in Tuvalu, is at present highly unregulated, with little rules or restrictions on harvests. Given the observed over-exploitation of species, disproportionate

capture of immature individuals, heavy fishing pressure and poor health of reef habitats, it is strongly recommended that a coastal fisheries management plan / regulations be developed that addresses various fishing activities (e.g. fishing gears and practices), restrictions on species' harvests (e.g. size limits, seasonal closures during spawning season), export of coastal resources, and community management practices.

Recommendations for Future Monitoring

To be able to assess the success of management interventions and well as monitor the status and trends in productivity of Funafuti Atoll's coastal fisheries and supporting habitats in the face of climate change and other anthropogenic stressors, it is highly recommended that continual monitoring is conducted. In addition to continuing the monitoring program established here, the following recommendations are proposed for future monitoring events:

- It is highly recommended that a 'core' monitoring team be established within Tuvalu's Department of Fisheries, in collaboration with other institutions (e.g. Department of Environment, Kapule). The development of a core team of monitoring staff will help maintain and build monitoring capacity, and help reduce surveyor biases that may otherwise preclude the detection of 'real' trends.

- It is recommended that permanent stakes be established at the beginning and end of the finfish and benthic habitat assessment transects. This is to ensure the same exact transect path is assessed each time, reducing variability associated with minor variations in transect positioning.

- In addition to continuing the monitoring methodologies presented here, it is highly recommended that ocean acidification indices, sedimentation rates and nutrient input (or suitable proxies such as sedimentary oxygen consumption (Ford et al. 2014)) within the study region be monitored.

- Furthermore, to ensure that results of future finfish surveys are not biased by differences in observer skill or experience should additional staff be trained, it is recommended that non-observer based techniques, such as videography, be investigated for use in conjunction with the D-UVC surveys.

- The creel surveys conducted at Funafuti Atoll represent a single 'snapshot' of fisher behavior, fishing patterns and catches at the time of survey. Further creel surveys are recommended to explore temporal variations in these parameters. Creel surveys could be conducted initially at least every 3-6 months, and could be scaled back should little temporal variation emerge.

- It is highly recommended that the biological monitoring program be expanded, through both an increase in the sample sizes of species collected here (in particular those species for which estimates of mortality were not possible), and inclusion of other exploited species. Given that all of the fished species for which mortality estimates were generated were found to be over-exploited, it is likely many species in Funafuti are similarly stressed. Monitoring of the age structure of exploited species is likely to be a more sensitive indicator of the effects of exploitation than monitoring of catch and effort data in isolation, due to the likelihood of catch rates for reef-associated species being affected by hyperstability (whereby stable CPUE may persist long after declines in overall population abundance have occurred, due to their high habitat dependencies and aggregative nature) (Newman and Dunk 2000).

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Appendix 1 GPS positions of finfish and benthic habitat assessment transects

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	8.435017	179.162317
	Back-reef	T2	8.435333	179.162983
	Back-reef	T3	8.435600	179.163600
	Lagoon reef	T37	8.482233	179.156183
	Lagoon reef	T38	8.481800	179.156867
	Lagoon reef	T39	8.481517	179.157383
	Outer-reef	T19	8.425017	179.133817
	Outer-reef	T20	8.425033	179.134617
	Outer-reef	T21	8.425050	179.13545
Fongafale 2	Reef flat	T31	8.564583	179.131483
	Reef flat	T32	8.564983	179.130933
	Reef flat	T33	8.564350	179.132050
	Back-reef	T34	8.564617	179.130933
	Back-reef	T35	8.564083	179.131600
	Back-reef	T36	8.563767	179.132267
	Lagoon reef	T40	8.550100	179.139917
	Lagoon reef	T41	8.551567	179.140067
	Lagoon reef	T42	8.551400	179.140650
	Outer-reef	T28	8.566833	179.134400
	Outer-reef	T29	8.566833	179.133667
	Outer-reef	T30	8.566933	179.132950
FCA 1	Reef flat	T7	8.485983	179.06745
	Reef flat	T8	8.486317	179.066567
	Reef flat	T9	8.486900	179.065883
	Back-reef	T10	8.494150	179.063967
	Back-reef	T11	8.494233	179.063417
	Back-reef	T12	8.493983	179.062283
	Lagoon reef	T43	8.498783	179.070750
	Lagoon reef	T44	8.499167	179.070983
	Lagoon reef	T45	8.499867	179.071317
	Outer-reef	T22	8.485017	179.061233
	Outer-reef	T23	8.485483	179.060650
	Outer-reef	T24	8.485983	179.060167
FCA 2	Reef flat	T16	8.590600	179.068400
	Reef flat	T17	8.591433	179.068617
	Reef flat	T18	8.593217	179.069233
	Back-reef	T13	8.590633	179.071467
	Back-reef	T14	8.590950	179.070833
	Back-reef	T15	8.591533	179.070617
	Lagoon reef	T46	8.586583	179.076483
	Lagoon reef	T47	8.586633	179.076850
	Lagoon reef	T48	8.587450	179.076183
	Outer-reef	T25	8.581450	179.063033
	Outer-reef	T26	8.582017	179.063333
	Outer-reef	T27	8.582750	179.06365

