Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change

Abemama Atoll
Kiribati

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Aaranteiti Kiareti[1,2], Toaea Beiateuea[2], Robinson Liu[1], Tuake Teema[2] and Brad Moore[1]

[1]Coastal Fisheries Programme, Secretariat of the Pacific Community
[2]Kiribati Ministry of Fisheries and Marine Resources Development

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ACRONYMS

AusAID	Australian Agency for International Development
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
FL	Fork length
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
kg	kilogram(s)
km	kilometre(s)
m	metre(s)
mm	millemetre(s)
MPA	Marine Protected Area
MCRMP	Millennium Coral Reef Mapping Project
MFMRD	Ministry of Fisheries and Marine Resources Development
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
SD	Standard deviation
SE	Standard error
SiQ	Soft infaunal quadrats
SST	Sea-surface temperature
TL	Total length
USD	United States dollar(s)
VBGF	von Bertalanffy growth function

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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 project aims to assist Pacific Island 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 due to climate change, as opposed to other causative factors. This report presents the results of the second survey for the project conducted at Abemama Atoll. Kiribati, in October–November 2013. Results are compared against those from the baseline survey of Abemama conducted in 2011.

Survey Design

Survey work at Abemama covered six disciplines (water temperature monitoring, finfish surveys, benthic habitat assessments, invertebrate surveys, creel surveys and biological monitoring of key reef species). All were conducted by a team from SPC's Coastal Fisheries Science and Management Section and staff from Fisheries Division of the Ministry of Fisheries & Marine Resources Development (MFMRD). In-water surveys were focused around Abatiku and Bike Islets, and along the inner edge of the Abemama main island. Creel surveys, included in the survey for the first time in 2013, focused on fishers landing along the main island. Biological sampling of key reef fish species was also performed for the first time in 2013, with samples collected by both fisheries-dependent and fisheries-independent sampling. The research included capacity building of the local counterparts by providing training in survey design and methodologies, data collection and entry and data analysis.

Finfish Surveys

Finfish resources of the Abatiku and Bike sites were surveyed using distance-sampling underwater visual census (D-UVC) methodology, conducted at the same sites as the 2011 assessment and the benthic habitat assessments. Three habitats were surveyed: back reefs, lagoon reefs and outer reefs. Finfish diversity was generally higher in 2013 than 2011 for all sites and habitats examined. Finfish density and biomass were highly variable, with differences among surveys observed for some species and habitats but not others. Overall, densities and biomasses of finfish were generally higher in 2013 than 2011. Further monitoring is required to determine whether these changes are a result of different surveyor skill or increased experience levels or whether they represent 'real' changes in finfish populations.

Benthic Habitat Assessments

Benthic habitats of Abemama Atoll were surveyed using two complementary approaches: a broad-scale method, using manta tows, and a fine-scale method, using a photoquadrat analysis.

Broad-scale surveys by manta tow were conducted around the inner and outer reefs of the Abatiku and Bike sites, and the inner edge of the main island. Considerable reductions in the cover of live coral and increases in the cover of rubble, coralline algae and other macroalgae were observed during broadscale assessments of the inner reefs of the Abatiku and Bike sites. While further monitoring is required to assess whether these changes result from observer effects or represent real changes in benthic habitat. In contrast, few differences were observed at the Abemama site among surveys, with benthic habitat composition appearing consistent among the 2011 and 2013 surveys.

Outer reef habitats were included in the broad-scale survey for the first time in 2014. Few differences were evident among the Abatiku and Bike sites, with the cover of live coral, dead coral, rubble, coralline algae and macroalgae similar among sites.

Fine-scale assessments of benthic habitats were conducted at the same sites as the 2011 assessment and the assessments of finfish communities, with 18 x 50 m transects surveyed in each of the Abatiku and Bike sites. Benthic habitats of both sites showed little difference among surveys. Cover of macroalgae was generally low for at all sites and habitats examined.

Invertebrate Surveys

Invertebrate resources of Abemama Atoll were surveyed using three complementary approaches: a broad-scale method, using manta tows, and two fine-scale approaches: reef benthos transects and soft infaunal quadrats. Invertebrate diversity for all methods was low, and showed little difference among surveys.

Densities of sea cucumber species were low, and fell well below the regional reference densities for healthy sea cucumber stocks. Few differences in the density of sea cucumber species were observed, suggesting that the low densities are neither deteriorating nor improving. Given the low densities there is little potential for commercial sea cucumber harvesting at this time, and stocks are in need of on-going protection to build until recommended minimum harvest densities are achieved.

Healthy densities of elongated giant clam, *Tridacna maxima*, were observed during the surveys. During reef benthos transect surveys mean densities reached 1841.67 individuals/ha at Abatiku and 1175.00 individuals observed at Bike. Mean densities of *T. maxima* showed little difference among 2011 and 2013 surveys at either site, and were considerably higher than the regional reference densities for healthy *T. maxima* stocks.

Of most concern, densities of crown-of-thorns starfish (COTS) were extremely high at the Abatiku site during the 2013 survey, with densities on individual transects reaching 733 individuals/ha and 3,500 individuals/ha for manta and RBt surveys, respectively. These densities greatly exceed reference densities considered to be an active outbreak. This indicates that substantial damage to the reefs of Abatiku is likely. Effort should be made to try to remove the COTS from the reef, while proactive monitoring is required at other locations to monitor COT outbreaks.

Creel surveys

Creel surveys were included in the survey at Abemama Atoll for the first time in 2013. To our knowledge these represented the first creel surveys ever conducted at Abemama. The objectives of the creel surveys were to meet fishers returning from fishing and document their demographics and fishing behavior (e.g. locations fished, distances travelled), catch (including length and weight of all individuals caught), effort (including trip duration, time spent fishing and gears used), catch-per-unit-effort (CPUE) and historical perceptions of the status of fisheries resources.

Twenty landings were met by the survey team at Abemama. The majority of landings (n=12) met were from fishers returning from gillnetting/*te ororo* for bonefish, *Albula glossodonta*. On average, bonefish fishing trips involved 2.08 fishers, and lasted 3.75 hours. The average catch per trip was 100.92 individual fish, or 61.22 kg. Average CPUE was 39.70 fish per hour, or 23.29 kg per hour. Fishing was conducted primarily by males, while women were responsible for processing the catch for sale or consumption. A total of 1,211 individual fishes were observed in the 12 landings, with nine different species observed in the catch. Few by-catch species were observed in the catch, with 1,129 individual *A. glossodonta* observed representing 93.2% of the total number and total weight of all fish caught.

Fork length (FL) data were collected for all bonefish surveyed. Lengths ranged from 23.8 cm FL to 56.5 cm FL, with a modal length class of 33.0–34.9 cm FL. The average length was 35.3 cm FL. Examination of length frequency by gillnet mesh size revealed that fishing trips that involved nets of smaller mesh diameters (2 inch or 2.5 inch) captured a larger proportion of small, potentially immature individuals than nets of larger (3 inch) mesh size.

Biological monitoring of key reef species

Biological monitoring of key reef fish species at Abemama Atoll was included for the first time during the 2013 survey. Monitoring focused on five species, including two commonly harvested species: humpback red snapper (*Lutjanus gibbus*), and orangespine surgeonfish (*Naso lituratus*) and three unharvested (‘control’) species: peacock grouper (*Cephalopholis argus*), striated surgeonfish (*Ctenochaetus striatus*) and redfin butterflyfish (*Chaetodon lunulatus*). Demographic parameters, including von Bertalanffy growth function (VGBF) parameters, age structures and total, natural and fishing mortality rates were determined for each species (where possible) to provide a baseline for Abemama for future comparisons. Unfortunately due to low samples sizes it was not possible to calculate VBGF parameters for *L. gibbus* or *N. lituratus*, or calculate mortality rates for any species. Greater sampling is required to fully assess the status of these species at Abemama.

Management recommendations for improving the resilience of coastal fisheries of Abemama 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, we outline several key management recommendations, based on the findings of the current study and anecdotal observations, that will help improve the resilience of the coastal fisheries of Abemama to both long-term (e.g. climate change) and short-term (e.g. overfishing) stressors, namely:

1) Finalise and implement the Kiribati Coastal Fisheries Management Plan;
2) Monitor and control outbreaks of crown-of-thorns starfish (COTS);
3) Creation of locally managed Marine Protected Areas;
4) Protect sharks and other iconic and ecologically-significant species;
5) Strengthen stakeholder awareness programs and exchange of information on coastal fisheries, the marine environment and climate change;
6) Strengthen collaborations with the National Government, Island Councils, NGOs, fishing communities and traditional leaders.

1. Introduction

Project Background

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 project 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 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, 19th–22nd April 2010) involving scientists and representatives of many PICTs. These methods include monitoring of water temperature using temperature loggers, finfish and invertebrate resources, benthic habitats, catch and fishing patterns and biological monitoring of key reef finfish species (Table 1). 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 (listed alphabetically by country): Pohnpei Island (Federated States of Micronesia), Abemama Atoll (Kiribati), Majuro Atoll (Marshall Islands), Manus Province (Papua New Guinea) and Funafuti Atoll (Tuvalu). Site selection was based on existing available data such as fish, invertebrate and socio-economic 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), presence of Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME), requests from countries, 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 Abemama, Kiribati, between October-November 2013 by a team from SPC's Coastal Fisheries Science and Management Section and Kiribati's Ministry of Fisheries and Marine Resources Development (MFMRD). Collected data are compared against those of the baseline survey of the study region conducted in 2011 (Siaosi et al. 2011). Recommendations for management and future monitoring events are also provided.

Table 1 Summary of activities and variables measured during the monitoring program in Abemama Atoll, Kiribati, 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 structures, age and growth relationships, mortality rates (where sample sizes permit)

Kiribati

Background

Kiribati is located in the Central Pacific Ocean near the equator, stretching from 6°N – 12°S and 168°E – 152°W (Figure 1). The country consists of 32 low-lying atolls and one raised limestone island, Banaba, also known as Ocean Island. The islands lie in three main groups which are the Gilbert, Phoenix and Line Islands, listed in sequence from west to east (Figure 1). The total land area of Kiribati is approximately 811 km^2, while the Exclusive Economic Zone (EEZ) totals approximately 3.6 million km^2 (Gillett 2009). In 2010, the estimated population of Kiribati was 100,835 (Kiribati National Statistics Office 2012). The capital is South Tarawa which is located in the Gilbert Islands.

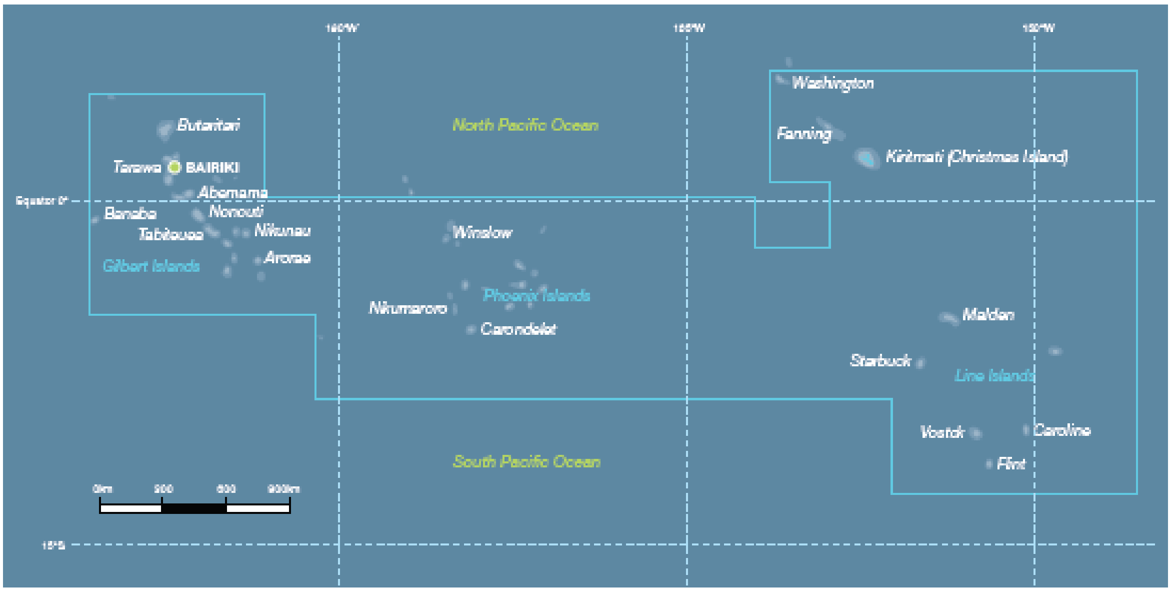


Figure 1 Kiribati (from PCCSP 2011).

Fisheries

Oceanic fisheries

Kiribati has a locally-based tuna fishery within its EEZ. Recent average annual catches are approximately 12,000 tonnes, worth > USD 21 million (Bell et al. 2011). Kiribati also licenses foreign vessels to fish for tuna within its EEZ. Between 1999 and 2008, foreign fleets made an average total annual catches of approximately 180,000 tonnes, worth USD 153 million (Bell et al. 2011). Licence fees from foreign purse seine and longline tuna vessels contributed approximately 40% to government revenue (GR). The small locally-based tuna fishery does not contribute to the gross domestic product (GDP) of Kiribati.

Table 2 Annual fisheries and aquaculture harvest in Kiribati, 2007 (Gillet 2009)

Harvest sector	Quantity (tonnes)	Value (AUD million)
Coastal commercial	7,000	22,000,000
Coastal subsistence	13,700	34,000,000
Offshore locally-based	0	0
Offshore foreign-based	163,215	234,491,135
Freshwater	0	0
Aquaculture	100 pieces plus 143 tonnes	90,000
Total	**184,058 t plus 100 pieces**	**290,581,135**

Coastal fisheries

The coastal fisheries of Kiribati can be grouped into four broad-scale categories; demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahimahi), invertebrates targeted for export, 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 20,700 tonnes, worth > USD 47 million. The commercial catch was 7,000 tonnes, and demersal fish are estimated to make up > 70% of the total catch (Gillet 2009).

Table 3 Estimated catch and value of coastal fisheries sectors in Kiribati, 2007 (Bell et al. 2011)

Coastal fishery category	Quantity (tonnes)	Contribution of catch (%)
Demersal finfish	15,075	73
Nearshore pelagic finfish	4,250	20
Targeted invertebrates	60	< 1
Inter/subtidal invertebrates	1,315	6
Total	**20,700**	**100**

Climate Change Projections for Kiribati

Air temperature

Historical air temperature data records for Kiribati are available for Tarawa only. An increase in average daily temperatures of approximately 0.19°C per decade has been observed since recording began in 1950 (Figure 2) (PCCSP 2011).

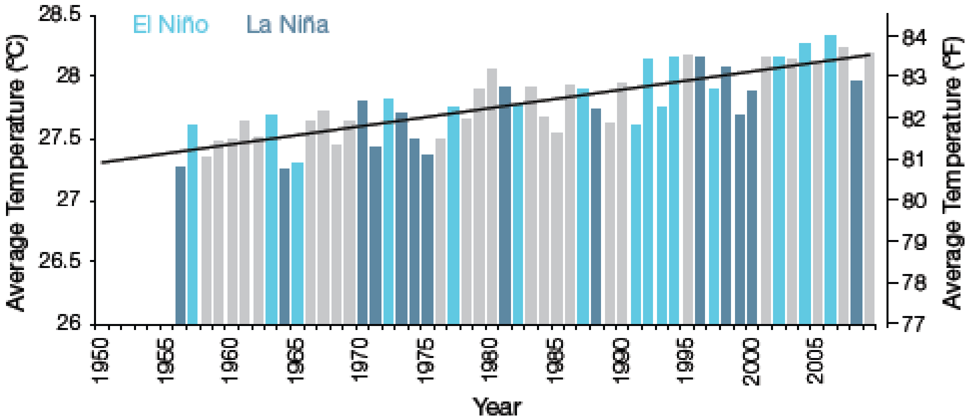


Figure 2 Mean annual air temperature at Tarawa (1956-2009) (from PCCSP 2011).

Mean air temperatures are projected to continue to rise, with increases of +0.7, +0.8, +0.8°C (relative to 1990 values) projected for 2030 for the Gilbert and Line Island groups, and +0.7, +0.9, +0.8°C (relative to 1990 values) projected for 2030 for the Phoenix Islands under the IPCC B1 (low), A1B (medium) and A2 (high) emission scenarios, respectively (PCCSP 2011) (Table 4).

Table 4 Projected air temperature increases (in °C) for Kiribati under various IPCC emission scenarios (from PCCSP 2011)

Island group	Emission scenario	2030	2055	2090
Gilbert Islands	B1	+0.7 ± 0.5	+1.3 ± 0.6	+1.7 ± 0.7
	A1B	+0.8 ± 0.6	+1.6 ± 0.7	+2.6 ± 0.9
	A2	+0.7 ± 0.5	+1.6 ± 0.6	+3.0 ± 0.8
Phoenix Islands	B1	+0.7 ± 0.5	+1.3 ± 0.6	+1.7 ± 0.7
	A1B	+0.9 ± 0.5	+1.6 ± 0.6	+2.6 ± 0.9
	A2	+0.8 ± 0.4	+1.6 ± 0.5	+3.0 ± 0.7
Line Islands	B1	+0.7 ± 0.5	+1.2 ± 0.6	+1.7 ± 0.7
	A1B	+0.8 ± 0.5	+1.6 ± 0.6	+2.5 ± 0.9
	A2	+0.8 ± 0.4	+1.5 ± 0.5	+2.9 ± 0.6

Sea-Surface Temperature

In accordance with mean air temperatures, sea-surface temperatures are projected to further increase, with increases of +0.7, +0.8, and +0.8°C (relative to 1990 values) projected for 2030 for the Gilbert and Phoenix Islands; and +0.7, +0.8, and +0.7°C (relative to 1990 values) projected for 2030 of the Line Islands under the IPCC B1 (low), A1B (medium) and A2 (high) emissions scenarios, respectively (PCCSP 2011) (Table 5).

Table 5 Projected sea-surface temperatures increases (in °C) for Kiribati (from PCCSP 2011)

Island group	Emission scenario	2030	2055	2090
Gilbert Islands	B1	+0.7 ± 0.5	+1.2 ± 0.7	+1.6 ± 0.9
	A1B	+0.8 ± 0.6	+1.5 ± 0.7	+2.5 ± 1.0
	A2	+0.8 ± 0.6	+1.5 ± 0.7	+2.9 ± 1.0
Phoenix Islands	B1	+0.7 ± 0.5	+1.2 ± 0.6	+1.6 ± 0.7
	A1B	+0.8 ± 0.5	+1.5 ± 0.5	+2.5 ± 0.9
	A2	+0.8 ± 0.5	+1.5 ± 0.6	+2.8 ± 0.8
Line Islands	B1	+0.7 ± 0.4	+1.1 ± 0.5	+1.6 ± 0.7
	A1B	+0.8 ± 0.5	+1.5 ± 0.6	+2.4 ± 0.9
	A2	+0.7 ± 0.4	+1.4 ± 0.6	+2.7 ± 0.7

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 Betio, Tarawa, Kiribati in December 1992. According to the 2010 Pacific country report on sea level and climate for the Kiribati (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 Tarawa (accounting for barometric pressure and tidal gauge movement) was calculated at +2.6 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 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 Kiribati, the aragonite saturation state has declined from about 4.5 in the late 18th century to an observed value of about 3.9±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. Climate model results suggested that the annual maximum aragonite saturation state will reach values below 3.5 by 2045 in the Gilbert Islands, by about 2030 in the Line Islands, and 2055 in the Phoenix Islands, and continue to decline thereafter (PCCSP 2011). These projections suggest that coral reefs of Kiribati 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 carbon dioxide in the water are expected to negatively impact on 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. 2009; 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 Kiribati

Kiribati has a large area of coral reefs (4,320 km^2), and small areas of mangroves, deepwater and intertidal seagrasses, and intertidal flats (Bell et al. 2011). Climate change is expected to add to the existing local threats to the coral reef, mangrove and seagrass habitats of Kiribati, resulting in declines in their quality and area (Table 6). Accordingly, 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 7) (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 7) (Bell et al. 2011).

Table 6 Projected changes in coastal fish habitat in Kiribati 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
Seagrass area	< -5	-5 to -10	-10 to -20

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

Table 7 Projected changes to coastal fisheries production in Kiribati 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[a]	+15 to +20	+20	+10
Targeted invertebrates	-2 to -5	-10	-20
Inter/subtidal invertebrates	0	-5	-10

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

2. Site and Habitat Selection

Site Selection

Abemama Atoll was selected as a pilot site for the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project within Kiribati following consultations with the Kiribati Ministry of Fisheries and Marine Resources. Abemama Atoll was selected as it offered a number of advantages as a study site, most notably:

- Abemama Atoll is close to Tarawa in terms of transportation allowing for ease of logistics;
- Fish, invertebrate and socio-economic data were collected by SPC under the PROCFish/C project in Abemama Atoll in 2004 (Awira et al. 2008);
- Although coral reef monitoring programs have been established at Tarawa and Abaiang Atolls (Donner et al. 2010), there is currently no ongoing monitoring of the corals reefs of Abemama. Coral reef monitoring at Abemama was raised as a priority by Donner et al. (2010);
- Being an atoll, Abemama has little terrigenous impact and less impacted than Tarawa by overfishing and water quality.

Abemama Atoll is located 153 km to the southeast of Tarawa, just north of the equator. The atoll has a lagoon on its west side, which is relatively silty with poor visibility in some locations (Awira et al. 2008). There are two main passages through the reef. The eastern part of the atoll of Abemama is linked by causeways making automobile traffic possible between the different islets. Abemama Atoll consists of approximately 16 km^2 of land area with a population of approximately 3,210 (Kiribati National Statistics Office 2012).

Fisheries Resources of Abemama

The waters surrounding Abemama Atoll support a highly diverse fish fauna. A total of 180 fish species were recorded from the waters surrounding Abemama Atoll during the PROCFish survey in 2004 (Awira et al. 2008). The people of Abemama Atoll are largely dependent on reef and lagoon resources for subsistence purposes. Socio-economic survey work conducted at Abemama Atoll as part of the PROCFish surveys by SPC in 2004 revealed that fisheries provide the first source of income for one-quarter of all households and the second source of income for 28% of households on Abemama (Awira et al. 2008). Per capita consumption of fresh fish was found to be approximately 117 kg/person/year; one of the highest rates in the Pacific and nearly four times the regional average of approximately 35 kg/person/year (Awira et al. 2008). Most of the finfish fishing is conducted within the sheltered coastal lagoon during both day and night using a variety of fishing techniques including nets, spears, hooks and lines (Awira et al. 2008).

By comparison, consumption of invertebrates is considerably lower, at approximately 1.69 kg/person/year (Awira et al. 2008). Invertebrate resources are mainly harvested for subsistence purposes. Species harvested include seaworms (*Sipunculus indicus)*, giant clams, lobsters (*Panulirus penicillatus* and *P. vericolor*), cockle shells (*Anadara species)*, and gastropods. During the PROCFish surveys, seaworm collection from intertidal areas was the main fishery, comprising > 66% of the total reported annual catch by wet weight for both home consumption and commercial purposes, followed by lobsters and giant clams (Awira et al. 2008). Most of the gleaning for invertebrates was done by females (> 80% of the annual total catch), however women are restricted from diving for lobsters and giant clams (Awira et al. 2008).

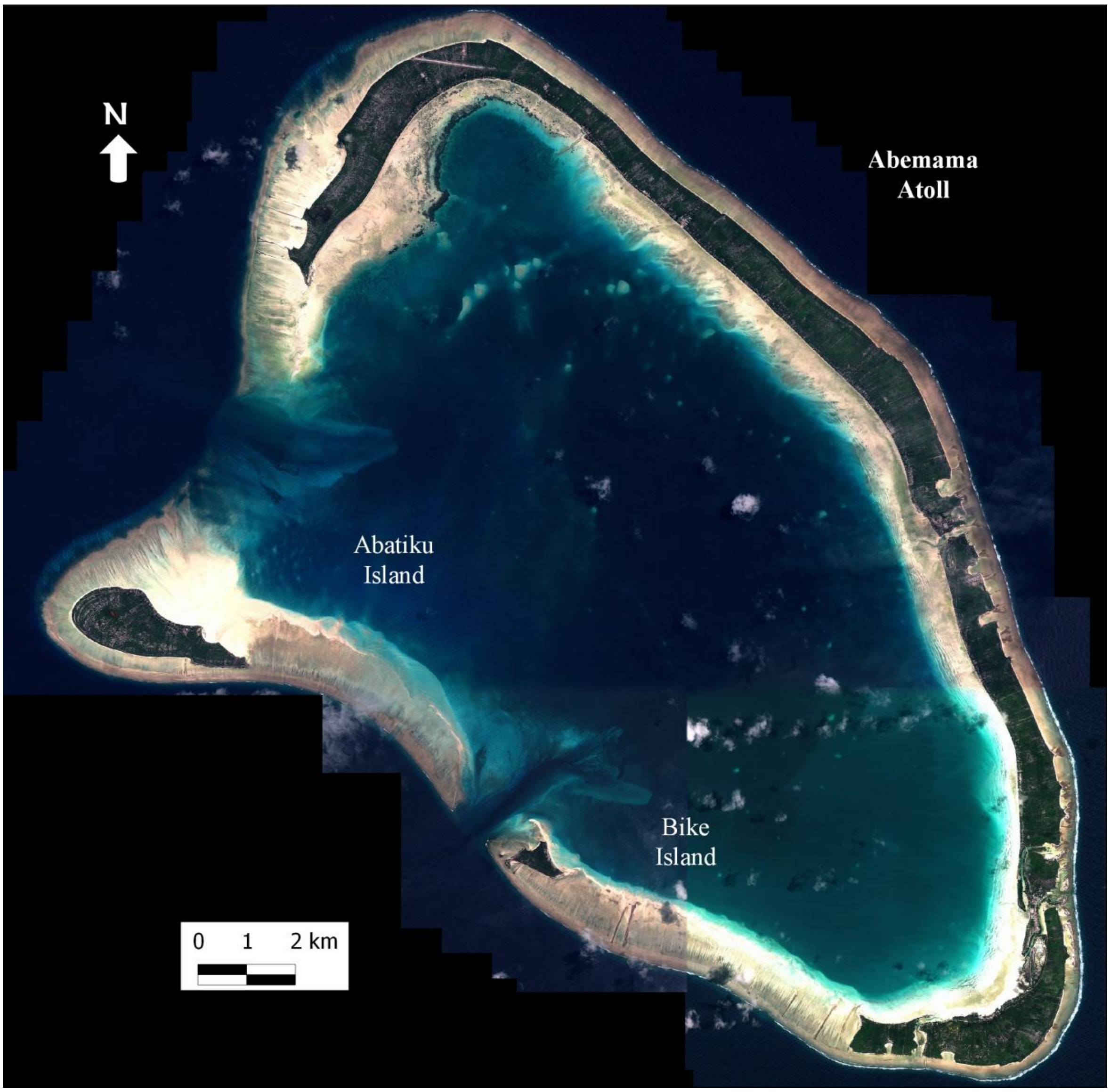


Figure 3 Abemama Atoll indicating the Abatiku and Bike study regions.

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 at Abemama Atoll, three general reef types were categorised:

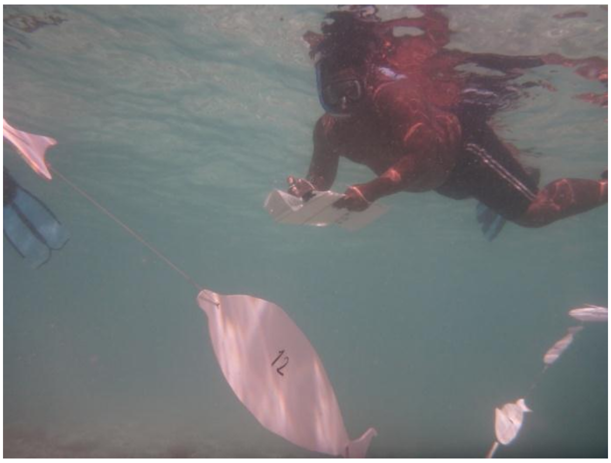
1) Lagoon reef: patch reef or finger of reef stemming from main reef body that is inside a lagoon or pseudo-lagoon;

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

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 MFMRD 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 (Figure 4).

Figure 4 A member of the survey team practicing fish size estimation



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. These data should not be considered as indicative of the actual available fisheries resources.

3. Monitoring of Water Temperature

Methodologies

To monitor the water temperature in coastal areas SPC obtained type RBR TR-1060 temperature loggers. In October 2011, two temperature loggers were deployed in Abemama: one on the outer reef and one in the lagoon (Figure 5). The loggers were calibrated to an accuracy of ±0.002ºC and programmed to record temperature every ten minutes. For security reasons both loggers were housed in PVC tube with holes to allow flow of water and encased in a concrete block. These blocks were then secured to the sea floor. Each logger was deployed at a depth of approximately 10 metres.

The RBR-TR1060 loggers were retrieved during the 2013 survey. Due to obvious battery life flaws (see Results), these loggers were replaced with a superior model (Sea-Bird SBE 56). The Sea-Bird SBE 56 loggers were housed in the original housing system.

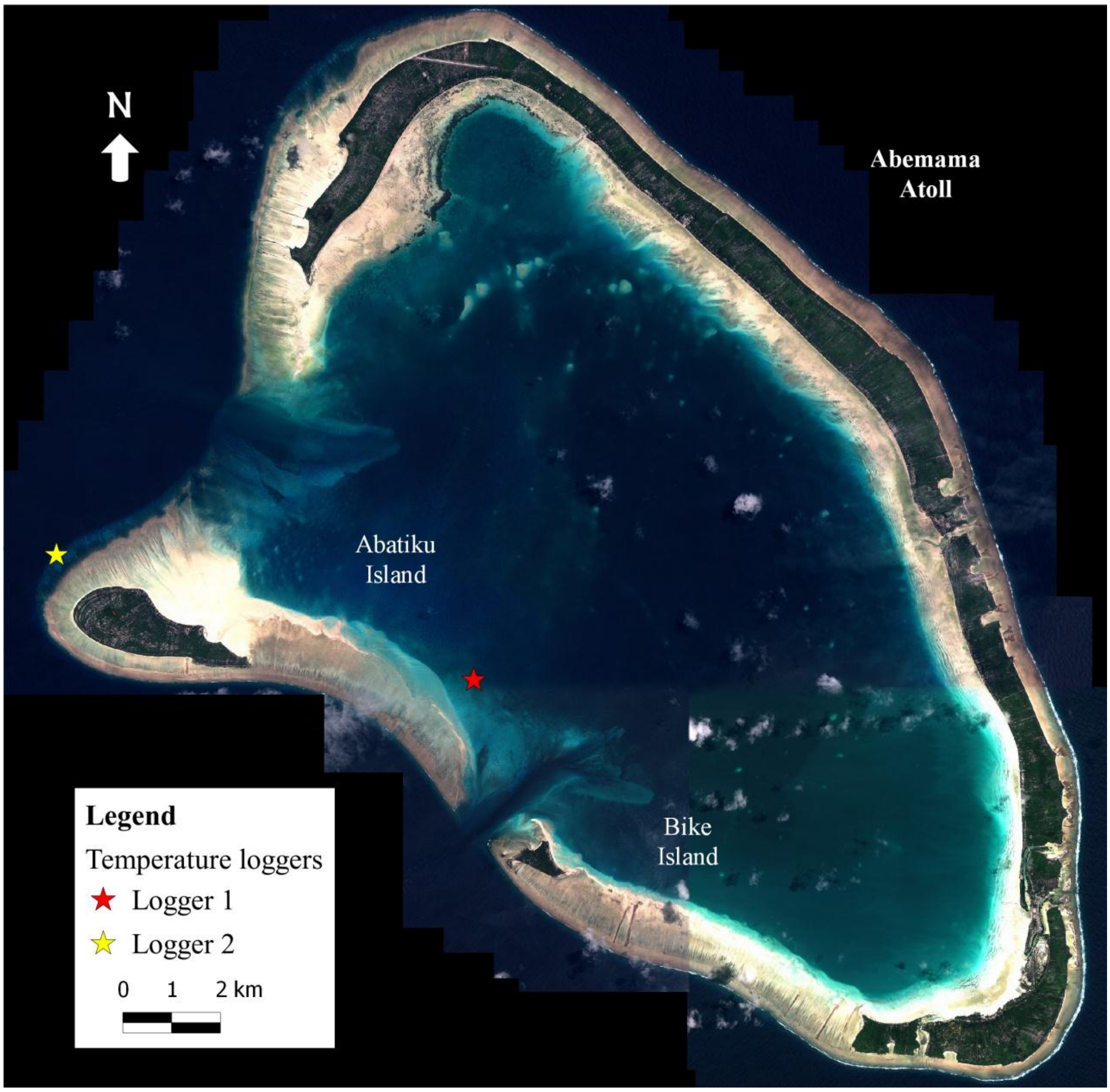


Figure 5 Location of the two water temperature loggers deployed at Abemama Atoll.

Table 8 Details of temperature loggers deployed at Abemama Atoll.

Details	**Logger 1**	**Logger 2**
Deployment date	15/10/2011	21/10/2011
Habitat	Lagoon	Outer reef
Longitude (E)	173º50.077'	173º45.235'
Latitude (N)	0º22.586'	0º23.535'
Depth	9 m	9 m

Figure 6 A member of the survey team replacing the temperature logger on the outer reef of Abemama, October 2013.

Results

Both loggers were retrieved on the 23rd October 2013, after they had been deployed for approximately two years. The logger in the lagoon (Abemama 1) recorded water temperature from its deployment in 2011 until the 4th April 2012 (Figure 7). The maximum temperature recorded over this period was 29.43ºC, reached on the 11th November 2011, while the minimum daily average was 26.06ºC, reached on the 20th February 2012.

The logger on the outer reef (Abemama 2) recorded water temperature from its deployment in 2011 until the 7th July 2012 (Figure 7). The maximum temperature recorded over this period was 28.93ºC, reached on the 28th June 2012, while the minimum daily average was 26.30ºC, reached on the 4th April 2012 (Figure 7).

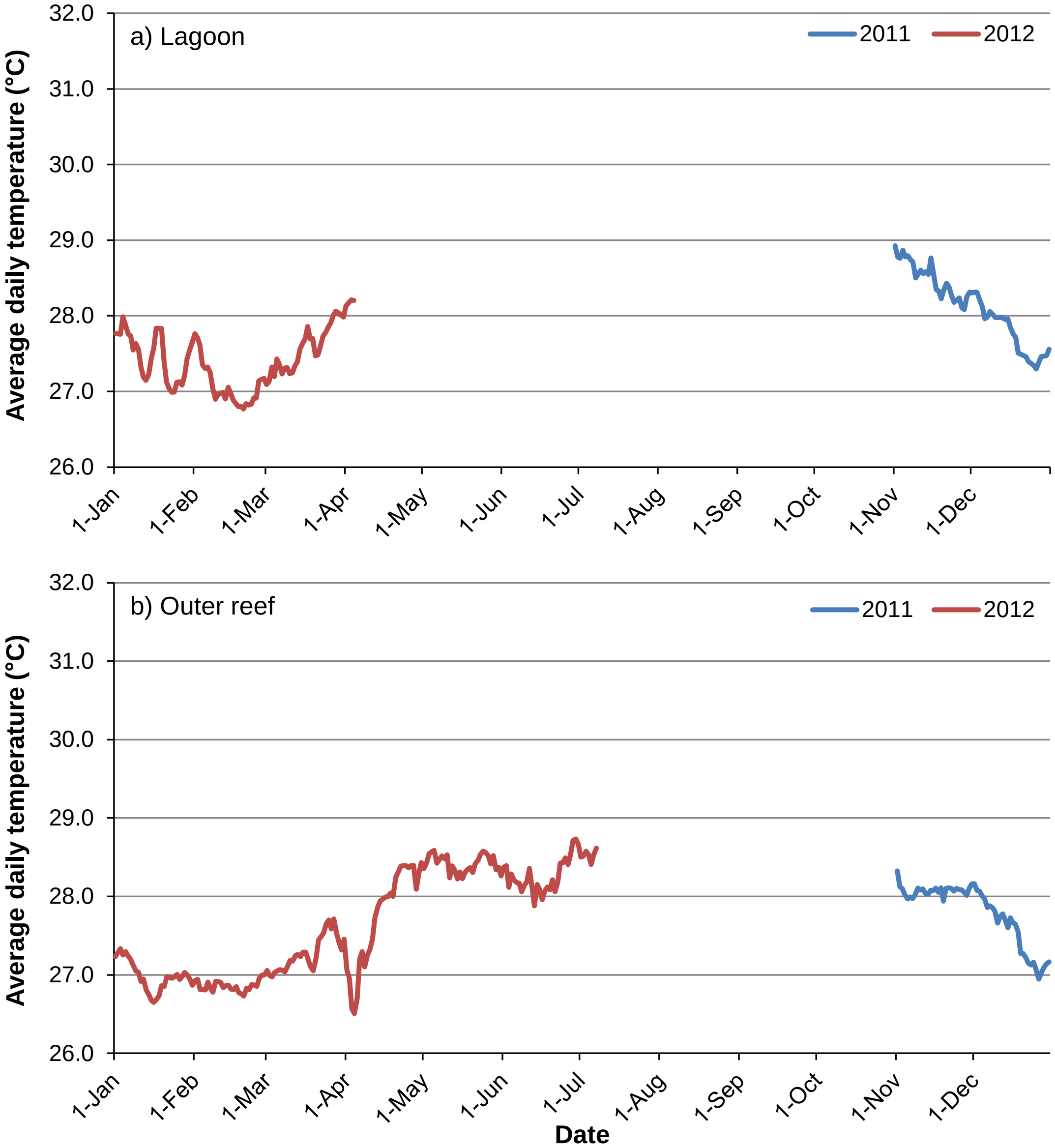


Figure 7 Mean daily water temperature at the a) lagoon and b) outer reef of Abemama Atoll. See Table 8 for logger locations.

4. Finfish Assessments

Methods and Materials

Data collection

Fish on reef habitats were surveyed using distance-sampling underwater visual census (D-UVC) methodology. Finfish assessments were conducted at two sites in Abemama Atoll: Abatiku and Bike (Figure 8). Within each site, finfish assessments typically focused on three habitats (back reef, lagoon reefs and outer reefs), with six replicate 50 m transects surveyed in each habitat at each of the sites (Figure 8). Each transect was completed by two SCUBA divers who recorded the species name, abundance and length of all fish observed. 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). 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.

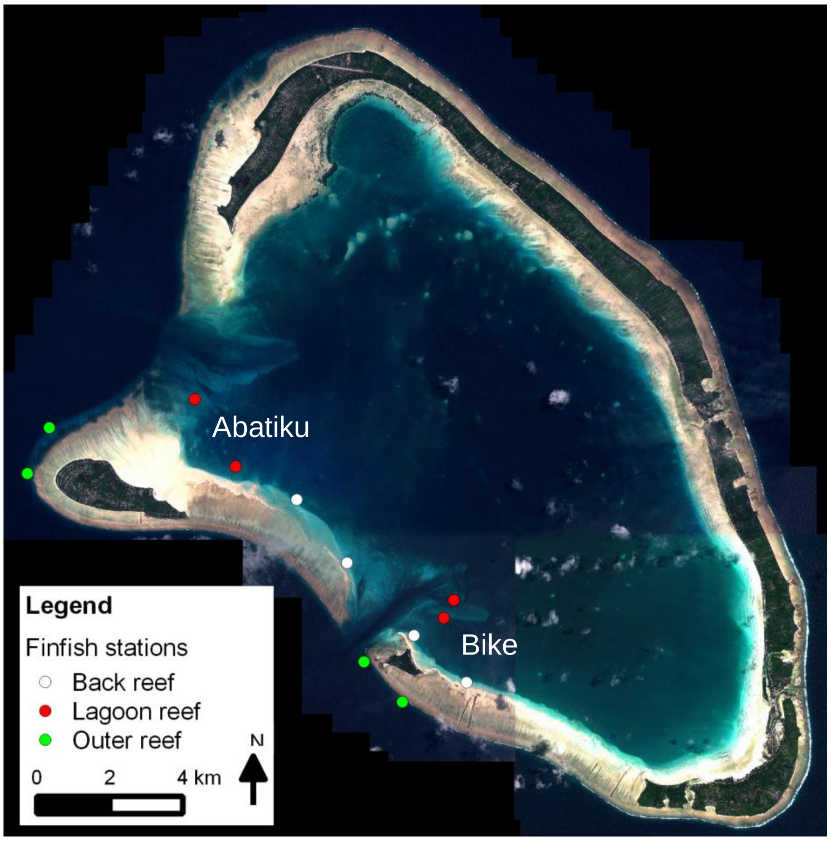


Figure 8 Location of finfish and fine-scale benthic habitat monitoring stations at Abemama Atoll. Note 3 x 50 m transects were completed at each point.

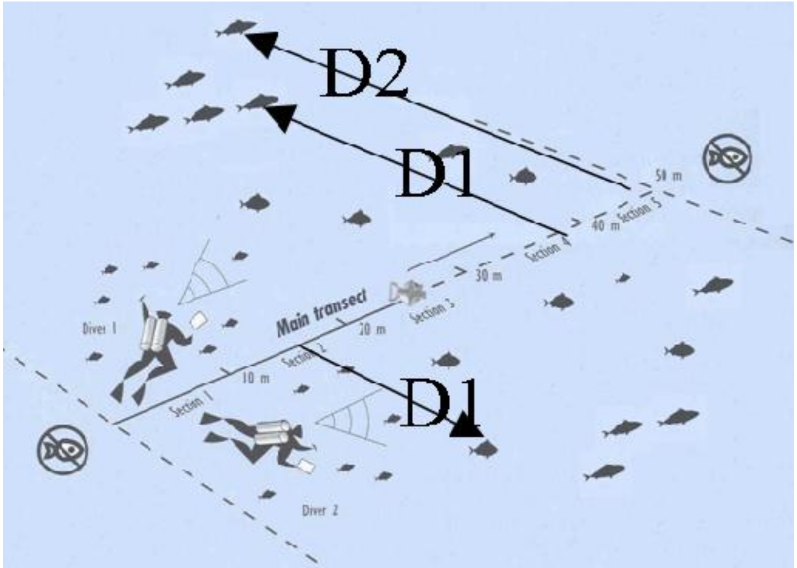


Figure 9 Diagram portraying the D-UVC method.

Habitats supporting finfish[1]

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

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

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

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) (±SE) – estimated from fish abundance in D-UVC, calculated at a total, functional group, family and individual species level.

Assignment of functional groups

For analysis 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 (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);
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) Scrapers/excavators (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) Grazer/detritivores (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) Browsers (roving herbivore that tends to bite or ‘crop’ algae leaving the basal portions and substrate intact. Browsers play an 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. Bike 2013, Abatiku 2013) and habitat (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 an unrestricted number of permutations of the data.

Site results

Abatiku monitoring site

Finfish assemblages within the Abatiku site have been monitored at three habitats to date. Lagoon and outer reef habitats were surveyed in both 2011 and 2013, while the finfish assemblages of back reef habitats were surveyed for the first time in 2013.

Finfish diversity within the Abatiku site was higher during the 2013 survey relative to 2011 for all habitats examined. The consistency of this result across all habitats and sites (see results for Bike site below) suggests this increase potentially reflects greater experience within the survey team rather than a true increase in diversity. Most functional groups were observed during the surveys. Browsing herbivores were absent from all transects in both surveys except the outer reef transects in 2013 (Table 9).

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

Parameter	Back reef		Lagoon reef		Outer reef	
	2011	2013	2011	2013	2011	2013
No. of families	-	19	14	18	19	21
No. of genera	-	55	39	52	54	64
No. of species	-	120	79	117	102	136
Diversity	-	54.8±3.4	30.7±2.1	54.5±6.2	38.7±4.4	65.3±3.4
Functional groups	-	7/8	7/8	7/8	7/8	8/8

At Abatiku, mean total density of finfish on lagoon reef transects was significantly higher in 2013 relative to 2011 (Figure 10). In contrast, no difference was evident on lagoon reef transects in terms of mean total biomass, or on outer reef transects for either density or biomass (Figure 10; Figure 11).

Back reefs

Back reefs of Abatiku were surveyed for the first time in 2013. Finfish communities on back reef transects were characterised predominantly by Pomacentridae (damselfish, in particular the species *Chromis margaritifer* and *C. viridis*), Scaridae (parrotfish, particular *Chlorurus sordidus*), Lutjanidae (snappers, in particular *Lutjanus gibbus*) and Labridae (wrasses) (Figure 12–Figure 15).

Lagoon reefs

Few differences were observed in density or biomass of the 18 key finfish families on the lagoon reef transects at Abatiku amongst the 2011 and 2013 surveys. Mean densities of Chaetodontidae, Pomacanthidae and Pomacentridae, and mean biomass of Chaetodontidae, Lethrinidae and Pomacentridae appeared significantly higher in 2013 relative to 2011 (Figure 14; Figure 15). In contrast no differences were observed in either mean density or mean biomass of the families Acanthuridae (surgeonfish), Balistidae (triggerfish), Ephippidae (batfish), Haemulidae (sweetlips), Kyphosidae (drummers), Labridae (wrasse), Lutjanidae (snappers), Mullidae (goatfish), Nemipteridae (coral breams), Scaridae (parrotfish), Serranidae (groupers), Siganidae (rabbitfish) or

Zanclidae (Moorish Idol) among surveys (Figure 14; Figure 15). In terms of functional groups, both the density and biomass of corallivores and planktivores were higher in 2013 relative to 2011 (Figure 16; Figure 17), largely due to increases in members of the Chaetodontidae and Pomacentridae as described above.

Outer reefs

In contrast to lagoon reefs, a number of differences were observed in density and/or biomass of the 18 key finfish families and eight functional groups on outer reef transects. Mean densities of Balistidae, Chaetodontidae. Lutjanidae, Scaridae and mean biomass of Chaetodontidae, Lutjanidae, Pomacentridae, Scaridae and Zanclidae appeared slightly yet significantly higher in 2013 relative to 2011 (Figure 14; Figure 15). Both the mean density and mean biomass of corallivores and scraping herbivores also appeared higher in 2013 relative to 2011 (Figure 16; Figure 17), again explained by increases in the density and biomass of Chaetodontidae and Scaridae.

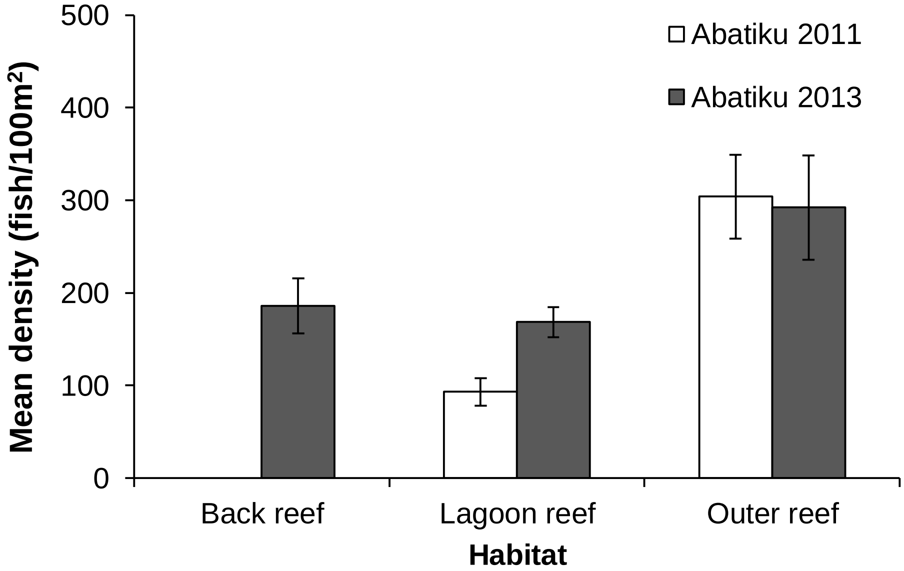


Figure 10 Mean total density of finfish (±SE) among survey years and habitats at the Abatiku monitoring site.