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

Fish form UVC PAGE /

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

Habitat Form UVC (new)

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 ☐

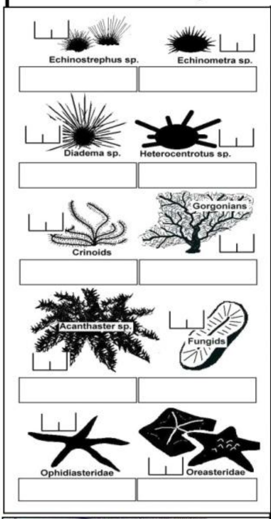
	current	oceanic influence	terrigenous influence
none	☐	☐	☐
medium	☐	☐	☐
strong	☐	☐	☐

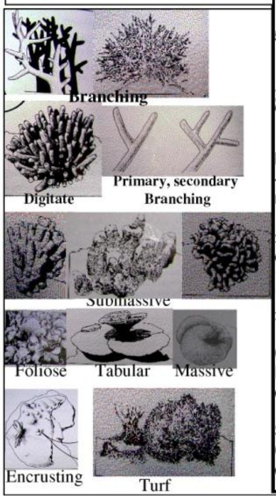
draw profile including estimate of slope in degree
Flat ☐ Floor ☐
Gentle slope ☐ Steep slope ☐

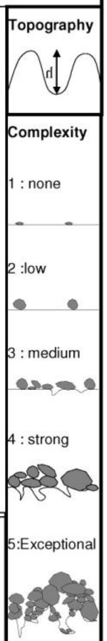
Remarks:

	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 PERMANOVA results for observed differences in finfish D-UVC surveys, 2011 vs. 2013.