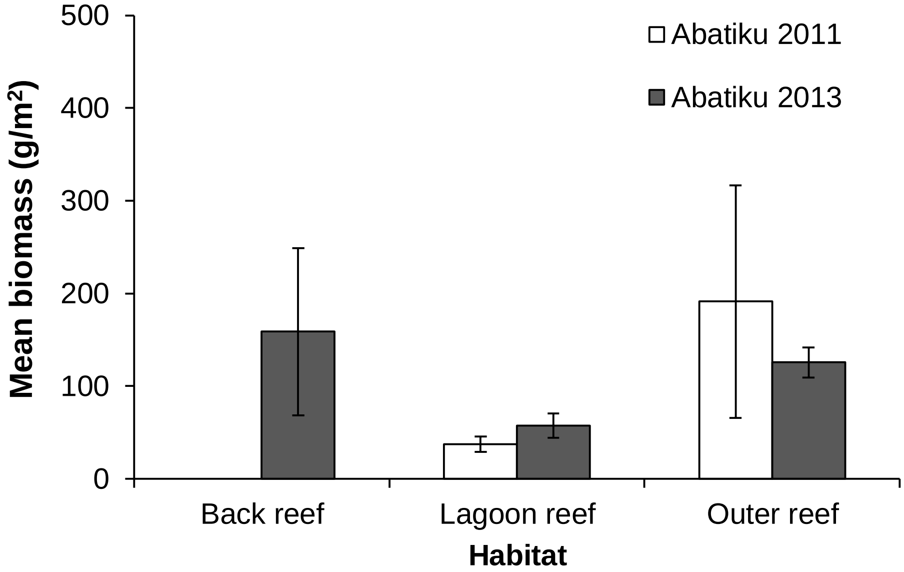


Figure 11 Mean total biomass of finfish (±SE) among survey years and habitats at the Abatiku monitoring site

Figure 12 Back reefs of the Abatiku site supported high densities of damselfish (Pomacentridae).

Figure 13 The biomass of lutjanids, in particular *Lutjanus gibbus*, was high on the back reefs of the Abatiku site.

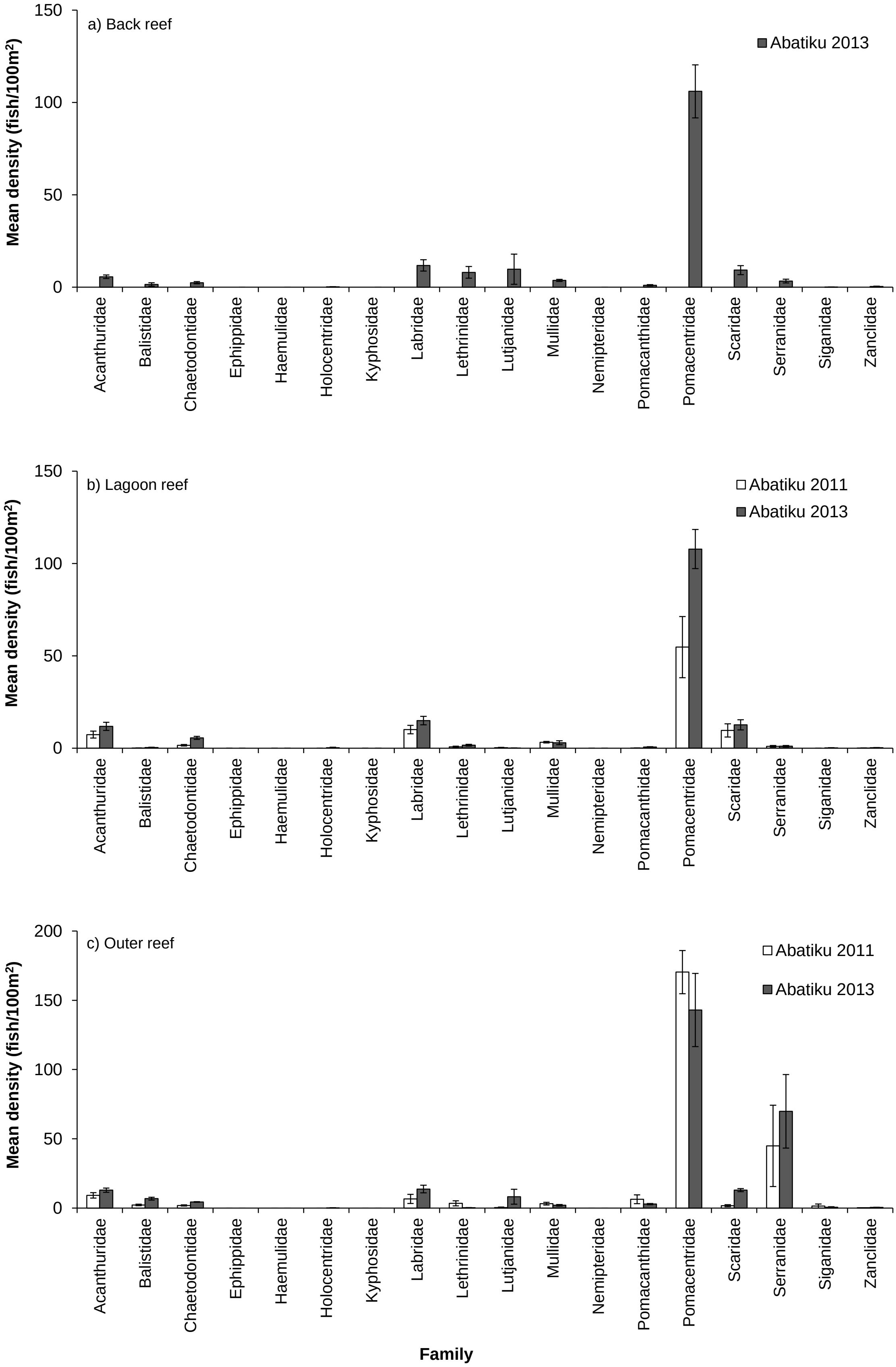


Figure 14 Mean density (±SE) of common finfish families among a) back reef, b) lagoon reef and c) outer reef habitats of the Abatiku monitoring site during the 2011 and 2013 surveys.

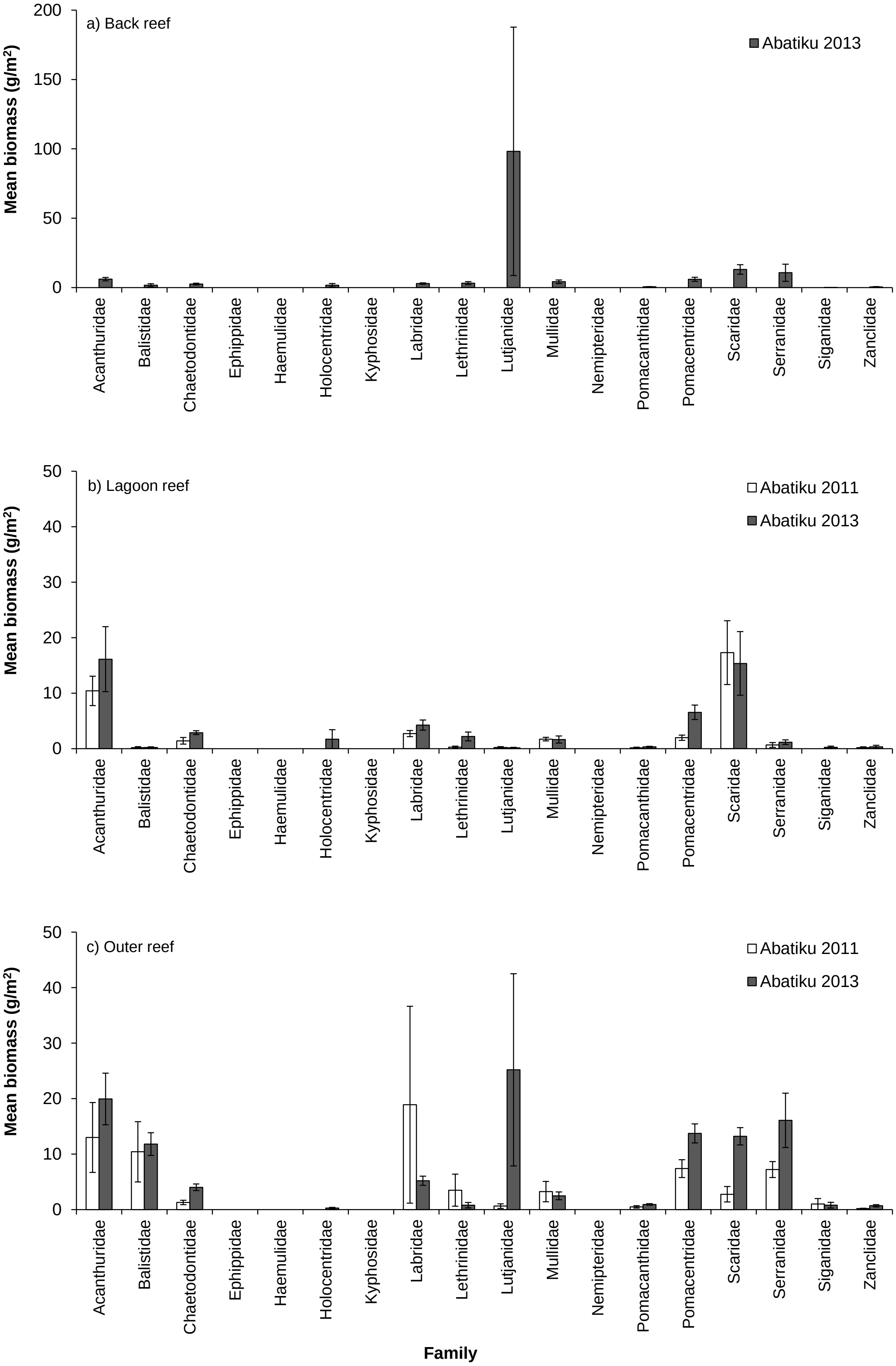


Figure 15 Mean biomass (±SE) of common finfish families among a) back reef, b) lagoon reef and c) outer reef habitats of the Abatiku monitoring site during the 2011 and 2013 surveys.

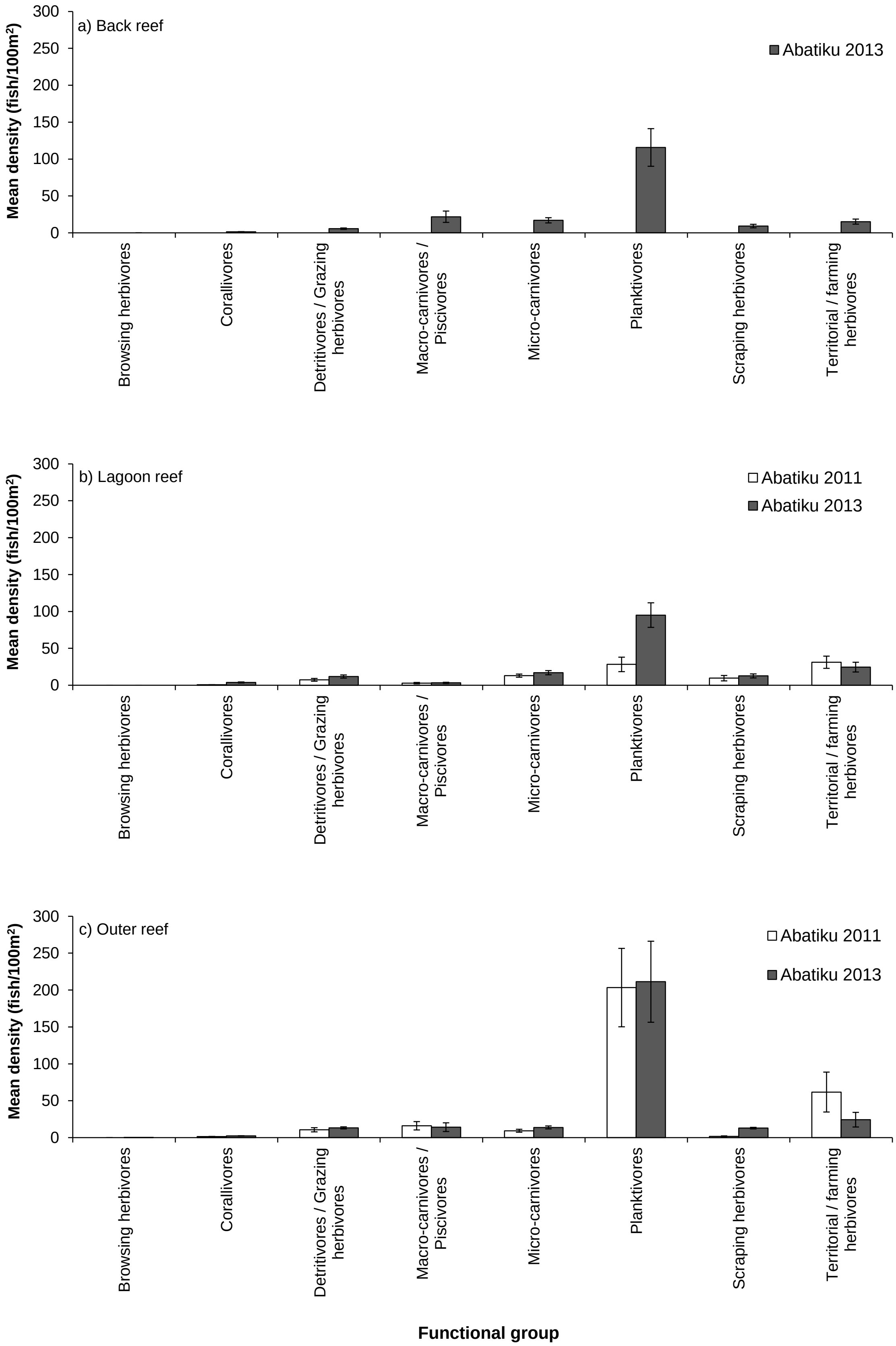


Figure 16 Mean densities (±SE) of key functional groups among a) back reef, b) lagoon reef and c) outer reef habitats of the Abatiku monitoring site during the 2011 and 2013 surveys.

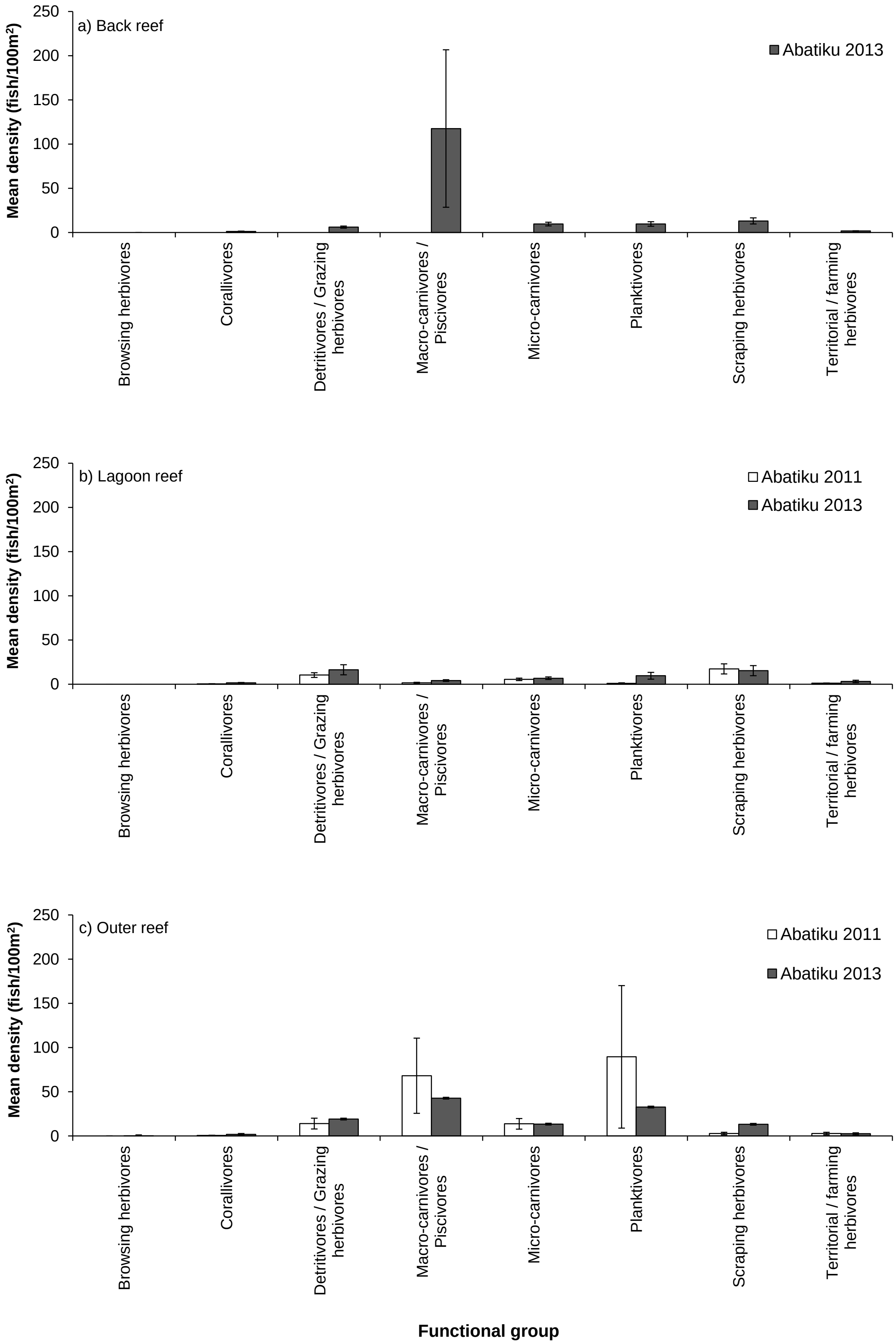


Figure 17 Mean biomass (±SE) of key functional groups among a) back reef, b) lagoon reef and c) outer reef habitats of the Abatiku monitoring site during the 2011 and 2013 surveys.

Bike

Finfish assemblages of the Bike site have been monitored at three habitats to date, with back reef, lagoon reef and outer reef habitats surveyed in both the 2011 and 2013 surveys.

As with the Abatiku monitoring site, finfish diversity within the Bike site was higher during the 2013 survey relative to 2011 for all habitats examined (Table 10). Most functional groups were observed during the surveys, with only browsing herbivores absent on the back reefs in both surveys (Table 10).

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

Parameter	Back reef		Lagoon reef		Outer reef	
	2011	2013	2011	2013	2011	2013
No. of families	15	16	18	25	20	20
No. of genera	26	41	42	73	57	69
No. of species	44	82	78	160	122	157
Diversity	15.0±5.3	41.17±3.1	43.3±8.4	74.8±5.2	47.2±4.9	74.0±4.1
Functional groups	7/8	7/8	8/8	8/8	8/8	8/8

Back reefs

Mean total density of finfish on back reef transects appeared significantly higher in 2013 relative to 2011, while no difference was observed in mean total biomass among surveys (Figure 18; Figure 19). Few differences were observed in density or biomass of the 18 key finfish families on back reef transects at Bike amongst surveys, with densities and biomass of the observed families Balistidae, Labridae, Lethrinidae, Lutjanidae, Mullidae, Pomacanthidae and Zanclidae all appearing similar in 2011 and 2013 (Figure 20; Figure 21). Mean density of Acanthuridae, Scaridae and Serranidae, and mean biomass of Chaetodontidae, Pomacentridae and Serranidae appeared higher in 2013 relative to 2011 (Figure 20; Figure 21). Accordingly, mean densities of the functional groups detritivores / grazing herbivores, planktivores and scraping herbivores, and mean biomass of detritivores / grazing herbivores and planktivores appeared higher in 2013 than 2011 (Figure 22; Figure 23).

Lagoon reefs

Mean total density and biomass of finfish resources on lagoon reef transects was similar in 2013 to that observed in 2011 (Figure 18; Figure 19). Mean density and mean biomass of Zanclidae appeared higher in 2013, while mean density of Mullidae, and mean biomass of Acanthuridae, Chaetodontidae and Mullidae appeared lower in 2013 relative to 2011 (Figure 20; Figure 21). Similarly the biomass of detritivores / grazing herbivores was lower in 2013 relative to 2011 (Figure 22; Figure 23).

Outer reefs

While little differences were evident in mean total density, mean total biomass on the outer reef transects at Bike was significantly higher in 2013 compared to 2011 (Figure 18; Figure 19). This difference was largely due to significantly higher biomasses of the families Lethrinidae, Lutjanidae, Pomacentridae, Scaridae and Serranidae in 2013 (Figure 21). Accordingly, the biomass of the functional groups macro-carnivores, planktivores and scraping herbivores was also higher in 2013 relative to 2011 (Figure 23).

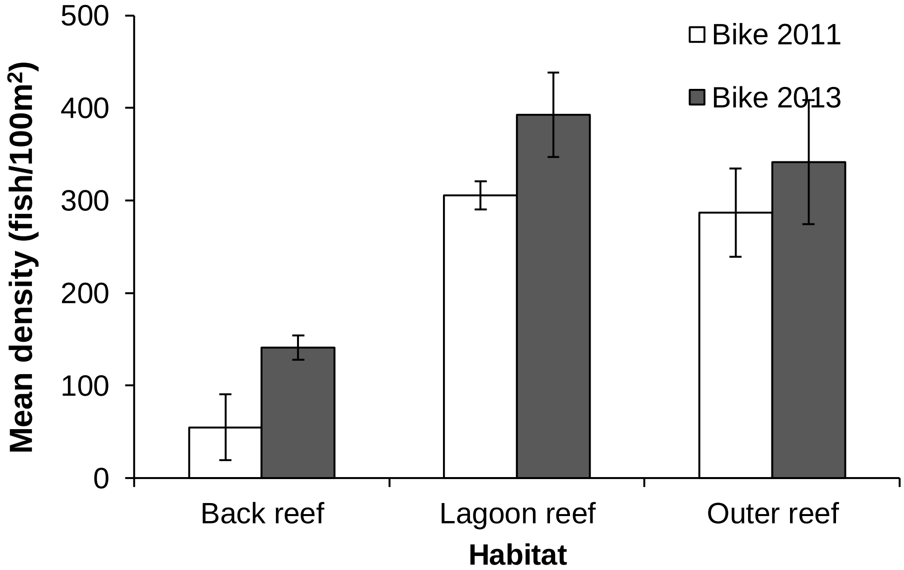


Figure 18 Mean total density of finfish (±SE) among survey years and habitats at the Bike monitoring site.

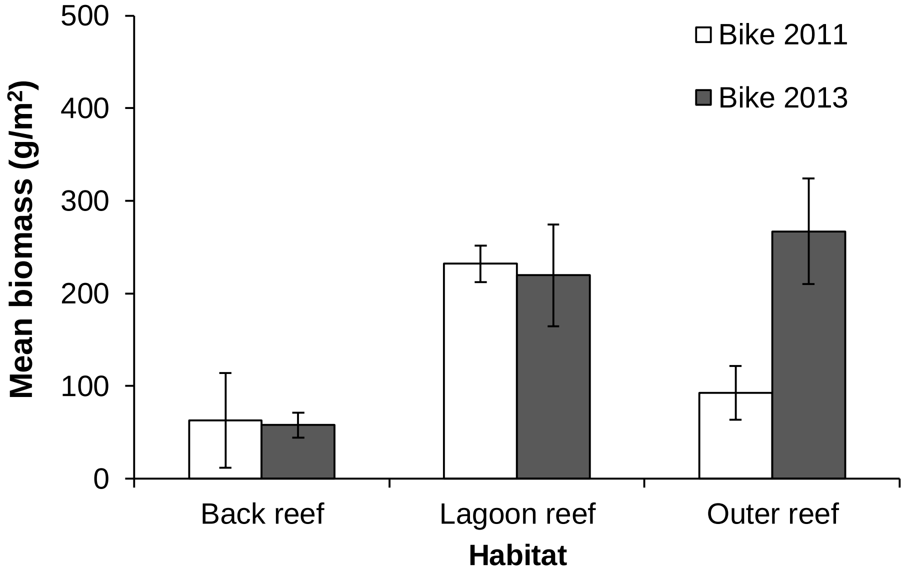


Figure 19 Mean total biomass of finfish (±SE) among survey years and habitats at the Bike monitoring site

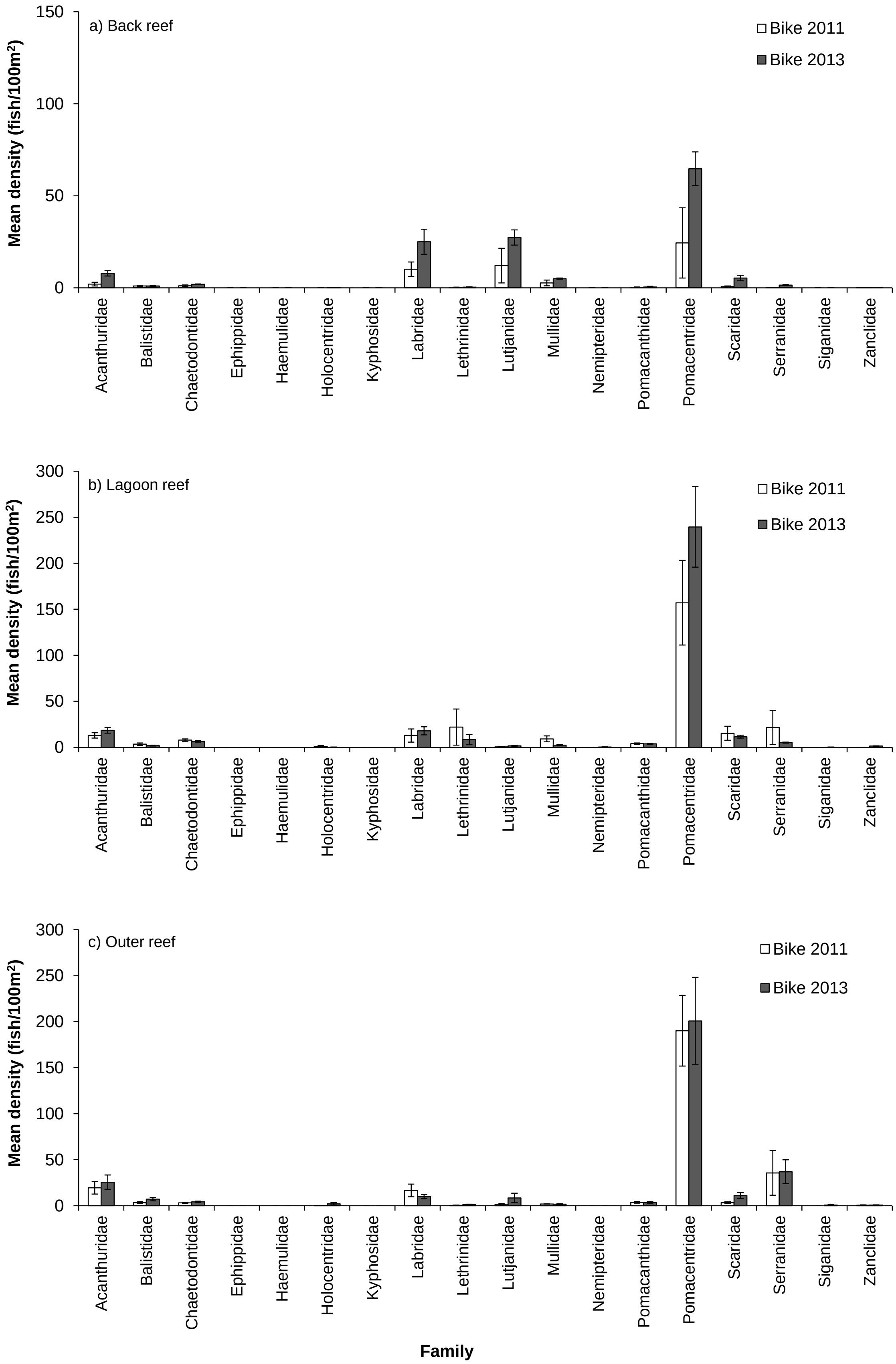


Figure 20 Mean densities (±SE) of common finfish families among a) back reef, b) lagoon reef and c) outer reef habitats of the Bike monitoring site during the 2011 and 2013 surveys.

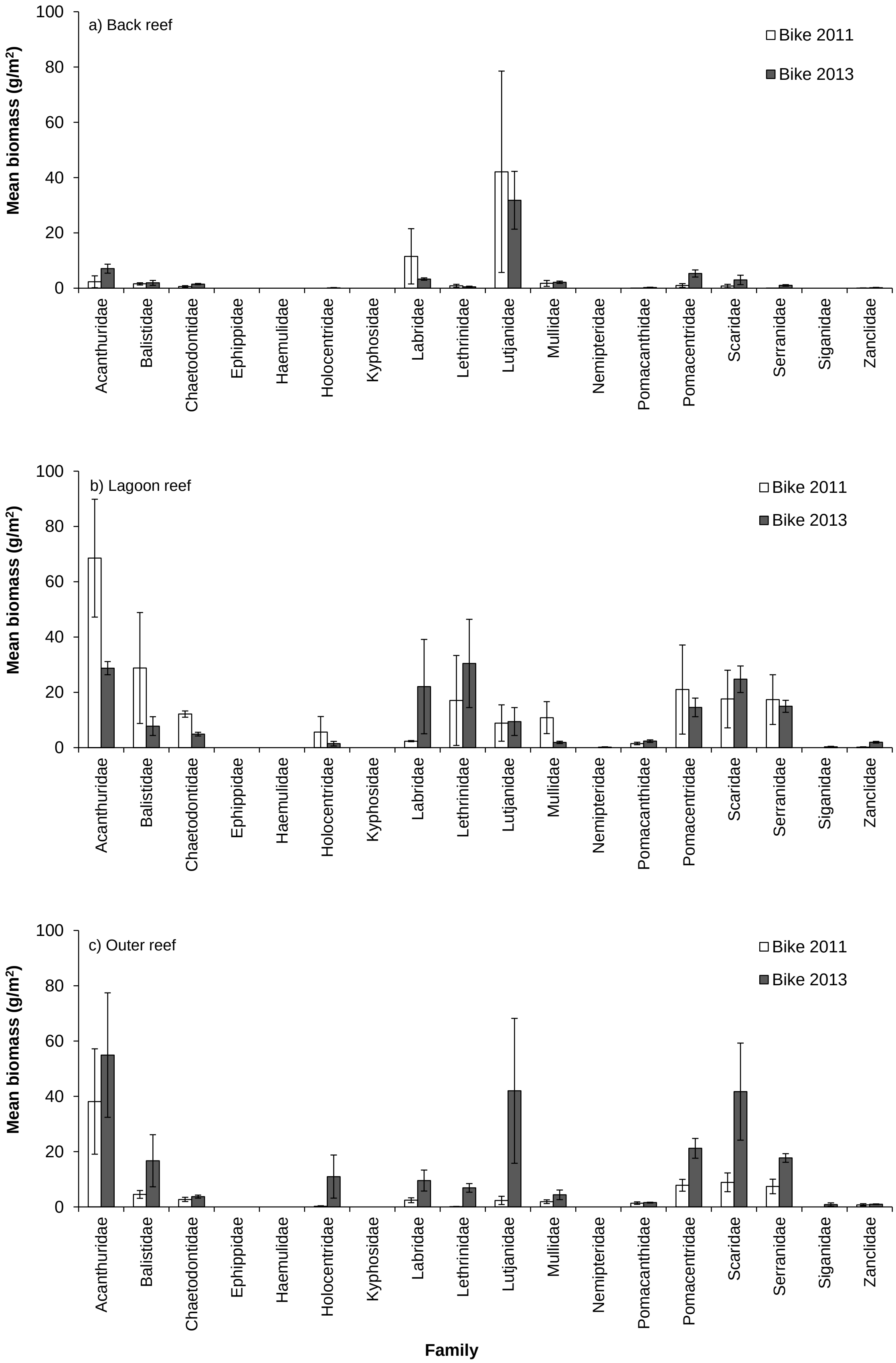


Figure 21 Mean biomass (±SE) of common finfish families among a) back reef, b) lagoon reef and c) outer reef habitats of the Bike monitoring site during the 2011 and 2013 surveys.

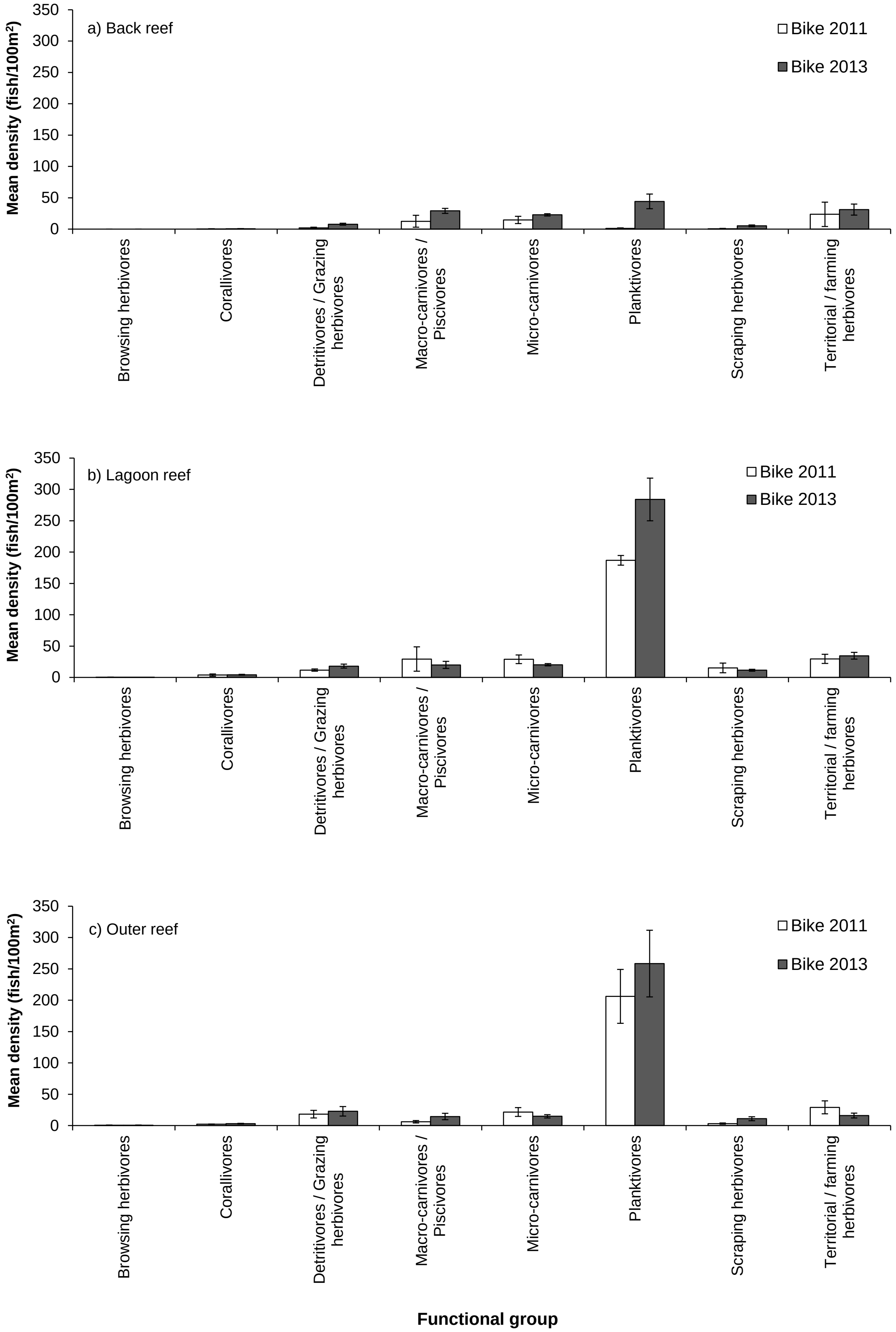


Figure 22 Mean densities (±SE) of key functional groups among a) back reef, b) lagoon reef and c) outer reef habitats of the Bike monitoring site during the 2011 and 2013 surveys

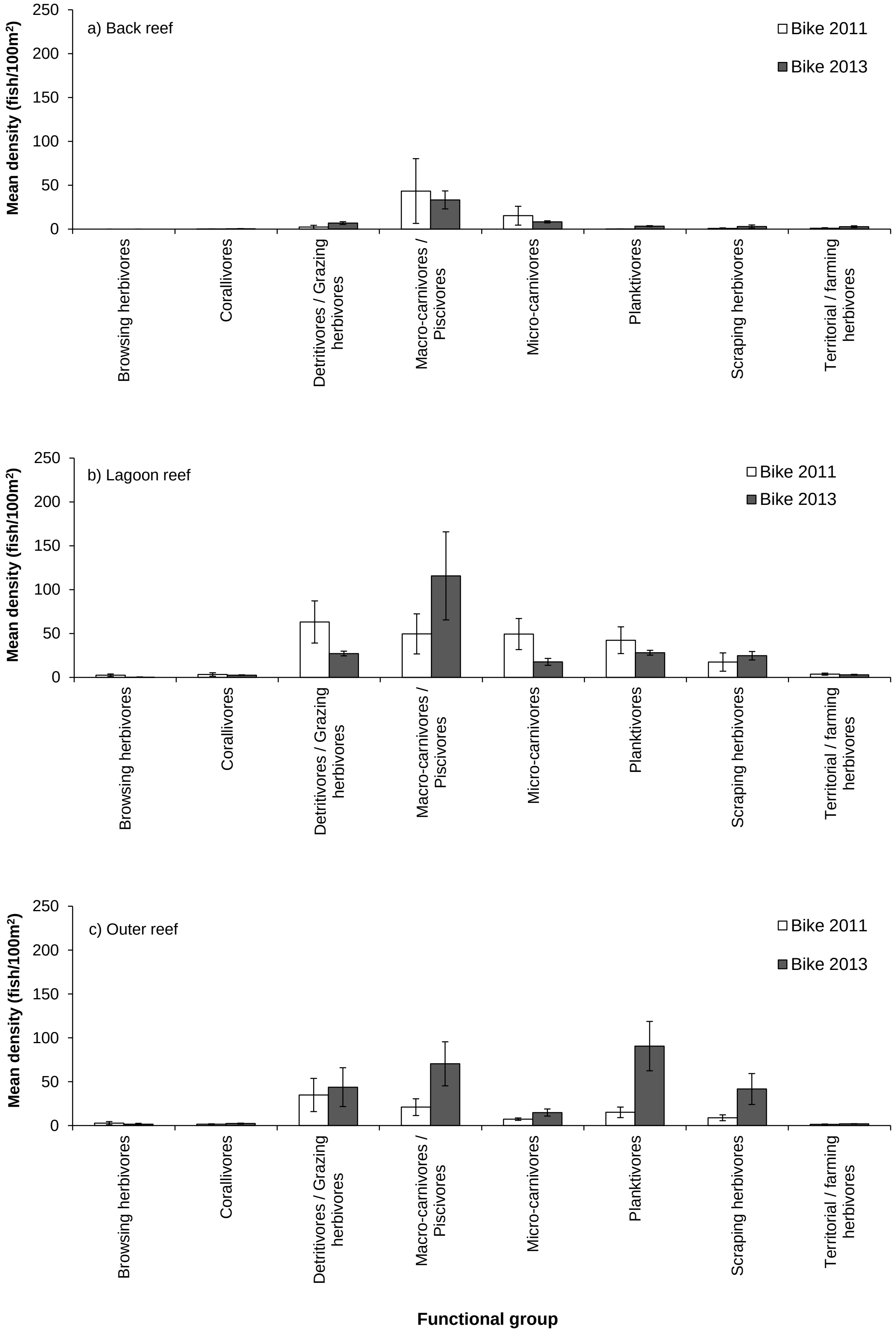


Figure 23 Mean biomass (±SE) of key functional groups among a) back reef, b) lagoon reef and c) outer reef habitats of the Bike monitoring site during the 2011 and 2013 surveys.

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5. Benthic Habitat Assessment

Methodologies

Broad-scale assessments

Data collection

Broad-scale assessments of the benthic habitats of the study region 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 Abatiku and Bike sites, and the inner edge of Abemama (Abemama site). 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.

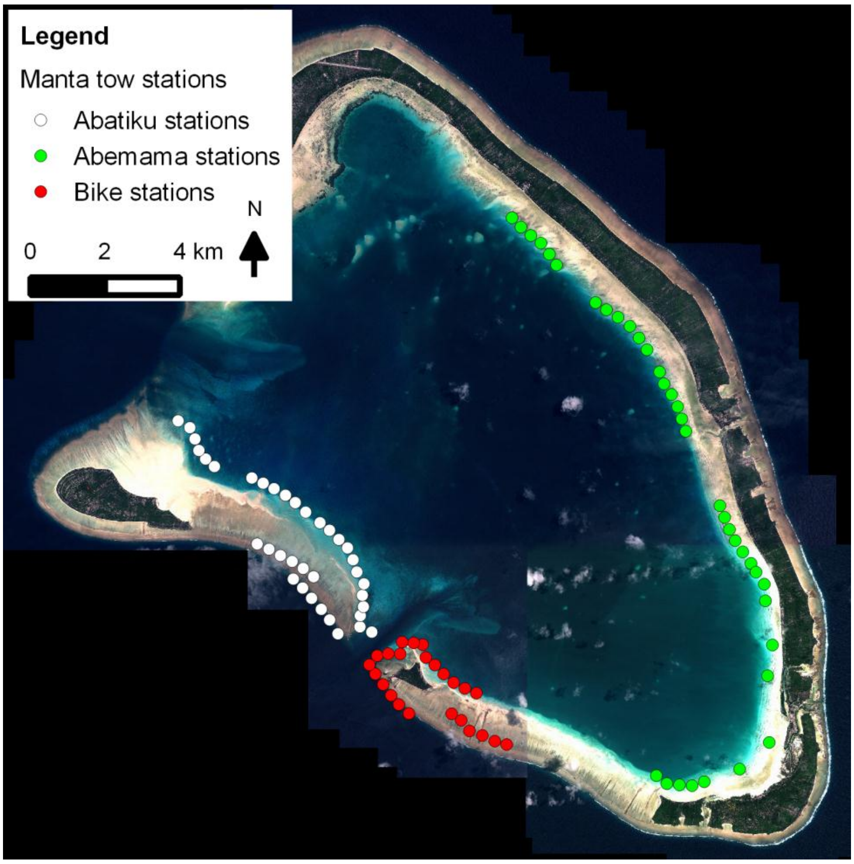


Figure 24 Location of broad-scale (manta tow) benthic habitat monitoring transects at Abemama Atoll. Note each point represents a single 300 m replicate transect.

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 (Abatiku, Bike, Abemama), habitat (inner reef, outer reef) and survey year (2011 and 2013) to explore whether differences occurred among 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 8), 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[2];
2. Other invertebrates – sum of invertebrate types including *Anemones*, *Ascidians*, *Cup sponge*, *Discosoma*, *Dysidea sponge*, *Gorgonians*, *Olive sponge*, *Terpios sponge*, *Other sponges*, *Soft coral*, *Zoanthids*, and *Other invertebrates* (other invertebrates not included in this list);
3. Macroalgae – sum of different types of macroalgae *Asparagopsis*, *Blue-green algae*, *Boodlea*, *Bryopsis*, *Chlorodesmis*, *Caulerpa*, *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, including that covering other categories;
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 visualise patterns of each major substrate category by habitat and survey year.

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

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 (PERMANOVA) at P = 0.05, using Primer 6.1.13, with site+survey year (e.g. Abatiku 2013) and habitat (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

Outer reef habitats

Outer reefs were included in the broadscale habitat survey for the first time in 2013, and focused on the southern edges of the atoll around the Abatiku and Bike sites (Figure 24). Results were generally consistent among sites, although Abatiku had a slightly higher cover of both live and dead coral than Bike (Figure 25).

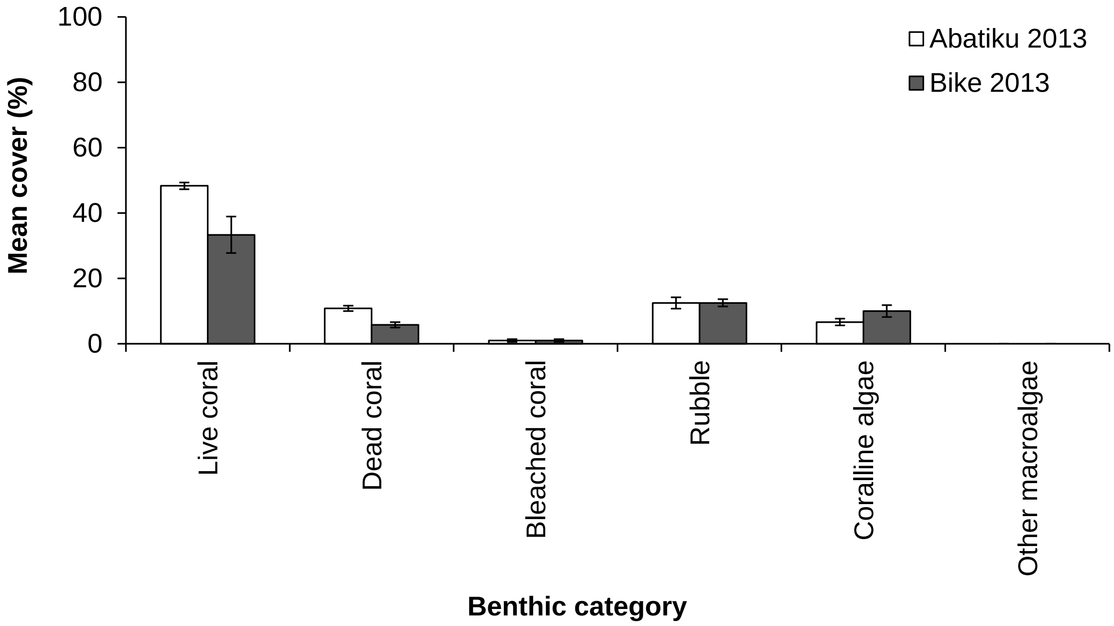


Figure 25 Percent cover of benthic categories observed on outer habitats during broad-scale habitat assessments via manta tow.

Inner reef habitats

Considerable reductions in the cover of live coral and increases in the cover of rubble, coralline algae and other macroalgae were observed during broadscale assessments of the inner reefs of the Abatiku and Bike sites (Figure 26). Further monitoring is required to assess whether these changes result from observer effects or represent real changes in benthic habitat. In contrast, few differences were observed at the Abemama site among surveys, with benthic habitats appearing consistent among the 2011 and 2013 surveys (Figure 26).