Site + habitat	Variable tested	Outcome	t	P	Unique perms
FCA reef flat	Mean density - Labridae	2013 > 2011	2.4058	0.018	315
FCA reef flat	Mean density - Mullidae	2013 < 2011	3.416	0.007	152
FCA reef flat	Mean density - Pomacentridae	2013 > 2011	2.4392	0.026	402
FCA reef flat	Mean biomass - Labridae	2013 > 2011	2.6609	0.031	316
FCA reef flat	Mean biomass - Mullidae	2013 > 2011	2.9358	0.015	202
FCA reef flat	Mean density - Farmers	2013 > 2011	2.3088	0.044	115
FCA back reef	Mean density - Pomacentridae	2013 > 2011	2.4174	0.032	307
FCA back reef	Mean biomass - Serranidae	2013 > 2011	2.3249	0.048	416
FCA outer reef	Mean density - Balistidae	2013 > 2011	2.7397	0.022	308
FCA outer reef	Mean density - Labridae	2013 > 2011	2.5480	0.044	238
FCA outer reef	Mean density - Mullidae	2013 < 2011	2.6494	0.020	44
FCA outer reef	Mean density - Scaridae	2013 > 2011	2.8255	0.027	309
FCA outer reef	Mean biomass - Mullidae	2013 < 2011	2.5959	0.036	63
FCA outer reef	Mean density – Scraping herbivores	2013 > 2011	2.8255	0.027	305
FCA outer reef	Mean density – Farmers	2013 > 2011	2.6222	0.038	305
Fongafale back reef	Mean total density	2013 > 2011	2.5783	0.023	413
Fongafale back reef	Mean density - Labridae	2013 > 2011	4.6273	0.004	204
Fongafale back reef	Mean density - Pomacanthidae	2013 > 2011	2.9742	0.003	35
Fongafale back reef	Mean density - Pomacentridae	2013 > 2011	3.0737	0.017	405
Fongafale back reef	Mean density - Farmers	2013 > 2011	1.9069	0.007	44
Fongafale back reef	Mean biomass - Farmers	2013 > 2011	2.3638	0.003	61
Fongafale outer reef	Mean density - Chaetodontidae	2013 > 2011	2.2464	0.027	407
Fongafale outer reef	Mean biomass - Lutjanidae	2013 > 2011	3.0247	0.022	304
FCA vs. Fongafale – reef flat	Mean total biomass	Fongafale > FCA	8.5577	0.003	414
FCA vs. Fongafale – reef flat	Mean density - Acanthuridae	Fongafale > FCA	3.7924	0.015	416
FCA vs. Fongafale – reef flat	Mean density - Chaetodontidae	Fongafale > FCA	5.5912	0.001	309
FCA vs. Fongafale – reef flat	Mean density - Pomacentridae	FCA > Fongafale	2.3609	0.025	312
FCA vs. Fongafale – reef flat	Mean density - Scaridae	Fongafale > FCA	3.1197	0.025	235
FCA vs. Fongafale – reef flat	Mean biomass - Acanthuridae	Fongafale > FCA	7.006	0.002	398
FCA vs. Fongafale – reef flat	Mean biomass - Chaetodontidae	Fongafale > FCA	5.6925	0.001	313
FCA vs. Fongafale – reef flat	Mean biomass - Scaridae	Fongafale > FCA	6.0922	0.002	312
FCA vs. Fongafale – back	Mean density - Acanthuridae	Fongafale > FCA	3.2867	0.015	411
FCA vs. Fongafale – back	Mean biomass - Mullidae	Fongafale > FCA	3.1021	0.023	411
FCA vs. Fongafale – lagoon	Mean total biomass	FCA > Fongafale	2.3394	0.043	412
FCA vs. Fongafale – lagoon	Mean density - Lethrinidae	FCA > Fongafale	2.4834	0.021	398
FCA vs. Fongafale – lagoon	Mean density - Lutjanidae	FCA > Fongafale	1.4006	0.043	31

FCA vs. Fongafale – lagoon	Mean density - Serranidae	FCA > Fongafale	2.3337	0.040	236
FCA vs. Fongafale – lagoon	Mean biomass - Lethrinidae	FCA > Fongafale	3.3509	0.002	408
FCA vs. Fongafale – lagoon	Mean biomass - Lethrinidae	FCA > Fongafale	2.4339	0.029	63
FCA vs. Fongafale – lagoon	Mean biomass - Serranidae	FCA > Fongafale	3.0451	0.009	304
FCA vs. Fongafale – outer	Mean density - Balistidae	FCA > Fongafale	3.0109	0.018	147
FCA vs. Fongafale – outer	Mean density - Chaetodontidae	Fongafale > FCA	2.1105	0.048	311
FCA vs. Fongafale – outer	Mean density - Lethrinidae	Fongafale > FCA	1.6675	0.018	24
FCA vs. Fongafale – outer	Mean density - Pomacanthidae	FCA > Fongafale	1.8700	0.019	231
FCA vs. Fongafale – outer	Mean density - Scaridae	FCA > Fongafale	2.7123	0.031	414
FCA vs. Fongafale – outer	Mean biomass - Balistidae	FCA > Fongafale	4.2129	0.007	315
FCA vs. Fongafale – outer	Mean biomass - Chaetodontidae	Fongafale > FCA	2.8848	0.017	399
FCA vs. Fongafale – outer	Mean biomass - Lethrinidae	Fongafale > FCA	2.6401	0.047	32

Appendix 5 PERMANOVA results for observed differences in fine-scale benthic habitat assessments, 2011 vs. 2013.