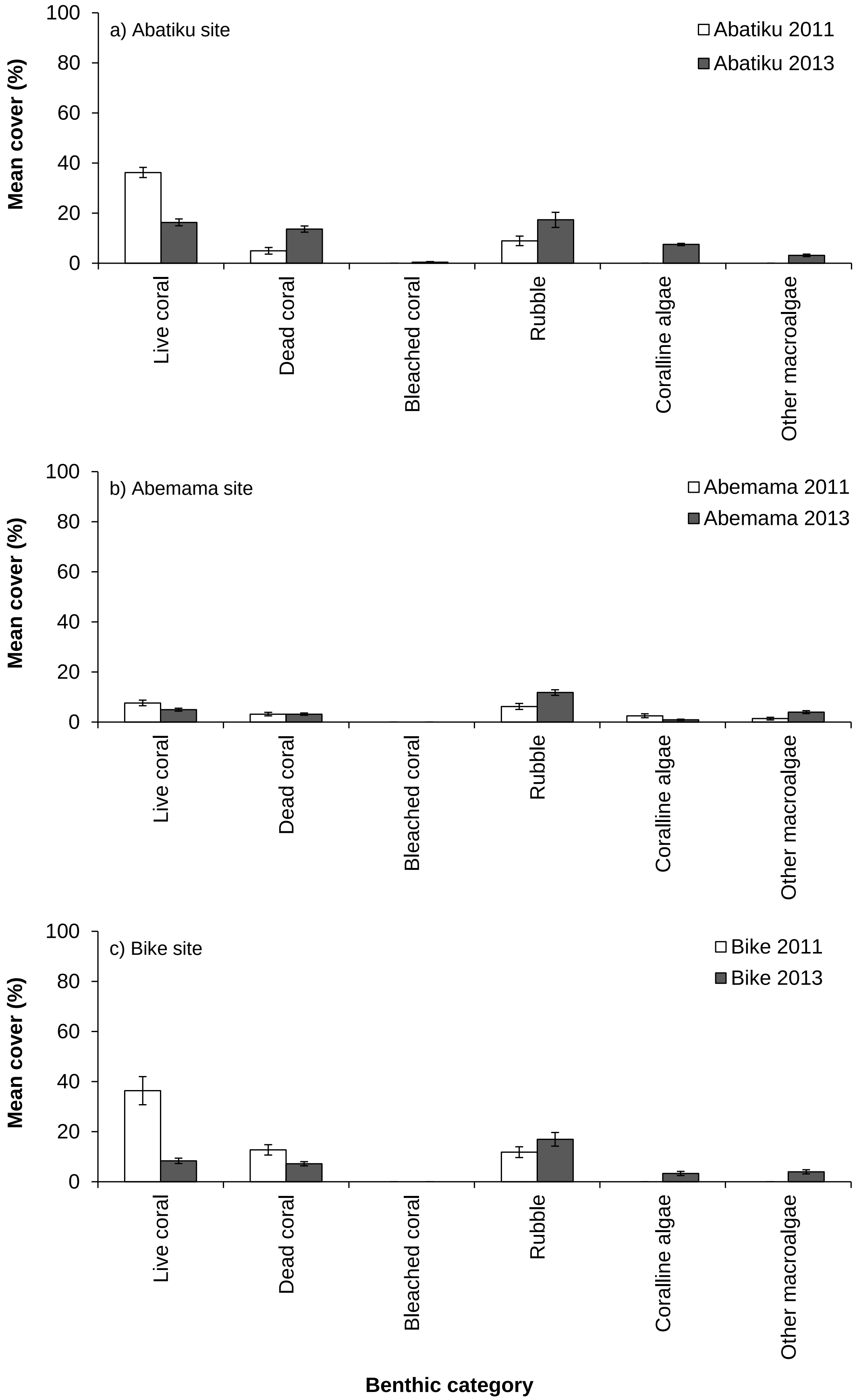


Figure 26 Percent cover of benthic categories observed on inner habitats during broad-scale habitat assessments via manta tow.

Fine-scale assessments

Abatiku monitoring site

Benthic communities of the Abatiku site have been monitored at three habitats during the project. Lagoon reef and outer reef habitats were surveyed in both 2011 and 2013, while benthic communities of back reefs were surveyed for the first time in 2013 (Appendix 1).

Back reefs of the Abatiku site were characterised by high cover of sand / silt and low cover of live hard coral (Figure 29). Lagoon reefs of the Abatiku site were similarly characterised by high cover of sand / silt, and to a lesser extent live hard coral, turf algae and rubble (Figure 27; Figure 29). No significant differences were observed in cover of any major benthic category on lagoon reef transects among the 2011 and 2013 surveys at the Abatiku site. Crown of thorns starfish (*Acanthaster planci*) and predated *Acropora* corals were a common sight on the back and lagoon reefs of the Abatiku monitoring site (Figure 28).

Outer reef habitats of the Abatiku site were characterised by moderate cover of live hard, sand crustose coralline algae and rubble during both the 2011 and 2013 surveys. In 2013 the cover of turf algae appeared significantly lower, and the cover of rubble significantly higher, relative to that observed 2011 (Figure 29; Appendix 5).

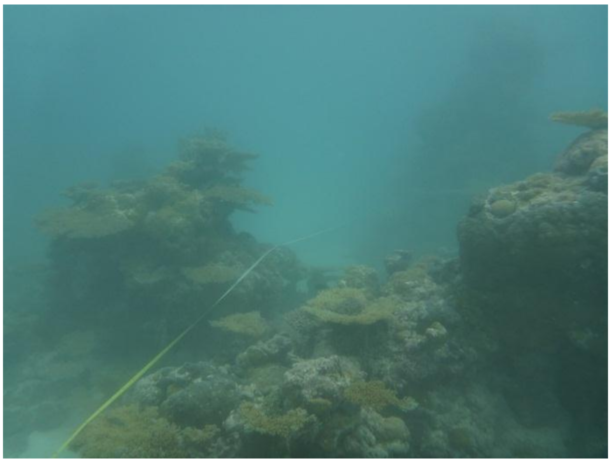


Figure 27 Lagoon reefs of the Abatiku site were characterised by patches of coral (mainly *Acropora* spp.) spp. interspersed by sand.

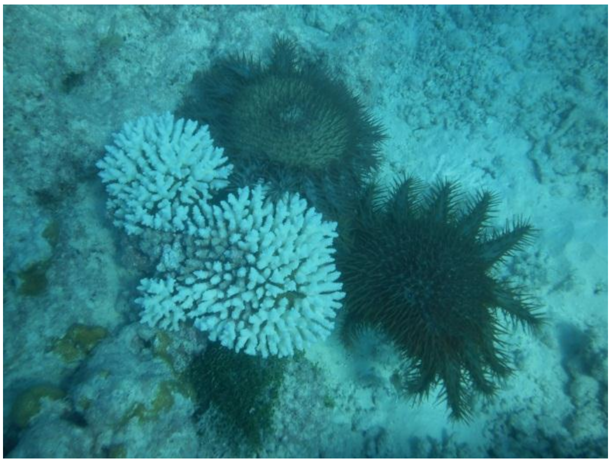


Figure 28 Crown-of-thorns starfish (*Acanthaster planci*) and predated corals were a common sight on the back and lagoon reefs of the Abatiku site in 2013.

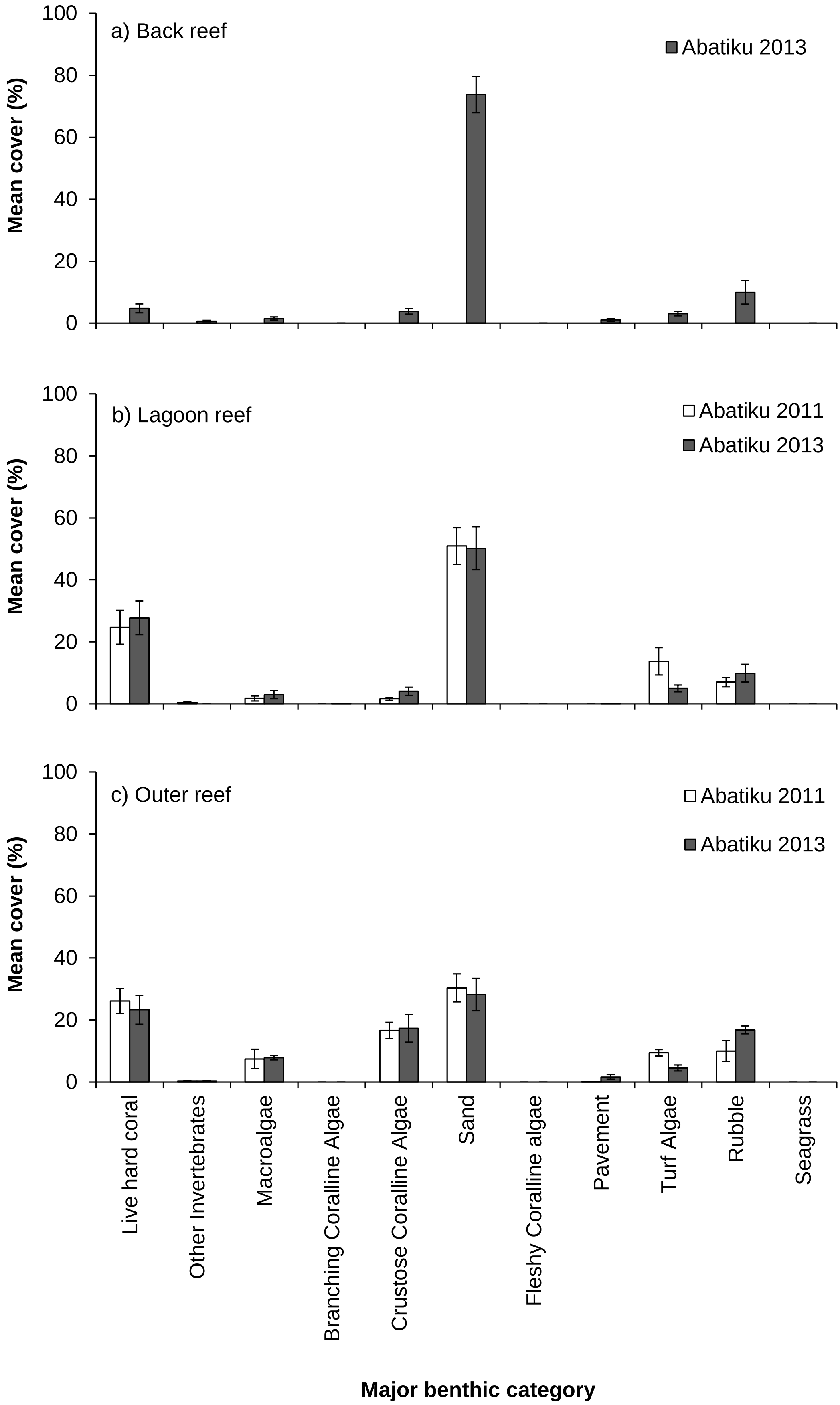


Figure 29 Percent cover of major benthic categories at a) back reef, b) lagoon reef and c) outer reef transects of the Abatiku monitoring site during the 2011 and 2013 surveys.

Bike monitoring site

Benthic communities of the Bike site have been monitored at three habitats during the project, with back reef, lagoon reef and outer reef habitats surveyed in both 2011 and 2013 (Appendix 1).

No significant differences were observed in any major benthic category on back reef transects among the 2011 and 2013 surveys (Figure 30). Back reefs of Bike were largely characterised by sand/silt, and to a lesser degree rubble, live hard coral (in particular *Acropora* and *Porites*-massive) and turf algae (Figure 30).

Lagoon reef habitats of the Bike monitoring had a high cover of sand/silt, moderate cover of live coral and low cover of macroalgae and turf algae (Figure 30). The cover of pavement/rock was significantly higher in 2013 than that observed in 2011 (Figure 30).

Consistent with other habitats, few differences were evident in benthic community composition of outer reef transects of the Bike site among the 2011 and 2013 surveys. No differences were observed in the cover of major categories of live hard coral, other invertebrates, macroalgae, crustose coralline algae, or rubble. The cover of both sand and turf algae decreased slightly in 2013 (Figure 30). Outer reef habitats of the Bike site were generally consistent with those of Abatiku, and were characterised by moderate cover of live hard coral, crustose coralline algae, sand and rubble (Figure 30).

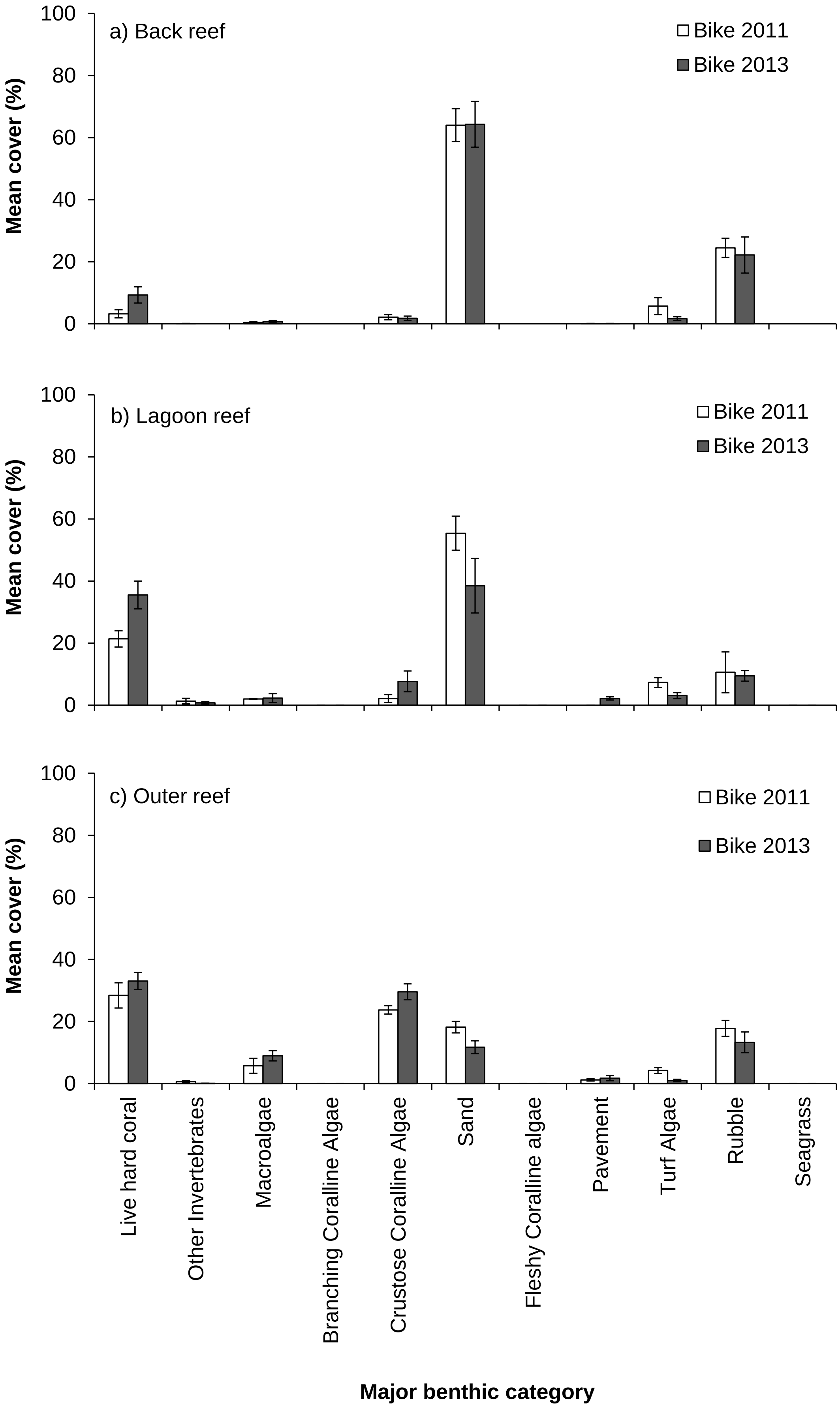


Figure 30 Percent cover of major benthic categories at a) back reef, b) lagoon reef and c) outer reef transects of the Bike monitoring site during the 2011 and 2013 surveys.

6. Invertebrate Surveys

Methods and Materials

Data collection

Invertebrates

Invertebrate resources of Abemama Atoll were surveyed using three complementary techniques: 1) manta tows; 2) reef benthos transects (RBt) and 3) soft infaunal quadrats (SiQ). Manta tows were used to provide a broad-scale assessment of invertebrate resources, and followed the same path used in the broadscale habitat assessments (Figure 24). 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 31). 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.

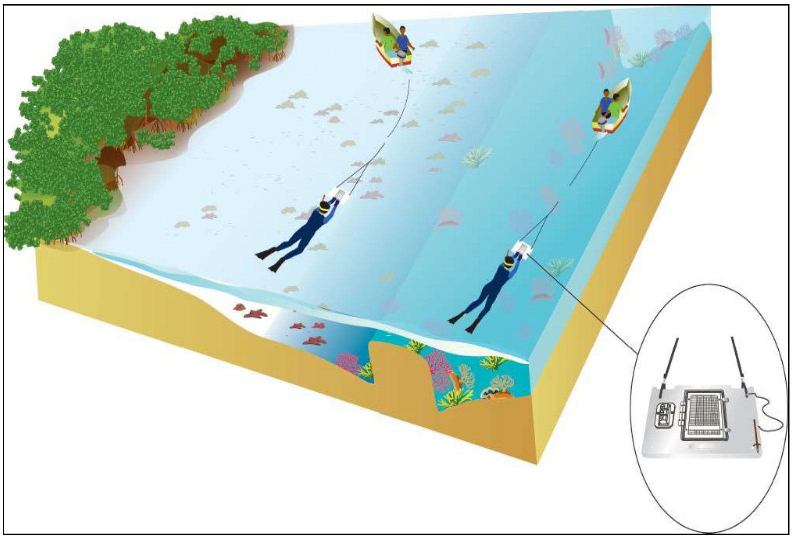


Figure 31 Diagrammatic representation of the manta tow survey method.

To assess the abundance, size and condition of invertebrate resources associated with reef habitats at finer-spatial scales, reef benthos transects (RBt) were conducted. A total of 10 RBt stations were surveyed, with five stations established at each of the Abatiku and Bike sites (Figure 33). Each station was surveyed by two surveyors equipped with measuring instruments attached to their record boards (slates) for recording the abundance and size of invertebrate species. For some species, such as sea urchins (e.g. *Echinometra sp*.), only abundance was recorded due to difficulty in measuring the size of these organisms. Each transect was 40 meters long with a one meter wide observation belt, conducted in depths ranging from one to three meters. The two snorkellers conducted three transects each, totalling six 40 m transects for each RBt station (Figure 32). The GPS position of each station was recorded in the centre of the station.

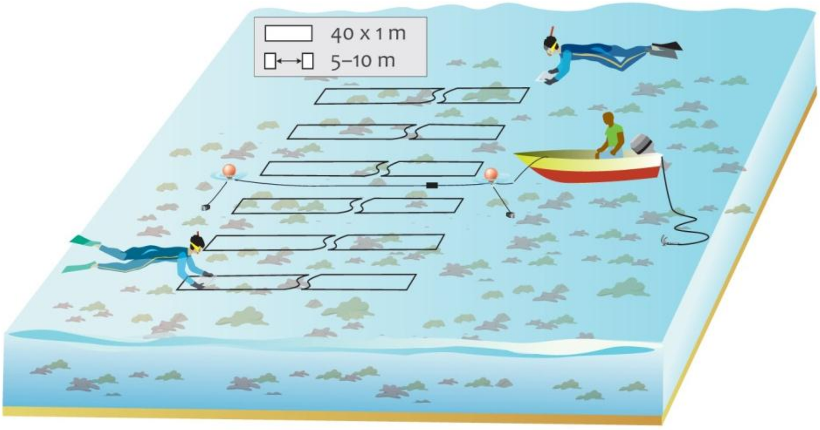


Figure 32 Diagrammatic representation of the reef benthos transect method.

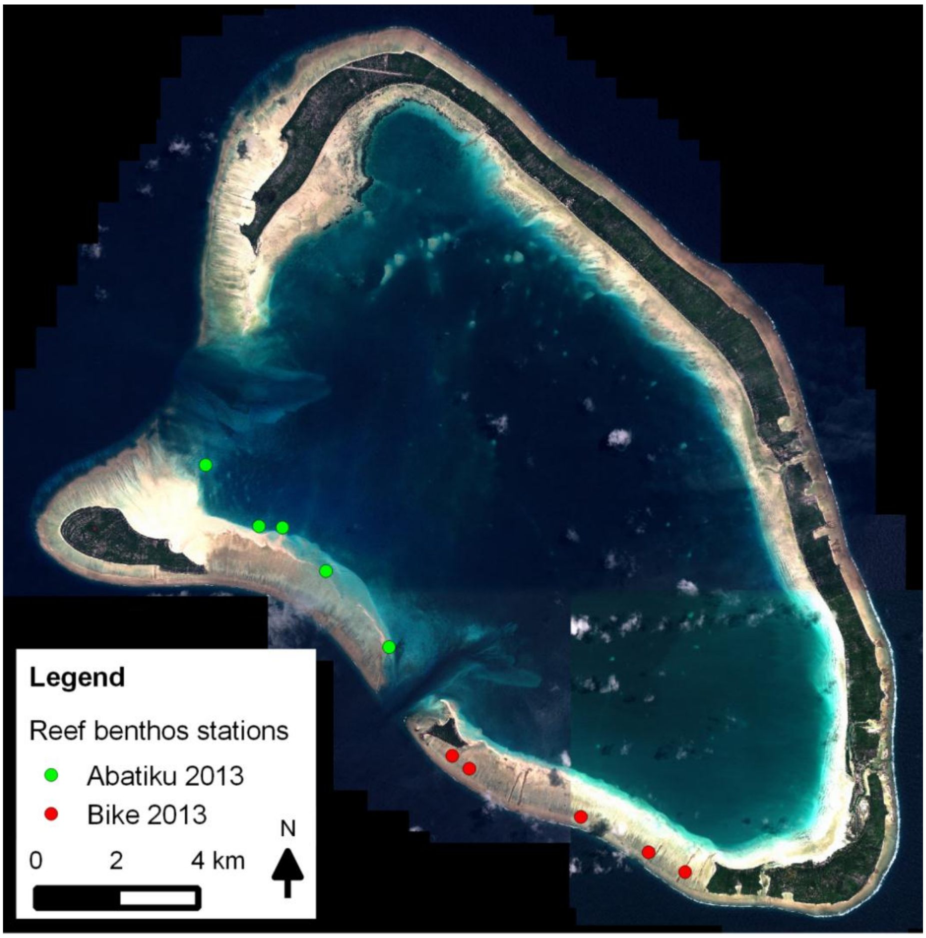


Figure 33 Map of Abemama Atoll showing approximate positions of reef benthos transect (RBt) stations. A list of GPS waypoints for the RBt stations is included as Appendix 8.

To assess the range, abundance and size of infaunal invertebrates in soft sediment areas, soft infaunal quadrat (SiQ) assessments were conducted. This method targets invertebrates such as *te bun* (*Anadara* species) and sea cucumbers associated with soft sediment and seagrass habitats. A total of 12 SiQ stations were established, with all stations situated along the soft sediment areas of the Abemama site (Figure 35).Up to five people conducted the survey at each station, including four surveyors and a recorder. At each station, eight sets of four randomly spaced 25 x 25 cm quadrats were sampled every 5 to 6 metres along a 40 m transect line. The sediment within each quadrat was retrieved by hand down to approximately 5–8 cm. Collected invertebrates were identified, measured and recorded.

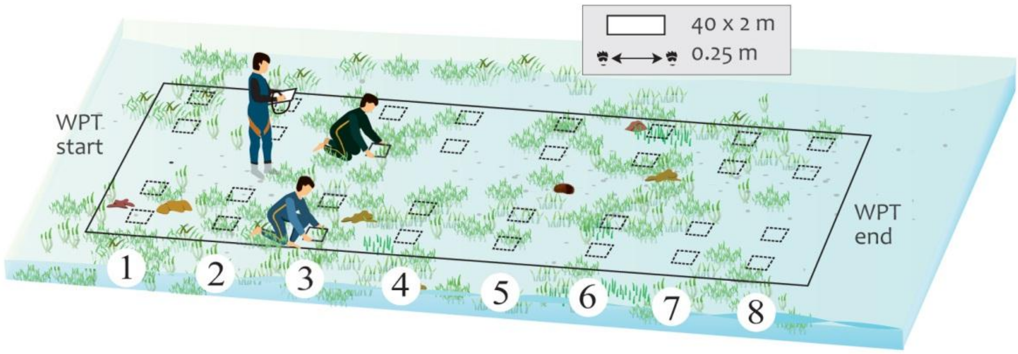


Figure 34 Diagrammatic representation of the soft infaunal quadrat method.