Site + habitat	Variable tested	Outcome	t	P	Unique perms
FCA back reef	Pavement	2013 > 2011	4.4274	0.016	6
FCA outer reef	Other invertebrates	2013 < 2011	3.3142	0.011	86
FCA outer reef	Turf algae	2013 < 2011	3.1426	0.015	405
Fongafale back reef	Turf algae	2013 < 2011	4.5067	0.003	414
FCA vs. Fongafale – reef flat	Live hard coral	Fongafale > FCA	7.4362	0.004	146
FCA vs. Fongafale – reef flat	Branching coralline algae	FCA > Fongafale	3.737	0.012	116
FCA vs. Fongafale – reef flat	Crustose coralline algae	Fongafale > FCA	3.1257	0.011	198
FCA vs. Fongafale – reef flat	Sand	FCA > Fongafale	6.1214	0.002	230
FCA vs. Fongafale – reef flat	Rubble	FCA > Fongafale	3.1827	0.017	408
FCA vs. Fongafale – back	Crustose coralline algae	FCA > Fongafale	8.6248	0.018	63
FCA vs. Fongafale – back	Turf algae	Fongafale > FCA	3.0063	0.024	84
FCA vs. Fongafale – lagoon	Live hard coral	FCA > Fongafale	2.187	0.046	402
FCA vs. Fongafale – lagoon	Crustose coralline algae	FCA > Fongafale	5.666	0.003	115
FCA vs. Fongafale – lagoon	Turf algae	Fongafale > FCA	3.0069	0.019	408
FCA vs. Fongafale – outer	Live hard coral	Fongafale > FCA	2.6926	0.039	403
FCA vs. Fongafale – outer	Macroalgae	FCA > Fongafale	6.4875	0.005	404
FCA vs. Fongafale – outer	Turf algae	FCA > Fongafale	2.9104	0.029	31

Appendix 6 Invertebrate survey form

SPC INVERTEBRATE SURVEYS

MAIN RECORD– if found pls return to: BP D5 98848 Noumea Cedex New Caledonia

DATE		RECORDER		Pg No	

STATION NAME																		
WPT / WIDTH OF REPLICATE																		
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 benthos																		
ENTERED / CHECKED	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/

Appendix 7 GPS positions of manta tow surveys conducted at the Fongafale and FCA monitoring sites

Site	Station ID	Replicate	Start Latitude (S)	Start Longitude (E)
Fongafale	Manta 1	1	8.493167	179.192167
Fongafale	Manta 1	2	8.490500	179.191583
Fongafale	Manta 1	3	8.487867	179.191183
Fongafale	Manta 1	4	8.485033	179.190600
Fongafale	Manta 1	5	8.482200	179.190200
Fongafale	Manta 1	6	8.479250	179.189783
Fongafale	Manta 2	1	8.471700	179.187700
Fongafale	Manta 2	2	8.469100	179.186300
Fongafale	Manta 2	3	8.466233	179.185267
Fongafale	Manta 2	4	8.463650	179.183983
Fongafale	Manta 2	5	8.460517	179.182917
Fongafale	Manta 2	6	8.457783	179.181633
Fongafale	Manta 3	1	8.437550	179.165217
Fongafale	Manta 3	2	8.435600	179.163133
Fongafale	Manta 3	3	8.434183	179.160700
Fongafale	Manta 3	4	8.432700	179.158317
Fongafale	Manta 3	5	8.431233	179.155333
Fongafale	Manta 3	6	8.430250	179.152500
Fongafale	Manta 4	1	8.437200	179.092067
Fongafale	Manta 4	2	8.436717	179.095550
Fongafale	Manta 4	3	8.432767	179.120017
Fongafale	Manta 4	4	8.431483	179.117033
Fongafale	Manta 4	5	8.431467	179.123250
Fongafale	Manta 4	6	8.431367	179.113833
Fongafale	Manta 7	1	8.550833	179.154000
Fongafale	Manta 7	2	8.549583	179.156367
Fongafale	Manta 7	3	8.547517	179.159067
Fongafale	Manta 7	4	8.543417	179.165300
Fongafale	Manta 7	5	8.541483	179.168050
Fongafale	Manta 7	6	8.539917	179.172233
Fongafale	Manta 8	1	8.562333	179.135850
Fongafale	Manta 8	2	8.560217	179.138617
Fongafale	Manta 8	3	8.558433	179.141317
Fongafale	Manta 8	4	8.556333	179.143817
Fongafale	Manta 8	5	8.553367	179.146300
Fongafale	Manta 8	6	8.553267	179.149633
Fongafale	Manta 13	1	8.465533	179.077400
Fongafale	Manta 13	2	8.463000	179.075017
Fongafale	Manta 13	3	8.460517	179.073450
Fongafale	Manta 13	4	8.458117	179.071783
Fongafale	Manta 13	5	8.455183	179.071317
Fongafale	Manta 13	6	8.452383	179.072000
Fongafale	Manta 14	1	8.442067	179.079717