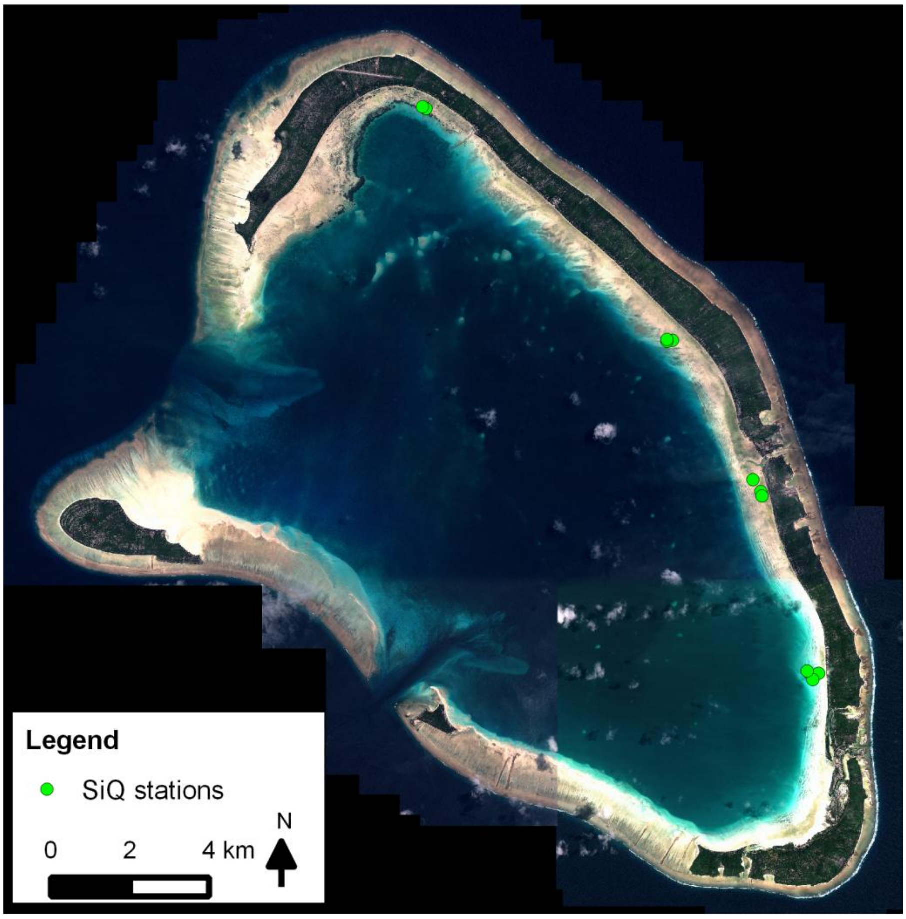


Figure 35 Map of Abemama Atoll showing approximate positions of soft infaunal quadrat (SiQ) stations. A list of GPS waypoints for the SiQ stations is included as Appendix 9.

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;
2) diversity – total number of observed genera and species per site divided by the number of stations; and
3) mean density per station (individuals/ha ±SE);
4) size class frequencies (mm).

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*

Summary graphs of mean density (±SE) by site and survey year were generated to explore spatial and temporal patterns in invertebrate assemblages from the manta tow, RBt and SiQ stations. Data was analysed on an individual species level except for gastropods and urchins, which were pooled to the genus level. Due to low numbers of invertebrates observed on the outer reefs, only back reef transects were used in the analyses of manta tow data.

Results

Manta tow

A total of five sea cucumber species were observed during the manta tow assessments (Figure 36; Figure 37; Table 12). Observations of sea cucumbers were sporadic at Abatiku and Bike sites; often reduced to a single individual or handful of individuals per station (Table 12; Figure 36; Figure 37). Mean densities of sea cucumbers at both Abatiku and Bike showed little difference among the 2011 and 2013 surveys (Figure 36; Figure 37). At the Abemama stations, mean overall density of brown sandfish (*Bohadschia vitiensis*) increased significantly among surveys, from zero individuals observed in 2011 to 6.01±2.42 individuals/ha in 2013. Mean densities of all sea cucumbers were well below the regional reference densities for healthy sea cucumber stocks proposed by Pakoa et al. (2014).

Few differences in mean density were observed for any invertebrate species during the manta tows at Bike in 2011 and 2013. At Abatiku, a considerable increase in the mean density of crown-of-thorns starfish (COTS), *Acanthaster planci*, was observed, with densities increasing from 0.69±0.69 in 2011 to 115±54 individuals/ha. Densities of COTS on individual transects reached as high as 733 individuals/ha. These densities are well above the active outbreak density of 37.5

individuals/ha considered by Pakoa et al. (2014), indicating significant coral damage to the reefs of Abatiku is likely.

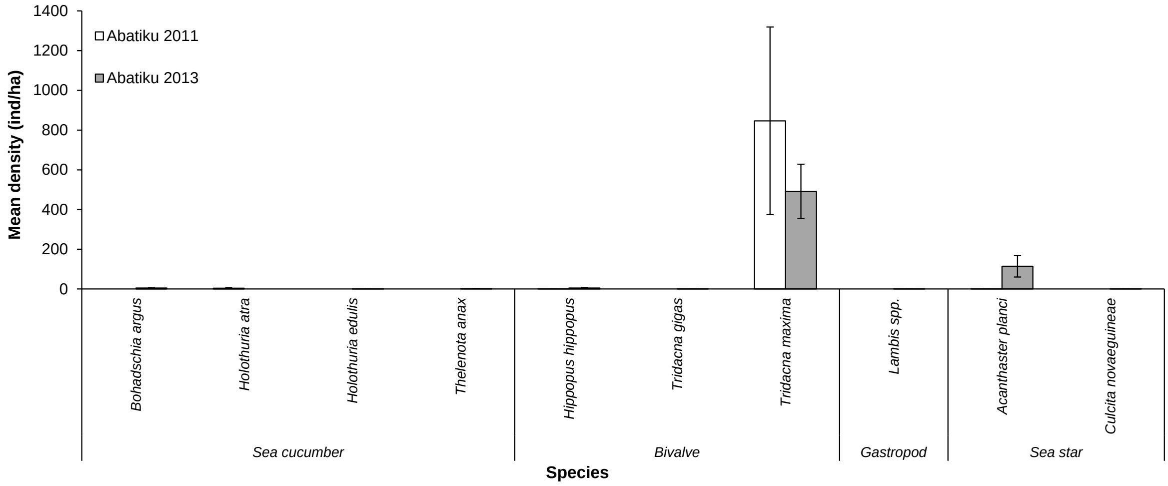


Figure 36 Overall mean densities (±SE) of invertebrate species observed during manta tow surveys at the Abatiku monitoring site, 2011 and 2013.

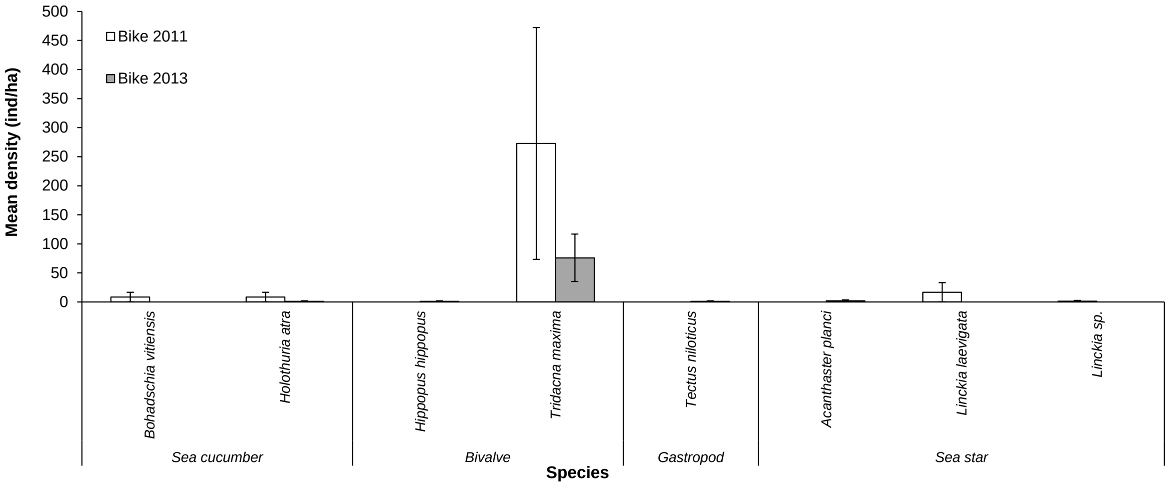


Figure 37 Overall mean densities (±SE) of invertebrate species observed during manta tow surveys at the Bike monitoring site, 2011 and 2013.

Table 12 Mean overall densities (±SE) of sea cucumber species at manta tow stations in 2011 and 2013. The regional reference density for healthy stocks (for manta tow surveys) is provided in the last column (from Pakoa et al. 2014).

Species	Abatiku		Abemama		Bike		Manta tow reference density
	2011	2013	2011	2013	2011	2013	
Bohadschia argus	-	5.00±2.22	-	-	-	-	50
Bohadschia vitiensis	-		-	6.02±2.42	8.33±8.33	-	160
Holothuria atra	4.17±2.66		239.35±96.03	587.04±420.01	8.33±8.33	0.93±0.93	2,400
Holothuria edulis	-	0.56±0.56	-	-	-	-	250
Thelenota anax	-	2.22±1.36	-	-	-	-	20

Reef benthos transects

The diversity of invertebrates at RBt stations was low at both sites during both the 2011 and 2013 surveys. Invertebrate diversity was slightly higher at Bike than Abatiku, and slightly higher in 2013 than 2011 at both sites (Table 13).

Three species of sea cucumber were recorded during the RBt surveys (Table 14). As with the manta tow assessments, observations of sea cucumbers were sporadic at each of the Abatiku and Bike sites; often reduced to a single or handful of individuals per site (Figure 41; Figure 42). Accordingly densities showed little difference among surveys. Densities of each of the three encountered species were well below the regional reference densities for healthy sea cucumber stocks proposed by Pakoa et al. (2014) (Table 14). Given their low densities and impoverished diversity there is little potential for commercial sea cucumber harvesting at this time, and stocks are in need of on-going protection to build until recommended minimum harvest densities are achieved.

Densities of the elongated giant clam, *Tridacna maxima*, were high at RBt stations at both the Abatiku and Bike sites, with 1841.67±675.64 individuals/ha observed at Abatiku and 1175.00±364.53 individuals observed at Bike. Mean densities of *T. maxima* showed little difference among 2011 and 2013 surveys at either site, and were considerably higher than the regional reference densities for healthy *T. maxima* stocks (Table 14). The size frequency distribution of *T. maxima* revealed that the bulk of individuals observed ranged from 21–130mm, with modal lengths of 61–70mm at each site (Figure 38).

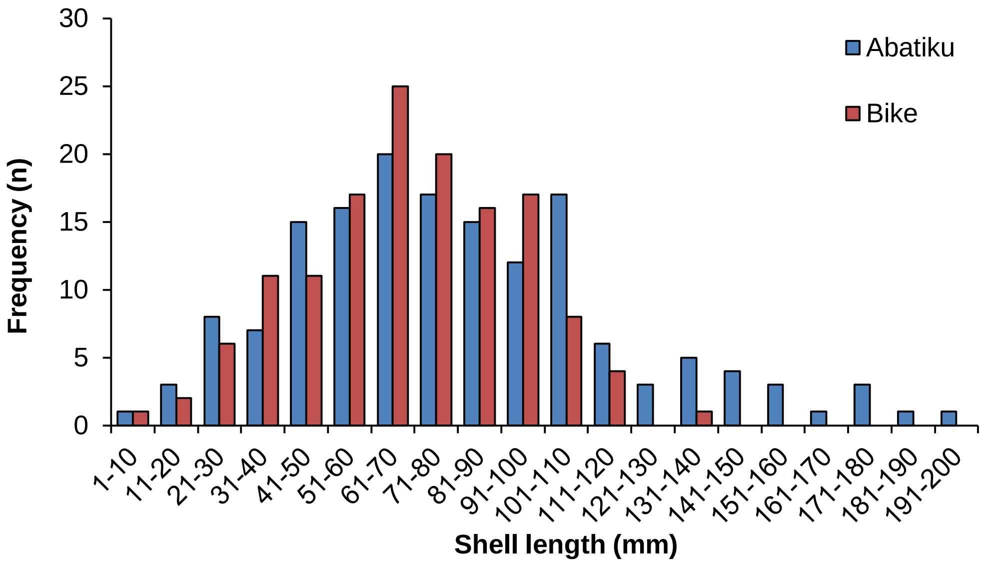


Figure 38 Size distribution of elongated giant clam (*te were*; *Tridacna maxima*) observed at the Abatiku and Bike sites during the 2013 survey.

Consistent with the manta tow surveys, a considerable increase in the density of COTS was observed at the Abatiku site, with densities increasing from zero in 2011 to 550±363 individuals/ha. On the individual transects COTS densities reached as high as or 3,500 individuals/ha.

Table 13 Total number of genera and species, and diversity of invertebrates observed during reef benthos transects at the Abatiku and Bike sites, 2011 and 2013.

Parameter	**Abatiku**		**Bike**	
	2011	**2013**	**2011**	**2013**
No. stations surveyed	5	5	5	5
No. of genera	8	11	12	18
No. of species	9	12	15	21
Diversity	1.8	2.4	3.0	4.2

Table 14 Mean overall densities (±SE) of sea cucumber species and *Tridacna maxima* at RBt stations in 2011 and 2013. The regional reference density for healthy stocks (for RBt surveys) is provided in the last column (from Pakoa et al. 2014).

Species	**Abatiku**		**Bike**		**RBt reference density**
	2011	**2013**	**2011**	**2013**	
Bohadschia argus	-	8.33±8.33	-	33.33±33.33	120
Holothuria atra	-	-	8.33±8.33	-	5,600
Thelenota ananas	-	8.33±8.33	-	-	30
Tridacna maxima	2442±1041	1842±676	792±297	1175±365	750

Figure 39 Crown-of-thorns starfish (*Acanthaster planci*) were observed in densities as high as 3,500 individuals/ha on some reef benthos transects.

Figure 40 Predated coral with crown-of-thorns starfish.

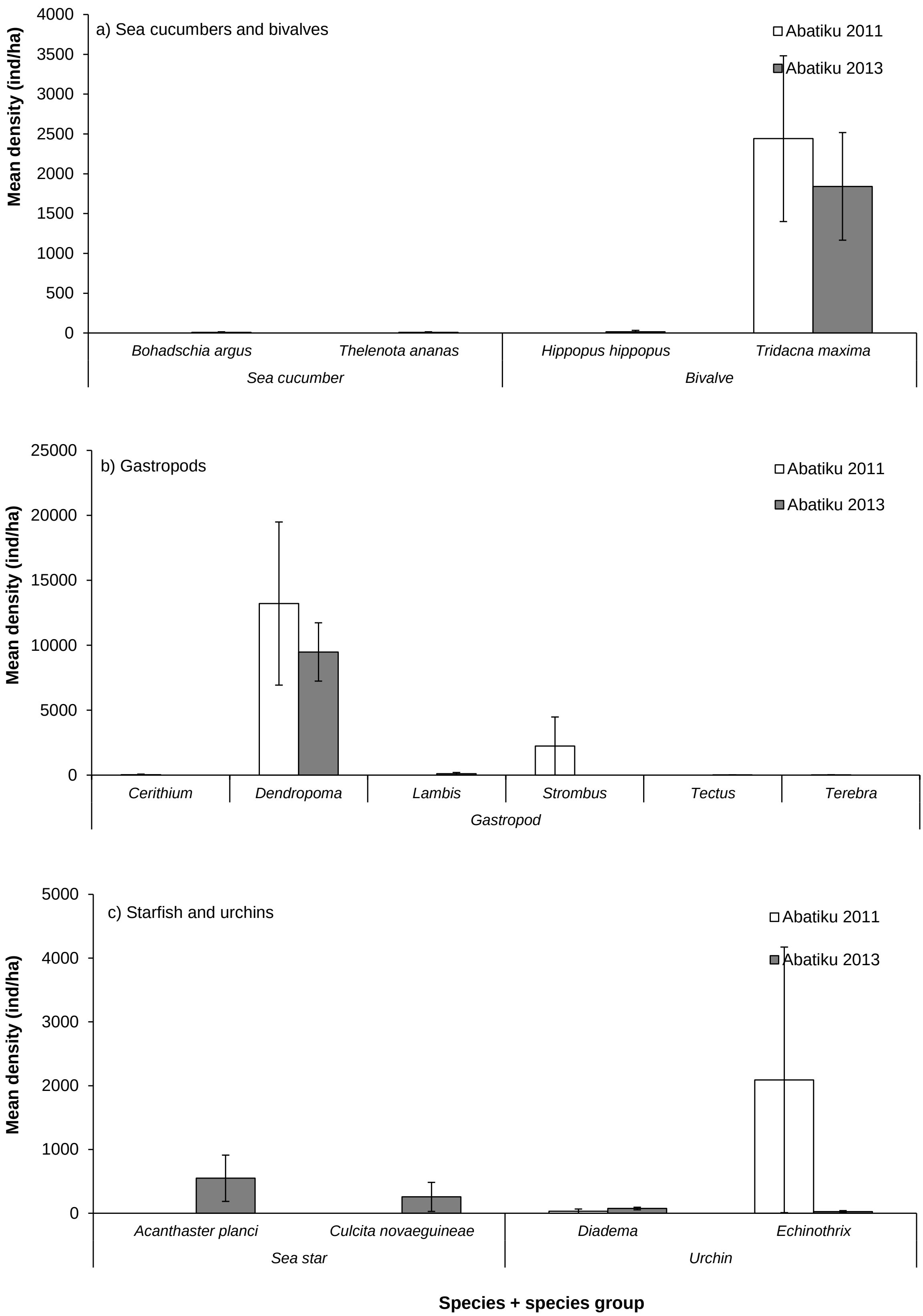


Figure 41 Overall mean densities (±SE) of a) sea cucumbers and bivalves, b) gastropods and c) starfish and urchins observed at RBt stations at the Abatiku monitoring site, 2011 & 2013.

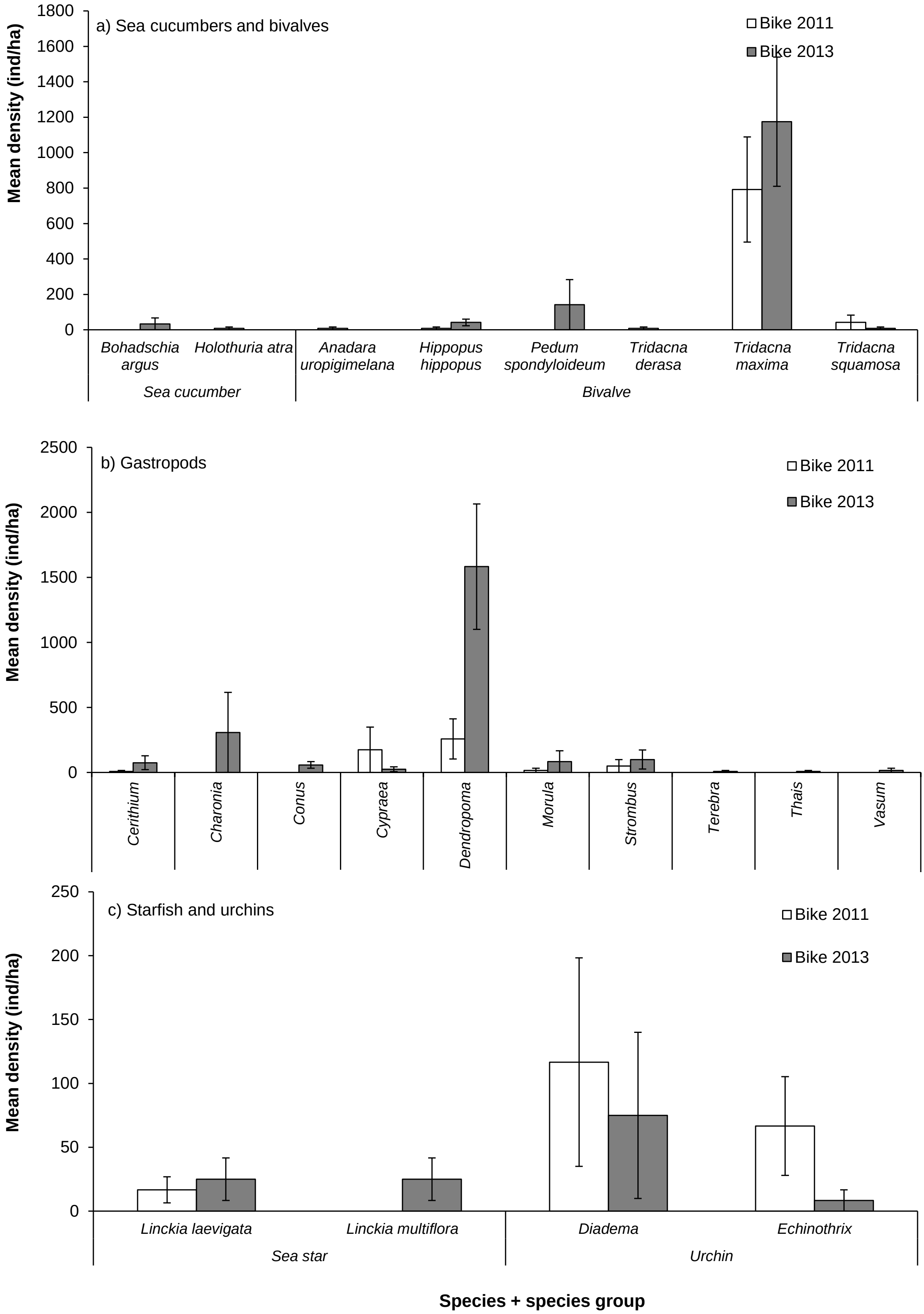


Figure 42 Overall mean densities (±SE) of a) sea cucumbers and bivalves, b) gastropods and c) starfish and urchins observed at RBt stations at the Bike monitoring site, 2011 & 2013.

Soft infaunal quadrats

No significant differences were observed in overall mean density of any species during SiQ surveys (Table 15). Mean densities of *te bun* (*Anadara uropigimelana*), appeared healthy, with 96,250±24,333 individuals observed per hectare (Table 15). While no specific minimum harvest size exists for this species, the majority of individuals observed were above the minimum harvest size of 45 mm proposed by Pakoa et al. (2014) for *A. antiquata* (Figure 43).

Table 15 Mean densities (individuals/ha±SE) of key invertebrate species encountered at SiQ stations at Abemama, 2011 & 2013.