Site	Station ID	Replicate	Start Latitude (S)	Start Longitude (E)
Fongafale	Manta 14	2	8.439050	179.079633
Fongafale	Manta 14	3	8.436650	179.081333
Fongafale	Manta 14	4	8.435083	179.083767
Fongafale	Manta 14	5	8.434700	179.089167
Fongafale	Manta 14	6	8.434667	179.086450
FCA	Manta 10	1	8.550600	179.060483
FCA	Manta 10	2	8.548100	179.058633
FCA	Manta 10	3	8.540333	179.057700
FCA	Manta 10	4	8.540183	179.055017
FCA	Manta 10	5	8.538050	179.054100
FCA	Manta 10	6	8.536467	179.052133
FCA	Manta 11	1	8.590150	179.071217
FCA	Manta 11	2	8.587167	179.070400
FCA	Manta 11	3	8.584300	179.070667
FCA	Manta 11	4	8.584000	179.069800
FCA	Manta 11	5	8.581200	179.069083
FCA	Manta 11	6	8.577733	179.068867
FCA	Manta 12	1	8.607783	179.076783
FCA	Manta 12	2	8.606067	179.074350
FCA	Manta 12	3	8.602900	179.074133
FCA	Manta 12	4	8.600450	179.073717
FCA	Manta 12	5	8.598167	179.072967
FCA	Manta 12	6	8.595717	179.071333
FCA	Manta 5	1	8.492300	179.065450
FCA	Manta 5	2	8.490800	179.063017
FCA	Manta 5	3	8.489200	179.061067
FCA	Manta 5	4	8.483117	179.063217
FCA	Manta 5	5	8.480750	179.064933
FCA	Manta 5	6	8.477983	179.066233
FCA	Manta 6	1	8.496233	179.043967
FCA	Manta 6	2	8.493867	179.045533
FCA	Manta 6	3	8.492067	179.047783
FCA	Manta 6	4	8.490200	179.050067
FCA	Manta 6	5	8.488383	179.053217
FCA	Manta 6	6	8.487617	179.059000
FCA	Manta 9	1	8.521250	179.048317
FCA	Manta 9	2	8.519000	179.046533
FCA	Manta 9	3	8.516883	179.044700
FCA	Manta 9	4	8.514617	179.043067
FCA	Manta 9	5	8.512683	179.044917
FCA	Manta 9	6	8.509867	179.044383

Appendix 8 GPS positions of reef-benthos transects conducted at the Fongafale and FCA monitoring sites

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 9 PERMANOVA results for observed differences in invertebrate assessments, 2011 vs. 2013.

Site + habitat	Variable tested	Outcome	t	P	Unique perms
Manta					
FCA 2011 vs. Fongafale 2011	Mean density – *Tridacna maxima*	FCA > Fongafale	15.227	0.011	16
FCA 2011 vs. Fongafale 2013	Mean density – *Tridacna maxima*	FCA > Fongafale	4.8988	0.007	57
RBt					
Fongafale	Mean density - Diadematidae	2013 > 2011	2.3015	0.042	24
FCA 2013 vs. Fongafale 2013	Mean density - Diadematidae	FCA > Fongafale	2.6144	0.023	480
FCA 2013 vs. Fongafale 2013	Mean density - Echinometridae	FCA > Fongafale	2.5486	0.025	150

Appendix 10 Form used during creel surveys

Creel survey carried out by: [Enter organisation / department]		***Serial / ID Number:***	
Type of creel survey: (if stratifying)			
Province / Island:			
Survey Time (Month / Year):		Currency used:	
Survey Site:			
Date and time of this replicate:			
Interviewers / surveyors names:	1.	2.	
Latitude (DD):		Longitude (DD):	

Slice C1 basic information on fishers

Lead Fisher's name:			
Date of Birth (DOB):		Gender:	
Address as Village / Town / City:			
Is the fisher with others?	Yes ☐ | No ☐		
→ (data on other fishers in the landing today)			
Total number of fishers (including lead fisher):			
Name of other fisher 1:		DOB:	Gender:
Other fisher 2:		DOB:	Gender:
Other fisher 3:		DOB:	Gender:
Other fisher 4:		DOB:	Gender:
→ (back to Lead Fisher)			
How often do you go fishing per month? /month		How many months a year do you fish (i.e. exclude closed months) months fished	
What fishing methods do you usually use (not only this fishing trip)?		Method 1:	
Method 2:		Method 3:	
Method 4:		Method 5:	
Where else do you land your fish? What other locations? List by priority			
Other location 1: (most often)		How often? /month	

Other location 2:		How often? /month
Other location 3:		How often? /month
Other location 4: (least often)		How often? /month
Why do you go fishing?	Subsistence ☐ | Income ☐ | Both ☐ | Other ☐	
Please provide details:		
About how much of today's catch will be eaten at home / sold?	%	%
What would you expect as income from today's catch overall?	Value:	
What is your eye-estimate of the total weight of the day's catch? (Estimated by you, not the fisher)	kg	

C3 Species sizes and C4 Species weights

Species name	All sizes in the catch in **cm** | All weights in **kg** (Separate by comma. Repeat species in a new line if you need more space)									
	Sz	**Wt**	**Sz**	**Wt**	**Sz**	**Wt**	**Sz**	**Wt**	**Sz**	**Wt**
Lutjanus gibbus	12.5	0.3	23.2	0.7						

C5 Effort data for CPUE

How many hours spent on the fishing trip today (includes travel time)?	hrs

Fishing method / gears used for each species group (separate pelagic fish, reef fish, crabs, lobsters etc) and how much time spent doing each activity

Species group	Methods / gears used	No hours
e.g. Herbivores	*Spear fishing*	*4*
e.g. Carnivores	*Line fishing*	*2*
1.		
2.		
3.		
4.		

Did you have any gear losses during this fishing trip? What and how much to replace or repair?

Gear	What loss / damage?	Cost to replace / repair
1.		
2.		
3.		
4.		

Please list any other costs of **this fishing trip**. Include fuel, wages, ice, food, drink, any other items

Item	Purchase price:
1.	
2.	
3.	
4.	
What is the distance to the furthest site you fished in today?	Km

Where did you leave from?

How many sites did you stop and fish in? Where are they?

Site	Location (on map, lat/long, or distance to each fishing ground)	Time spent at location
1.		
2.		
3.		
4.		

What kind of boat used today?

Construction:	Wood ☐ | Fibreglass ☐ | Plastic ☐ | Steel ☐ | Concrete ☐
Type of boat:	Canoe ☐ | Dinghy ☐ | Banana boat ☐ | Other ☐

If "Other", What kind of boat?

How is the boat powered?	Paddle ☐ | Sail ☐ | Inboard ☐ | Outboard: 2 stroke ☐ 4 Stroke ☐
Length (m):	Engine (hp):
What safety gear do you have onboard today? (tick all that apply)	Oars ☐ | Life jackets ☐ | Water ☐ | EPIRB ☐ | GPS ☐ | Flares ☐ | Bailer / Bilge ☐ | Extra fuel ☐

C6 Catch prices

Where will you use / sell **this** catch?	Home ☐ | Market ☐ | Buyer domestic ☐ | Buyer export ☐

How are the items sold (units of sale) and what prices can you expect?

Item / group	Unit of sale	No. Per unit	Price / unit of sale	Price / item
1. Crabs	*String*	*5*	*$25 / string*	*$5/crab*

1.				
2.				
3.				
4.				

C7 Perceptions of fishers

How long have you been fishing?	years
How long have you been doing **this type** of fishing?	years
What **other types** of fishing have you done in the **past**?	
Do you do **other types** of fishing **now**? Yes ☐ | No ☐	Describe:
Are you fishing in the same **areas** as 5 years ago? Yes ☐ | No ☐	Please explain:
Are you catching the same **quantities** as 5 years ago? Yes ☐ | No ☐	Please explain:
Are you catching the same **size** as 5 years ago? Yes ☐ | No ☐	Please explain:
If catches are **different**, what has changed?	
Do you have any **concerns** about the resources?	