Species group	Species	2011	2013
Bivalve	*Anadara uropigimelana*	72,916.7 ± 33,543.6	96,250.0 ± 24,333.0
	Ctena bella	-	56,250.0 ± 31,844.3
	Gafrarium pectinatum	30,833.3 ± 20,420.1	68,333.3 ± 34,969.3
Gastropod	*Cypraea* spp.	3,750.0 ± 2,664.0	4,166.7 ± 2,289.1
	Strombus spp.	10,416.7 ± 5,451.5	4,166.7 ± 2,940.9

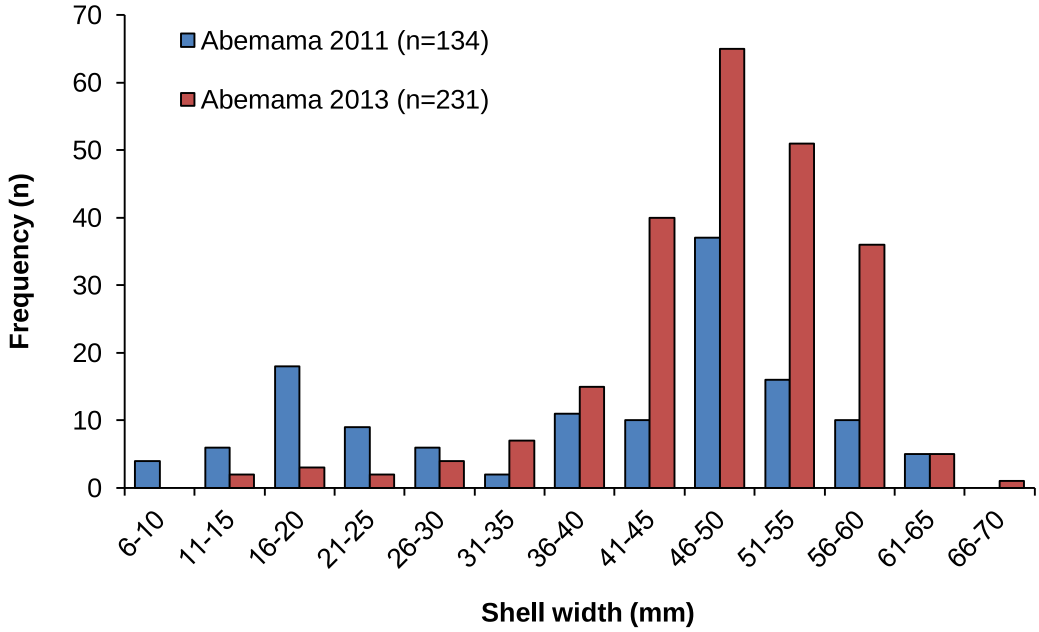


Figure 43 Size distribution of *te bun* (*Anadara uropigimelana*) observed during the 2011 & 2013 surveys.

7. Creel Surveys

Methods

Creel surveys at Abemama focused on commercial gillnet, handline/bottom fishing and spear 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), effort (including trip duration, time spent fishing and gears used) and catch-per-unit-effort (CPUE) for monitoring purposes.
4) Document fisher's perceptions of the status of fisheries resources.

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 finfish 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 10.

Data analysis

Summary statistics, including mean number of fishers per trip, mean trip duration, mean catch (individual fish and kg) were compiled for each fishing method. Where weight data were not recorded (i.e. when a fish was damaged), weights were estimated from length-weight relationships in FishBase (Froese and Pauly 2013). Length-frequency plots were established for key target species. Catch-per-unit-effort was calculated for each fishing method. 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:

$$n = (\text{SD} / (\text{P}*\text{avg}))^2$$

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

Results

A total of 20 landings were met at Abemama, with four general fishing activities observed: scoop netting for flying fish (including trolling to/from the fishing sites), gillnetting/te ororo for bonefish, handlining (1 survey) and circle netting (primarily for mullet; 1 survey). Due to low numbers of landings of scoop netting (6 landings), handlining (1 landing) and circle netting (1 landing), below we provide an analysis into bonefish fishing only.

Bonefish fishing

Twelve landings of bonefish gillnetting/te ororo were met. On average, bonefish fishing trips involved 2.08±0.08 fishers, and lasted 3.75±0.70 hours. The average catch was 100.92±16.52

individual fish, or 61.22±9.66 kg. Average catch per unit effort was 39.70±9.44 fish per hour, or 23.29±4.70 kg per hour. Fishing was conducted primarily by males, while women were responsible for processing the catch for sale or consumption (Figure 44). Analysis revealed that a minimum of 17 and 12 surveys are required to detect a change in CPUE measured in terms of abundance or weight, respectively, at the lowest recommended precision level of P = 0.2 (Table 16).

A total of 1,211 individual fishes were observed in the 12 landings, with nine different species observed in the catch (Figure 45). Fishing was very much targeted towards bonefish (*Albula glossodonta*), with 1,129 individual *A. glossodonta* observed, representing 93.2% of the total number and total weight of fish caught (Figure 45).

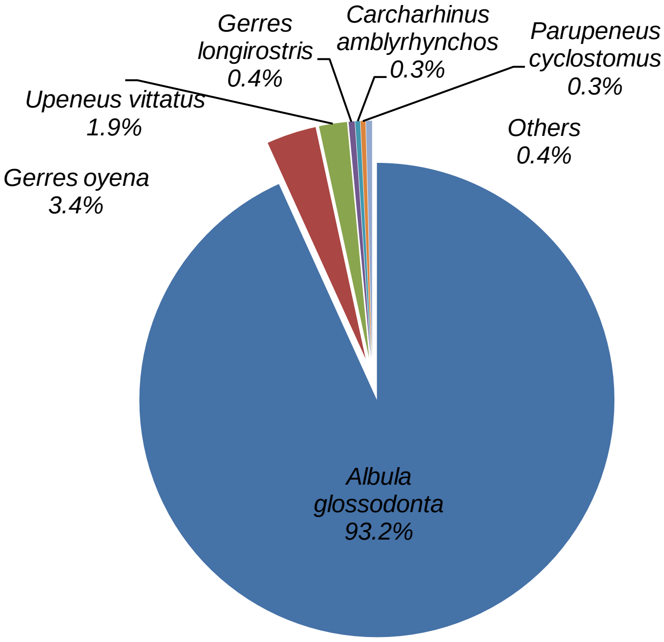
Length (FL) data were collected for all bonefish surveyed. Lengths ranged from 23.8 cm FL to 56.5 cm FL, with a modal length class of 33.0–34.9 cm FL (Figure 46). The average length was 35.3±0.1 cm FL. Examination of length frequency by gillnet mesh size revealed that fishing trips that involved nets of smaller mesh diameters (2 inch or 2.5 inch) captured a larger proportion of small, likely immature individuals than nets of larger (3 inch) mesh size (Figure 46).

Figure 44 Abemama ladies processing a catch of bonefish, *Albula glossodonta*.

Table 16 Number of surveys required to detect at change in catch-per-unit-effort (in terms of fish number/weight caught per trip duration) at different precision levels.

Precision level	No. of landings needed to survey to detect change in CPUE by abundance	No. of landings needed to survey to detect change in CPUE by weight
0.1	68	49
0.2	17	12
0.3	8	5

a) Total by abundance



b) Total by weight

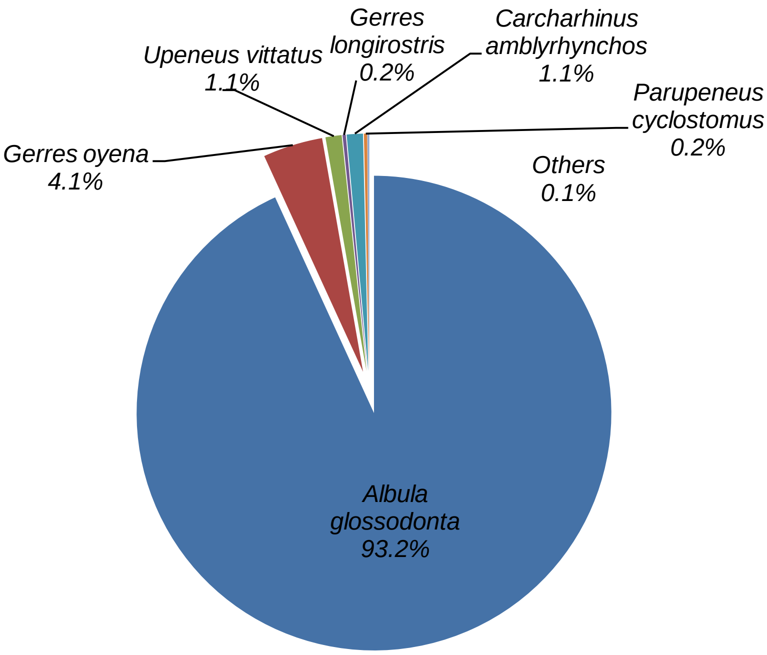


Figure 45 Catch composition by abundance (top) and weight (below) of species caught during bonefish fishing trips, Abemama, October–November 2013.

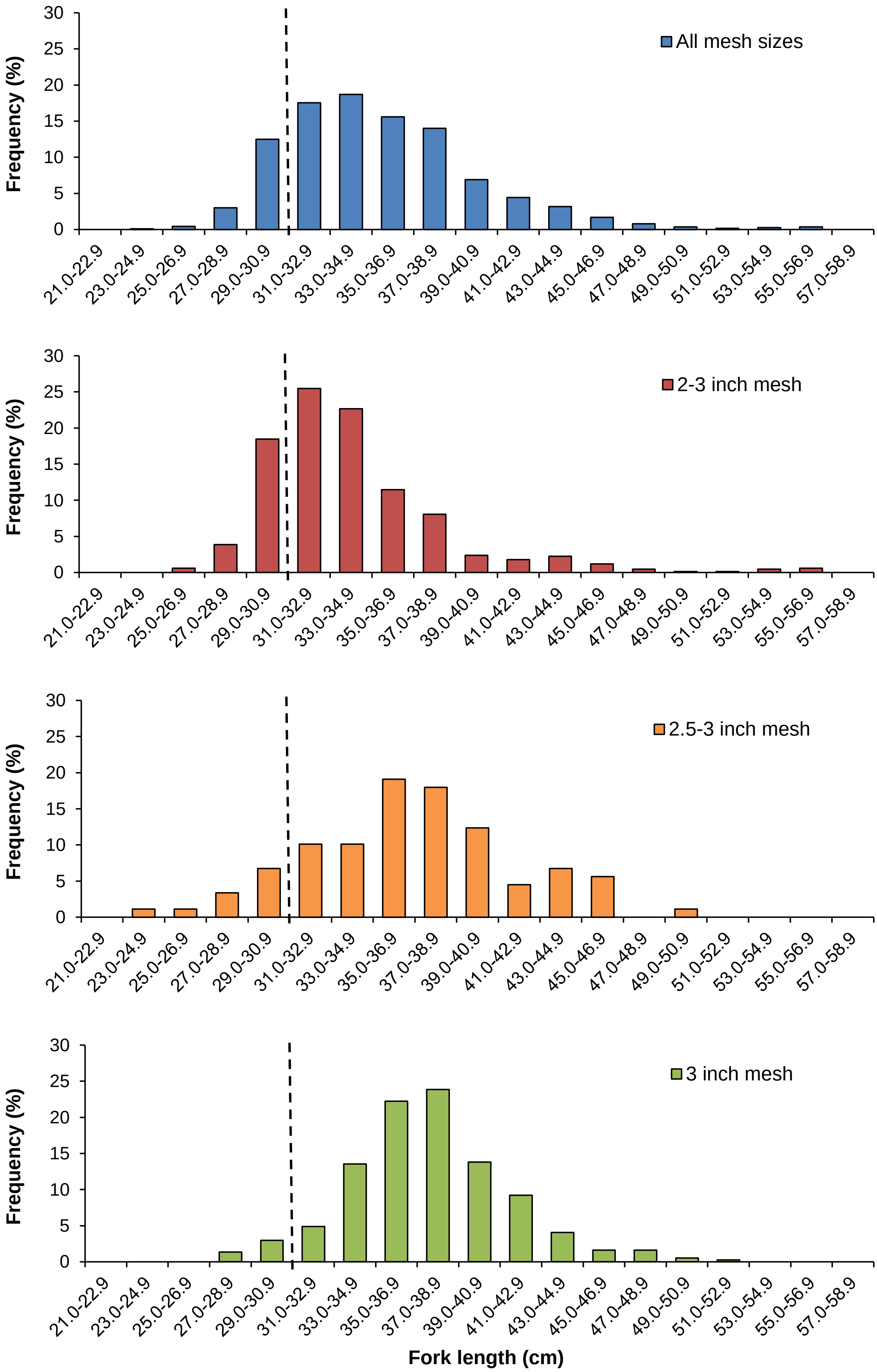


Figure 46 Length frequency distribution of bonefish, *Albula glossodonta*, by gillnet mesh sizes. The dashed line indicates estimated length at 50% maturity (SPC unpublished data).

Fisher perceptions

Fisher perceptions were collected from 8 landings[3]. All fishers that perception data were collected from were male. The majority of fishers surveyed indicated that they had seen little change in the fishery in the last few years, with 63% of all respondents claiming they considered the quantity of fish caught was the same as five years ago, and 50% of all respondents claiming sizes of fish were the same as five years ago. During the creel surveys fishers were asked their concerns. Most fishers were not particularly concerned with the state of the resources, saying that there were still plenty of fish around.

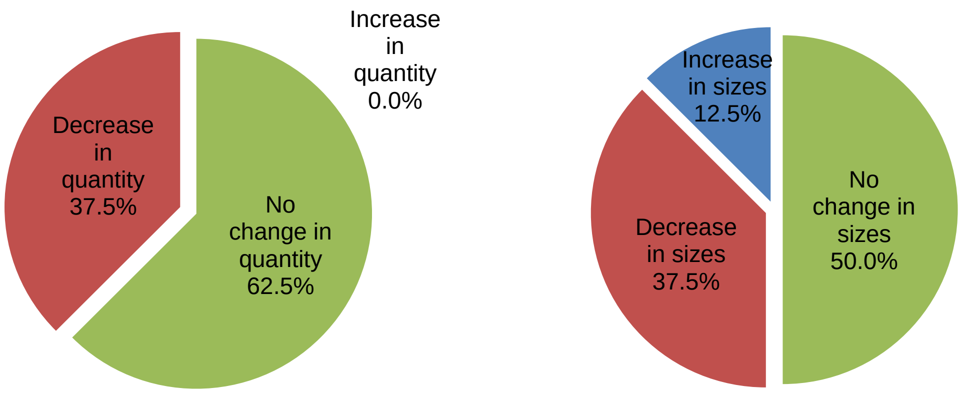


Figure 47 Responses of lead fishers to questions on perceptions on whether catch quantities (left) or fish sizes (right) have changed over the last five years.

[3] 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 Abemama focused on two harvested species: humpback red snapper (*Lutjanus gibbus*) and orangespine unicornfish (*Naso lituratus*) and three unharvested ('control') species: peacock grouper (*Cephalopholis argus*)[4], redfin butterflyfish (*Chaetodon lunulatus*) and striated surgeonfish (*Ctenochaetus striatus*), which were included to control for the effects of fishing. Fish were collected from fishers or by fisheries-independent spearfishing. 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 0.1 g unless damaged or eviscerated. Sex was determined from a macroscopic examination of the gonads. Gonads were weighed to the nearest 0.001 g. 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. argus, C. striatus, L. gibbus 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 described in Krusic-Golub and Robertson (2014). Briefly, a single otolith from each fish was 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 (400, 88, 1200 and 1500 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 five 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 *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; Shimose and

[4] While this species is harvested in many Pacific Island countries, it is not harvested at Abemama, due to concerns over ciguatera fish poisoning.

Nanami 2014). 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:

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

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 (*C. argus*), while sex-specific VBGFs were initially fitted for gonochoristic species (*C. lunulatus*, *C. striatus*, *L. gibbus* 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. While the original intention was to also examine mortality rates, samples sizes for all species were too low for these calculations.

Results

Fifty peacock grouper (*Cephalopholis argus*) were sampled by fisheries-independent spearfishing from the outer reefs of Abemama Atoll, with 47 of these aged to date. Estimated ages ranged from 4–14 years, with a modal age of 7 years (Figure 48; Table 17). Although sample sizes were insufficient to calculate mortality rates, the wide range of age classes and relatively old modal age suggests fishing mortality on this species is currently low and populations are relatively healthy. Greater sampling of this species at Abemama is required to confirm this hypothesis.

Twenty-four redfin butterflyfish (*C. lunulatus*) were sampled by fisheries-independent spearfishing from the outer reefs of Abemama, 21 of which have been aged. Estimated ages ranged from 2–8 years, with a multi-modal age of 3, 5 and 6 years (Figure 48; Table 17). Growth was similar amongst sexes, and was rapid early in life, consistent with descriptions of growth elsewhere across the species' range (Figure 49) (Berumen et al. 2012). Due to low sample sizes it was not possible to calculate mortality rates for this species. Greater sampling is required to assess the status of this species at Abemama.

Fifty-one striated surgeonfish (*C. striatus*) were sampled by fisheries-independent spearfishing from Abemama. Of these, 39 have been aged to date. Estimated ages ranged from 1-26 years, with a modal age of 10 years (Figure 48; Table 17). Growth showed little initial variation amongst sexes, although sampled males tended to be larger and older than females (Figure 49). Due to low sample sizes it was not possible to calculate mortality rates for this species. Greater sampling is required to assess the status of this species at Abemama.

Forty-one humpback red snapper (*L. gibbus*) were sampled from Abemama Atoll, 36 of which have been aged. Estimated ages ranged from 1–5 years, with a modal age of 3 years (Figure 48; Table 17). Due to the limited age range and low sample sizes it was not possible to calculate VBGF parameters or mortality rates for this species. Greater sampling is required to assess the status of this species at Abemama.

Twenty-three orangespine unicornfish (*Naso lituratus*) were sampled from Abemama Atoll, with 21 of these aged to date. Estimated ages ranged from 6–13 years, with a modal age of 8 years (Figure 48; Table 17). Again, due to the limited age range and low sample sizes it was not possible to calculate VBGF parameters or mortality rates for this species. Greater sampling is required to assess the status of this species at Abemama.

Table 17 Demographic parameter estimates for selected reef fish species from Abemama Atoll, Kiribati, Oct–Nov 2013. VBGF parameters (where calculated) are based on constrained (t_0=0) estimates.

Species	**No. collected**	**No. aged to date**	**Size range (cm)**	**Age range**	**L_∞**	**K**
Cephalopholis argus	50	47	20.9–37.0	4–14	31.44	0.29
Chaetodon lunulatus	24	21	10.5–13.0	2–8	12.24	0.94
Ctenochaetus striatus	51	39	11.0–20.8	1–26	18.45	0.55
Lutjanus gibbus	41	36	14.0–31.5	1–5	-	-
Naso lituratus	23	21	23.1–31.3	6–13	-	-

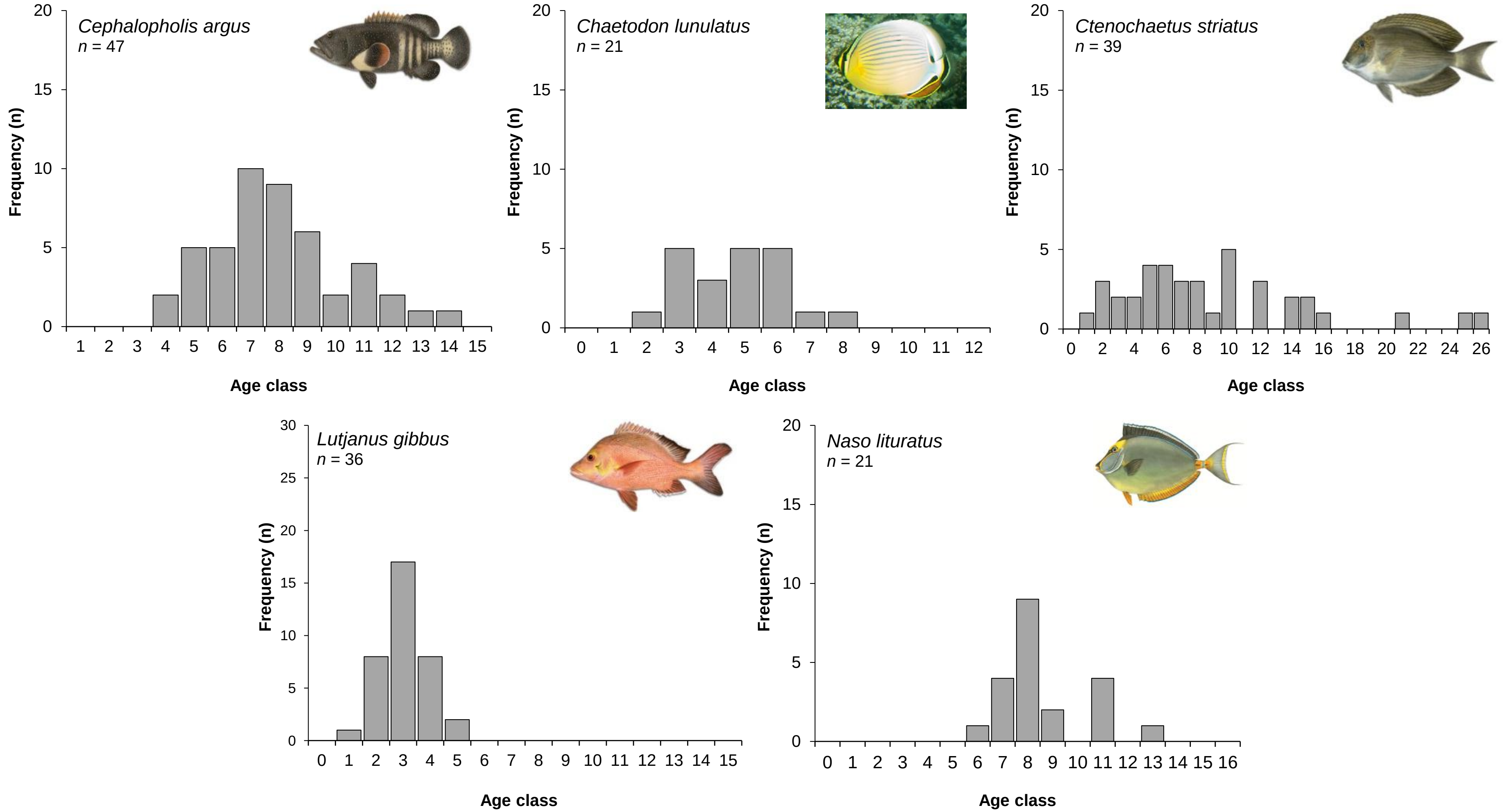


Figure 48 Age class frequencies (left) and von Bertalanffy growth function curves (right) for five monitored finfish species at Abemama Atoll, Oct–Nov 2013.

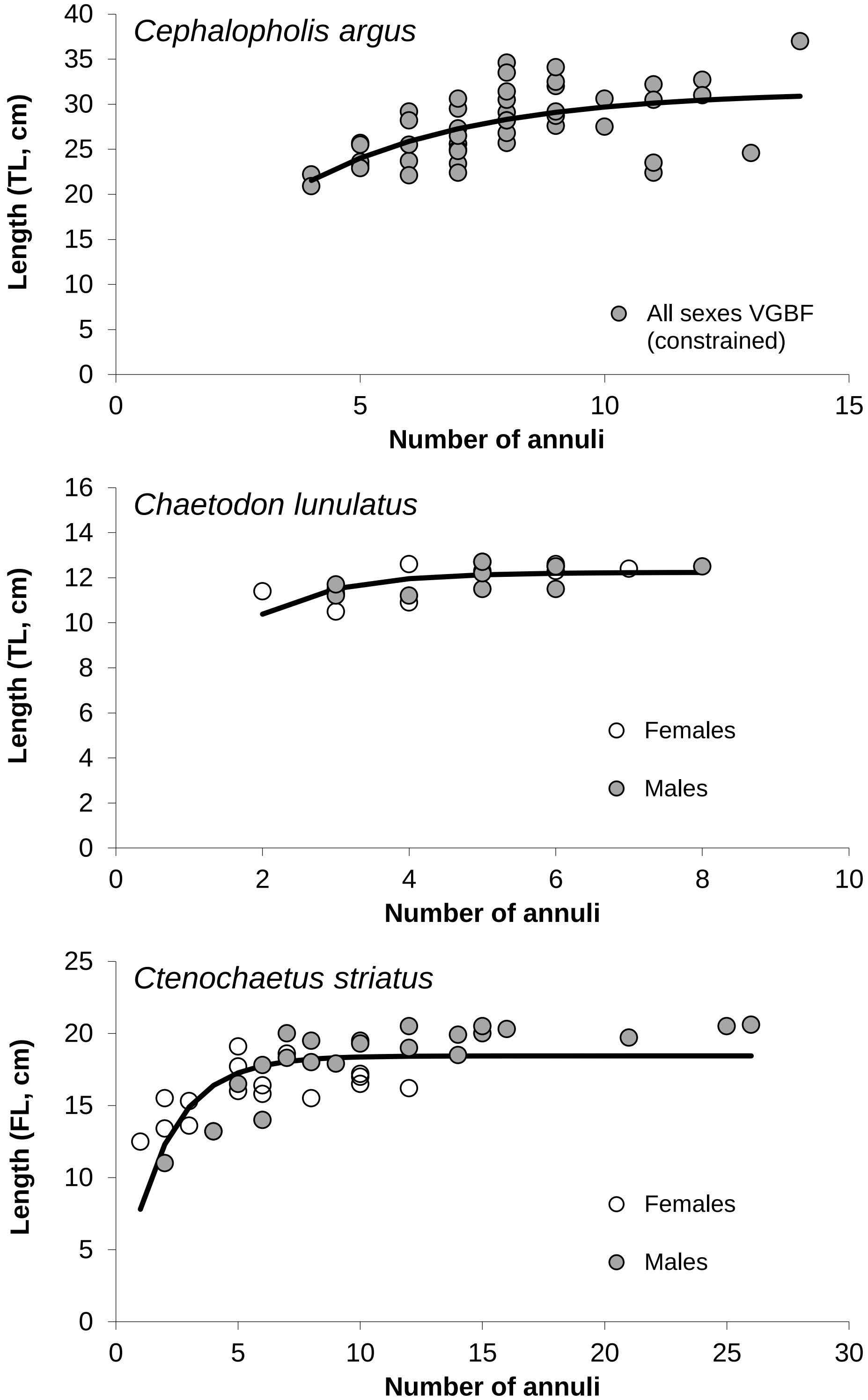


Figure 49 von Bertalanffy growth function curves for monitored finfish species at Abemama Atoll, Oct–Nov 2013.