Appendix 11 Number of finfish individuals observed from handline catches, April–May 2013, and relative percent contribution to overall catch

Species	Number observed	% Contribution by abundance	% Contribution by weight
Lutjanus gibbus	261	36.30	25.61
Lutjanus kasmira	77	10.71	3.63
Lethrinus obsoletus	41	5.70	5.09
Sphyraena forsteri	36	5.01	11.85
Epinephelus polyphekadion	32	4.45	6.80
Epinephelus tauvina	26	3.62	7.90
Epinephelus merra	21	2.92	0.52
Lutjanus fulvus	20	2.78	1.49
Lutjanus monostigma	19	2.64	3.38
Sargocentron spiniferum	19	2.64	2.05
Lethrinus olivaceus	15	2.09	4.83
Priacanthus hamrur	15	2.09	2.11
Lethrinus ornatus	14	1.95	1.90
Lutjanus bohar	13	1.81	2.29
Lethrinus rubrioperculatus	11	1.53	1.62
Myripristis berndti	11	1.53	0.51
Carangoides orthogrammus	10	1.39	1.68
Aprion virescens	8	1.11	3.69
Caranx sexfasciatus	8	1.11	3.22
Cephalopholis spiloparaea	8	1.11	0.22
Myripristis pralinia	8	1.11	0.50
Monotaxis grandoculis	7	0.97	1.43
Lethrinus xanthochilus	5	0.70	1.32
Selar crumenophthalmus	4	0.56	0.34
Gnathodentex aureolineatus	3	0.42	0.07
Lethrinus nebulosus	3	0.42	0.94
Sargocentron tiere	3	0.42	0.14
Cephalopholis argus	2	0.28	0.47
Cephalopholis urodeta	2	0.28	0.10
Epinephelus maculatus	2	0.28	0.25
Lutjanus fulviflamma	2	0.28	0.22
Plectropomus leopardus	2	0.28	0.73
Anyperodon leucogrammicus	1	0.14	0.14
Caesio caerulaurea	1	0.14	0.18
Caranx melampygus	1	0.14	1.04
Epinephelus fuscoguttatus	1	0.14	0.43
Epinephelus spilotoceps	1	0.14	0.04
Macolor macularis	1	0.14	0.22
Myripristis murdjan	1	0.14	0.05
Neoniphon opercularis	1	0.14	0.07
Parupeneus cyclostomus	1	0.14	0.09
Plectropomus areolatus	1	0.14	0.48
Pseudobalistes flavimarginatus	1	0.14	0.36

Appendix 12 Number of finfish individuals observed from night spearfishing catches, April–May 2013, and relative percent contribution to overall catch

Species	Number observed	% Contribution by abundance	% Contribution by weight
Naso unicornis	83	16.05	26.01
Naso lituratus	79	15.28	6.46
Naso caesius	47	9.09	17.22
Sphyraena forsteri	47	9.09	10.10
Hipposcarus longiceps	31	6.00	6.87
Lutjanus gibbus	30	5.80	3.27
Acanthurus lineatus	23	4.45	0.87
Myripristis berndti	19	3.68	0.90
Sargocentron spiniferum	19	3.68	2.51
Lutjanus kasmira	13	2.51	0.46
Siganus argenteus	11	2.13	0.98
Monotaxis grandoculis	9	1.74	1.75
Naso brevirostris	9	1.74	1.97
Chlorurus microrhinos	8	1.55	4.42
Epinephelus polyphekadion	8	1.55	1.62
Lutjanus monostigma	8	1.55	1.15
Anyperodon leucogrammicus	7	1.35	1.66
Myripristis adusta	7	1.35	0.44
Lethrinus ornatus	6	1.16	0.57
Naso vlamingii	6	1.16	1.76
Myripristis kuntee	5	0.97	0.15
Siganus punctatus	5	0.97	0.60
Caranx melampygus	4	0.77	1.43
Myripristis amaena	4	0.77	0.21
Parupeneus barberinus	4	0.77	0.56
Acanthurus mata	3	0.58	0.64
Acanthurus xanthopterus	3	0.58	0.56
Epinephelus melanostigma	3	0.58	0.42
Epinephelus tauvina	3	0.58	0.55
Lethrinus erythropterus	3	0.58	0.44
Epinephelus fuscoguttatus	2	0.39	2.27
Aphareus furca	1	0.19	0.11
Caranx sexfasciatus	1	0.19	0.19
Epinephelus areolatus	1	0.19	0.14
Lutjanus bohar	1	0.19	0.08
Macolor niger	1	0.19	0.38
Myripristis murdjan	1	0.19	0.05
Naso annulatus	1	0.19	0.18
Priacanthus hamrur	1	0.19	0.05