9. Management recommendations for improving the resilience of coastal fisheries of Abemama 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 Abemama 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 Kiribati islands. This list is by no means intended to be exhaustive; rather it provides salient information on the key recommendations.

2) **Finalise and implement the Kiribati Coastal Fisheries Management Plan.** Coastal fisheries of Kiribati are at present highly unregulated, with little rules or restrictions on harvests. Given the high dependency of I-Kiribati on marine resources and the multi-species nature of coastal fisheries in Kiribati it is strongly recommended that the draft coastal fisheries management plan be finalized as a priority measure. This plan should address various fishing activities (e.g. fishing gears and practices), restrictions on species' harvests (e.g. size limits, seasonal closures during spawning season), the export of coastal resources, and community management practices.

3) **Monitor and control outbreaks of crown-of-thorns starfish (COTS).** The high density of COTS observed during the 2013 surveys indicates that an active outbreak of this species is taking place. Given the observed densities it is likely that significant coral death and damage to the reefs of Abemama will occur. The potential for *A. planci* to damage reefs should not be underestimated. For example, COTS have been identified as a major cause of the 50% decline in coral cover observed on the Great Barrier Reef, Australia, during the last 27 years (De'ath et al. 2012). Accordingly, every effort should be made to reduce the numbers of *A. planci* from the reef. Island councils and local community members should be encouraged to play an active role in removing COTS from the reef. Potentially a bounty scheme could be introduced, whereby community members are offered a small reward for every COT they remove. Once removed, COTS should be buried on land to prevent regeneration or injury to the public. Staff from the MFMRD should provide training of Island Councils and community members in the safe removal of COTS from reefs. Additionally, given reports of recent COT outbreaks in the Marshall Islands (C. Guavis, Marshall Islands Marine Resource Authority, pers. comm.) and northern islands of the Gilbert group (A. Kiareti, pers. obs.) monitoring and surveillance of COT numbers on other Kiribati islands is highly recommended.

1) **Creation of locally managed Marine Protected Areas.** Locally managed Marine Protected Areas (MPAs) can play a critical role in protecting diversity and managing marine resources. MPAs should be designed to include multiple habitats, such as outer reef areas, channels, reef flats and deeper lagoon areas. The design, monitoring and enforcement of the MPA network in Pohnpei should involve community input and take into account conservation targets, socio-

ecological and economic interests, and the home ranges of species the MPA is intended to protect (Rhodes et al. 2008; Green et al. 2013). Green et al. (2013) provide a guide to designing marine protected areas to achieve conservation objectives in tropical ecosystems. As a general rule of thumb, they recommend the following:

a. that MPAs represent 20–40% of the available area of each habitat;
b. that protected areas are established across widely separated areas, to minimise the risk that all areas will be adversely impacted by the same disturbance; and
c. that MPAs be twice the size of the minimum home range of the species they are implemented to protect. For example, most species of browsing or scraping herbivores, considered to be key for reducing overgrowth of coral by macroalgae (and thus preventing coral-algae regime shifts) have home ranges in the order of 500 m to 2 km (Green et al. 2013).

4) **Protect sharks and other iconic and ecologically-significant species.** Protection should be offered to ecologically significant species, in particular sharks, humphead wrasse, (*Cheilinus undulatus*) and bumphead parrotfish (*Bolbometopon muricatum*). Sharks are apex predators that play a key role in maintaining healthy reef ecosystems. Despite extensive time in the water, only a single shark was 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. We recommend that a permanent ban on sale of shark fin be put in place, or that a moratorium be placed on the shark-fin fishery until such time as shark-fin regulations are in place. Similarly, the humphead wrasse and bumphead parrotfish are listed as Endangered and Vulnerable, respectively, on the IUCN Red List in recognition of their slow population turnover and vulnerability to fishing, in particular nighttime spearfishing (Aswani and Hamilton 2004; Dulvy and Polunin 2004; Choat et al. 2006). To conserve these iconic species we recommend that a moratorium be placed on the commercial sale of *C. undulatus* and *B. muricatum*, ideally at the national level.

5) **Strengthen stakeholder awareness programs and exchange of information on coastal fisheries, the marine environment and climate change.** It cannot be expected that citizens of Abemama and other Kiribati islands will be able to access the outcomes of this and other studies of their reefs through normal channels. Accordingly, education and awareness programs promoting responsible reef management practices and incorporating relevant scientific information should be provided to communities. The translation of relevant material into Kiribati and distribution to communities would help inform the public. 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. The Ministry of Fisheries & Marine Resources Development should play a central role in facilitating these programs.

6) **Strengthen collaborations with National, Government, Island Councils, NGOs, fishing communities and traditional leaders.** While some management measures, such as gear restrictions, monthly sales ban and size limits, can be effectively implemented by marine

resource management agencies to reduce fishing pressure, many of the issues threatening the coastal fisheries resources and marine ecosystems of Abemama Atoll and other islands of Kiribati are best addressed by other groups or are outside the mandate of fisheries agencies. Accordingly, greater collaboration among is required to address and manage the many fishing and non-fishing related local threats to the coastal ecosystems of Kiribati. Such a cooperative approach would be more effective if steered jointly by authorities responsible for governance, resource management and key stakeholders, such as National governments, Island Councils, communities and traditional leaders.

Recommendations for Future Monitoring

To be able to assess the success of management interventions and monitor the status and trends in productivity of the region's coastal fisheries and supporting habitats in the face of climate change and other anthropogenic stressors, continual monitoring is needed. Finfish communities in particular typically show high inter-annual variation (e.g. Sweatman et al. 2008), meaning that a long time-series of data is required to detect prevailing trends. 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 incorporating staff from the Fisheries Division of the Ministry of Fisheries & Marine Resources Development and the Environment and Conservation Division of the Ministry of Environment, Lands and Agricultural Development. 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 Abemama represent a single 'snapshot' of fisher behavior, fishing patterns and catches at the time of survey. Additional creel surveys, including both at Abemama and other islands are recommended to explore spatial and temporal variations in these parameters. Creel surveys at a location could be conducted initially at least every 3–6 months and could be later scaled back should little intra-annual variation emerge.

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Appendix 1 GPS positions of finfish and benthic habitat assessment transects

Station ID	Habitat	Transect name	Latitude (N)	Longitude (E)
Abatiku 1	Back reef	Rb1	0.383517	173.820417
	Back reef	Rb2	0.384000	173.819917
	Back reef	Rb3	0.384500	173.819417
	Lagoon reef	Rl10	0.408483	173.795300
	Lagoon reef	Rl11	0.409267	173.794517
	Lagoon reef	Rl12	0.409800	173.793883
	Outer reef	Rs4	0.400267	173.758067
	Outer reef	Rs5	0.400833	173.758733
	Outer reef	Rs6	0.401417	173.759483
Abatiku 2	Back reef	Rb13	0.367817	173.832800
	Back reef	Rb14	0.368683	173.832600
	Back reef	Rb15	0.369433	173.832217
	Lagoon reef	Rl7	0.391417	173.806417
	Lagoon reef	Rl8	0.391750	173.805367
	Lagoon reef	Rl9	0.392183	173.803967
	Outer reef	Rs16	0.392500	173.754150
	Outer reef	Rs17	0.391583	173.753967
	Outer reef	Rs18	0.390033	173.754083
Bike 1	Back reef	Rb25	0.348033	173.848900
	Back reef	Rb26	0.348867	173.849283
	Back reef	Rb27	0.349783	173.849267
	Lagoon reef	Rl31	0.354117	173.856617
	Lagoon reef	Rl32	0.354467	173.855667
	Lagoon reef	Rl33	0.354583	173.854817
	Outer reef	Rs19	0.344883	173.836067
	Outer reef	Rs20	0.344000	173.836367
	Outer reef	Rs21	0.343233	173.836950
Bike 2	Back reef	Rb28	0.338117	173.862200
	Back reef	Rb29	0.338017	173.862917
	Back reef	Rb30	0.337667	173.863533
	Lagoon reef	Rl34	0.358567	173.859100
	Lagoon reef	Rl35	0.358833	173.858350
	Lagoon reef	Rl36	0.359000	173.857517
	Outer reef	Rs22	0.334367	173.844900
	Outer reef	Rs23	0.333850	173.845617
	Outer reef	Rs24	0.333267	173.846417

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 [ ]

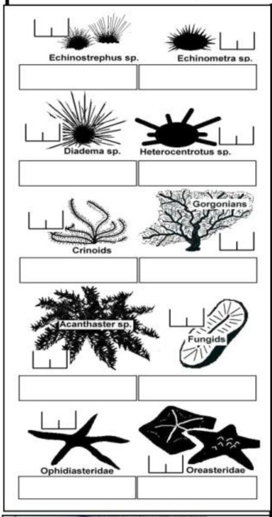
	current	oceanic influence	terrigenous influence
none	[ ]	[ ]	[ ]
medium	[ ]	[ ]	[ ]
strong	[ ]	[ ]	[ ]

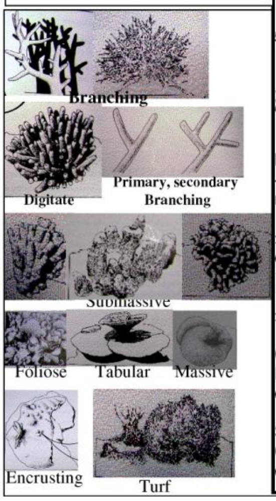
draw profile including estimate of slope in degree
Flat [ ] Floor [ ]
Gentle slope [ ] Steep slope [ ]

Remarks:

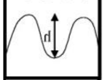
	Quadrat limits	0–10	10–20	20–30	30–40	40–50	%
	Depth of transect line (m)						
	Slope only: Depth of crest (m)						
	Slope only: Depth of floor (m)						
	Line of sight visibility (m)						
	Topography (1-5)						
	Complexity (1-5)						
1st layer	Hard substrate						100
	Soft substrate						
2nd layer	(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

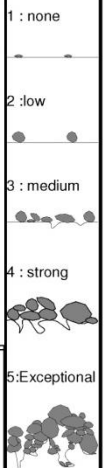




Topography



Complexity



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
Abatiku lagoon reef	Mean total density	2013 > 2011	3.6145	0.007	416
Abatiku lagoon reef	Mean density - Chaetodontidae	2013 > 2011	4.3747	0.004	231
Abatiku lagoon reef	Mean density - Pomacanthidae	2013 > 2011	3.0909	0.032	34
Abatiku lagoon reef	Mean density - Pomacentridae	2913 > 2011	2.7734	0.035	316
Abatiku lagoon reef	Mean biomass - Chaetodontidae	2013 > 2011	2.3627	0.035	405
Abatiku lagoon reef	Mean biomass - Lethrinidae	2013 > 2011	2.7197	0.031	400
Abatiku lagoon reef	Mean biomass - Pomacentridae	2013 > 2011	4.5879	0.003	409
Abatiku lagoon reef	Mean density - Corallivores	2013 > 2011	4.4610	0.003	231
Abatiku lagoon reef	Mean density - Planktivores	2013 > 2011	3.6749	0.004	419
Abatiku lagoon reef	Mean biomass - Corallivores	2013 > 2011	4.1974	0.005	408
Abatiku lagoon reef	Mean biomass - Planktivores	2013 > 2011	4.0116	0.003	416
Abatiku outer reef	Mean density - Balistidae	2013 > 2011	4.0753	0.011	307
Abatiku outer reef	Mean density - Chaetodontidae	2013 > 2011	5.0677	0.003	312
Abatiku outer reef	Mean density - Lutjanidae	2013 > 2011	1.5178	0.005	151
Abatiku outer reef	Mean density - Scaridae	2013 > 2011	8.4865	0.002	308
Abatiku outer reef	Mean biomass - Chaetodontidae	2013 > 2011	3.7482	0.010	409
Abatiku outer reef	Mean biomass - Lutjanidae	2013 > 2011	3.9637	0.002	201
Abatiku outer reef	Mean biomass - Pomacentridae	2013 > 2011	2.5680	0.031	410
Abatiku outer reef	Mean biomass - Scaridae	2013 > 2011	4.3573	0.006	404
Abatiku outer reef	Mean biomass - Zanclidae	2013 > 2011	2.6035	0.021	150
Abatiku outer reef	Mean density - Corallivores	2013 > 2011	2.4985	0.025	173
Abatiku outer reef	Mean density - Scrapers	2013 > 2011	8.4865	0.002	307
Abatiku outer reef	Mean biomass - Corallivores	2013 > 2011	2.4460	0.034	413
Abatiku outer reef	Mean biomass - Scrapers	2013 > 2011	4.3573	0.004	411
Bike back reef	Mean total density	2013 > 2011	2.7709	0.037	411
Bike back reef	Mean density - Acanthuridae	2013 > 2011	3.2841	0.026	300
Bike back reef	Mean density - Scaridae	2013 > 2011	2.8382	0.015	150
Bike back reef	Mean density - Serranidae	2013 > 2011	5.2560	0.009	111
Bike back reef	Mean biomass - Chaetodontidae	2013 > 2011	2.5978	0.032	402
Bike back reef	Mean biomass - Pomacentridae	2013 > 2011	3.8180	0.009	315
Bike back reef	Mean biomass - Serranidae	2013 > 2011	4.1814	0.006	198
Bike back reef	Mean density - Grazers	2013 > 2011	3.2336	0.013	316
Bike back reef	Mean density - Planktivores	2013 > 2011	3.9091	0.011	205
Bike back reef	Mean density - Scrapers	2013 > 2011	2.8382	0.022	148
Bike back reef	Mean biomass - Grazers	2013 > 2011	2.5857	0.033	403
Bike back reef	Mean biomass - Planktivores	2013 > 2011	7.9175	0.003	206

Bike lagoon reef	Mean density - Mullidae	2011 > 2013	3.0864	0.026	63
Bike lagoon reef	Mean density - Zanclidae	2013 > 2011	3.9465	0.007	31
Bike lagoon reef	Mean biomass - Acanthuridae	2011 > 2013	3.5368	0.020	84
Bike lagoon reef	Mean biomass - Chaetodontidae	2011 > 2013	4.4085	0.008	84
Bike lagoon reef	Mean biomass - Mullidae	2011 > 2013	3.2581	0.013	84
Bike lagoon reef	Mean biomass - Zanclidae	2013 > 2011	5.1804	0.009	63
Bike lagoon reef	Mean biomass - Grazers	2011 > 2013	2.6602	0.012	84
Bike outer reef	Mean total biomass	2013 > 2011	3.1480	0.014	409
Bike outer reef	Mean density - Scaridae	2013 > 2011	2.4609	0.011	415
Bike outer reef	Mean biomass - Lethrinidae	2013 > 2011	6.3376	0.007	118
Bike outer reef	Mean biomass - Lutjanidae	2013 > 2011	2.9496	0.005	200
Bike outer reef	Mean biomass - Pomacentridae	2013 > 2011	3.6493	0.006	398
Bike outer reef	Mean biomass - Scaridae	2013 > 2011	2.7561	0.019	415
Bike outer reef	Mean biomass - Serranidae	2013 > 2011	3.7698	0.020	404
Bike outer reef	Mean density - Scrapers	2013 > 2011	2.4609	0.007	411
Bike outer reef	Mean biomass - Macro-carnivores	2013 > 2011	2.6787	0.030	409
Bike outer reef	Mean biomass - Planktivores	2013 > 2011	4.3819	0.008	400
Bike outer reef	Mean biomass - Scrapers	2013 > 2011	2.7561	0.020	414

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
Abatiku outer	Turf	2011 > 2013	3.3242	0.024	401
Abatiku outer	Rubble	2013 > 2011	2.0691	0.045	412
Bike lagoon	Pavement	2013 > 2011	3.6949	0.036	17
Bike outer reef	Sand	2011 > 2013	2.3765	0.046	414
Bike outer	Turf	2011 > 2013	4.3288	0.012	175
Outer reef - 2013	Sand	Abatiku > Bike	3.0888	0.002	413
Outer reef - 2011	Sand	Abatiku > Bike	2.3765	0.046	408

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 Abatiku, Abemama and Bike monitoring sites

Site	Station ID	Replicate	Start Latitude (N)	Start Longitude (E)
Abatiku	Manta_5	1	0.353850	173.836783
	Manta_5	2	0.355133	173.833933
	Manta_5	3	0.357833	173.834017
	Manta_5	4	0.359983	173.834767
	Manta_5	5	0.362750	173.834517
	Manta_5	6	0.365517	173.834900
	Manta_6	1	0.368383	173.833200
	Manta_6	2	0.371333	173.832283
	Manta_6	3	0.374200	173.830950
	Manta_6	4	0.376233	173.828883
	Manta_6	5	0.378467	173.826633
	Manta_6	6	0.380283	173.824333
	Manta_7	1	0.382850	173.820900
	Manta_7	2	0.385150	173.818400
	Manta_7	3	0.386933	173.816050
	Manta_7	4	0.388517	173.813300
	Manta_7	5	0.389850	173.810683
	Manta_7	6	0.391117	173.807967
	Manta_8	1	0.393883	173.798967
	Manta_8	2	0.395700	173.796850
	Manta_8	3	0.397767	173.795233
	Manta_8	4	0.400550	173.794300
	Manta_8	5	0.403283	173.793067
	Manta_8	6	0.404933	173.790250
	Manta_15	1	0.353450	173.828650
	Manta_15	2	0.356800	173.826650
	Manta_15	3	0.359367	173.824650
	Manta_15	4	0.362033	173.822317
	Manta_15	5	0.364517	173.820167
	Manta_15	6	0.366683	173.817933
	Manta_16	1	0.367233	173.822800
	Manta_16	2	0.369250	173.820300
	Manta_16	3	0.370950	173.817650
	Manta_16	4	0.372367	173.814833
	Manta_16	5	0.373900	173.812083
	Manta_16	6	0.375167	173.809250
Abemama	Manta_1	1	0.319133	173.905167
	Manta_1	2	0.317200	173.907683
	Manta_1	3	0.316900	173.910717

Site	Station ID	Replicate	Start Latitude (N)	Start Longitude (E)
	Manta_1	4	0.316717	173.913750
	Manta_1	5	0.317650	173.916667
	Manta_1	6	0.320717	173.925200
	Manta_2	1	0.327150	173.932300
	Manta_2	2	0.343267	173.931917
	Manta_2	3	0.350700	173.933083
	Manta_2	4	0.361383	173.931400
	Manta_2	5	0.365400	173.931117
	Manta_2	6	0.368317	173.929133
	Manta_9	1	0.402383	173.912267
	Manta_9	2	0.405367	173.911300
	Manta_9	3	0.408317	173.910317
	Manta_9	4	0.411250	173.908867
	Manta_9	5	0.413833	173.907017
	Manta_9	6	0.416717	173.905983
	Manta_10	1	0.422083	173.902950
	Manta_10	2	0.424933	173.901050
	Manta_10	3	0.427767	173.898867
	Manta_10	4	0.429933	173.895983
	Manta_10	5	0.431750	173.893217
	Manta_10	6	0.433483	173.890600
	Manta_11	1	0.442583	173.881217
	Manta_11	2	0.445183	173.879500
	Manta_11	3	0.447867	173.877467
	Manta_11	4	0.449700	173.875050
	Manta_11	5	0.451750	173.872667
	Manta_11	6	0.453983	173.870533
	Manta_12	1	0.370433	173.927933
	Manta_12	2	0.373217	173.925950
	Manta_12	3	0.375933	173.924133
	Manta_12	4	0.378633	173.922750
	Manta_12	5	0.381550	173.921583
	Manta_12	6	0.384367	173.920467
	Manta_3	1	0.334100	173.855983
	Manta_3	2	0.332533	173.858283
	Manta_3	3	0.329967	173.860250
	Manta_3	4	0.328867	173.863350
	Manta_3	5	0.327483	173.866333
	Manta_3	6	0.326667	173.869183
	Manta_14	1	0.348133	173.838083
	Manta_14	2	0.348633	173.840750
	Manta_14	3	0.348600	173.843600

Site	Station ID	Replicate	Start Latitude (N)	Start Longitude (E)
	Manta_14	4	0.351450	173.844083
	Manta_14	5	0.351233	173.846850
	Manta_14	6	0.350833	173.849000
	Manta_13	1	0.334167	173.845700
	Manta_13	2	0.336333	173.843283
	Manta_13	3	0.338567	173.841417
	Manta_13	4	0.341183	173.839500
	Manta_13	5	0.343733	173.837633
	Manta_13	6	0.345950	173.836200
	Manta_17	1	0.347733	173.849783
	Manta_17	2	0.345900	173.851933
	Manta_17	3	0.343700	173.854067
	Manta_17	4	0.341633	173.856450
	Manta_17	5	0.340233	173.859150
	Manta_17	6	0.339083	173.861917

Appendix 8 GPS positions of reef benthos transects conducted at Abatiku and Bike monitoring sites

Site	**Station ID**	**Latitude (N)**	**Longitude (E)**
Abatiku	RBt_6	0.362283	173.833850
	RBt_7	0.379233	173.819850
	RBt_8	0.389217	173.805000
	RBt_9	0.388933	173.810200
	RBt_10	0.402883	173.793183
Bike	RBt_1	0.312133	173.899467
	RBt_2	0.316533	173.891367
	RBt_3	0.324433	173.876350
	RBt_4	0.335183	173.851633
	RBt_5	0.338050	173.847850

Appendix 9 GPS positions of soft infaunal quadrat stations conducted at the Abemama monitoring site

Site	**Station ID**	**Latitude (N)**	**Longitude (E)**
Abemama	SiQ_1	0.395100	173.920367
	SiQ_2	0.394100	173.920617
	SiQ_3	0.397817	173.918567
	SiQ_4	0.353550	173.933500
	SiQ_5	0.352100	173.932167
	SiQ_6	0.354083	173.930900
	SiQ_7	0.429700	173.900283
	SiQ_8	0.429483	173.899033
	SiQ_9	0.429900	173.899033
	SiQ_10	0.482717	173.844283
	SiQ_11	0.482717	173.844283
	SiQ_12	0.483133	173.843483

Appendix 10 Form used during creel surveys at Abemama Atoll

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 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)			
Number of fishers:			
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 fishing today?	hrs

Fishing method / gears used for each species group (separate pelagic fish, reef fish, crabs, lobsters etc) and how much they cost the fisher to buy

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

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

Site	**Location** (on map, lat/long, or distance to each fishing ground) and **reef type (back, lagoon patch, outer etc)**
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?	