Climate Change Baseline Assessment

Abemama Atoll
Kiribati

September-November 2011

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ACRONYMS

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

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EXECUTIVE SUMMARY

Introduction

Considering the concerns of climate change and its impacts on coastal fisheries resources, SPC is implementing the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project with funding assistance from the 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 are due to climate change, as opposed to other causative factors. This report presents the results of baseline field surveys for the project conducted in Abemama Atoll, Kiribati, between September and November 2011.

Survey Design

Survey work at Abemama covered four disciplines (water temperature monitoring, benthic habitat assessments and assessments of finfish and invertebrate resources), and was conducted by a team from SPC's Coastal Fisheries Science and Management Section and staff from Kiribati Marine Resources Division (KMRD). The fieldwork included capacity building of the local counterparts by providing training in survey design and methodologies, data collection and entry, and data analysis.

Two survey sites were established in the south-west of Abemama Atoll: one at Abatiku Island and one at Bike Island. The Abatiku site was considered as an 'impacted' site as it has a large surrounding population and high levels of fishing pressure. The Bike site was considered a 'control' site, as it has no residing population and low levels of fishing, allowing for decoupling of the effects of over-fishing against other factors (i.e. climate change). The data collected provides a quantitative baseline that will be analysed after future monitoring events to examine changes in coastal habitat and fishery resources over time.

Water Temperature

Water temperature loggers were deployed at two sites within Abemama in September 2011, with one logger deployed on the outer reef and one in the lagoon of Abatiku Island. Results will be made available following collection and re-deployment of the temperature loggers.

Benthic Habitat Assessments

Benthic habitats of the Abatiku and Bike sites were assessed via using photoquadrat methodologies. Twenty-six 50 m benthic habitat assessment transects were established across the back-, lagoon- and outer-reef habitats of the Abatiku and Bike stations, with 12 transects completed at the Abatiku site and 14 transects completed at the Bike site. Up to 50 photographs of the benthos were taken per transect (with one photo taken approximately every metre) using a housed underwater camera and a quadrat frame measuring an area of 0.25 m^2. Photographs were analysed using SPC software. In general, the back- and lagoon-reefs habitats of Bike and lagoon-reef habitats of Abatiku were characterised by a high cover of sand (> 50%) and moderate (> 20%) cover of rubble. Although hard coral diversity was relatively high, overall hard coral cover was relatively low (< 10%). *Porites-massive* and *Acropora* were the most common coral types within the back- and lagoon-reef habitats of both Abatiku and Bike stations. Outer reef habitats of both Abatiku and Bike stations were largely characterised by a high percent cover of crustose coralline algae and hard coral, and a low percent cover of sand. *Halimeda* spp. was the most common macroalgae genus observed in all back-, lagoon- and outer reefs of both Abatiku and Bike monitoring stations.

Finfish Surveys

Finfish resources and their supporting habitats of Abatiku and Bike were surveyed using distance-sampling underwater visual census (D-UVC) methodology. Twenty-six 50 m D-UVC monitoring transects were completed across the back-, lagoon- and outer-reef habitats of the Abemama region, with 12 transects completed at the Abatiku site and 14 at the Bike site. Habitat supporting finfish at both Abatiku and Bike sites were largely similar to those recorded during the benthic habitat assessments, with back-reef habitats consisting of high cover of sand, lagoon-reefs consisting of a high cover of sand, live and dead corals and outer-reefs typically consisting of a high cover of live and dead corals.

A total of 23 families, 76 genera, 181 species and 30,485 individual fish were recorded from the 26 transects. Of these, 19 families, 61 genera, 117 species and 14,079 individual fish were recorded from the Abatiku monitoring stations, while 20 families, 64 genera, 138 species and 16,406 individual fish were recorded from the Bike monitoring stations. Within the Abatiku stations, overall mean density appeared greater within the outer-reef habitats compared to the lagoon-reefs. Within the Bike stations, overall mean density appeared greater within the lagoon- and outer-reef habitats compared to the back-reef habitats, while no difference was observed between the lagoon- and outer-reef habitats. The overall mean density and mean biomass of lagoon-reef finfish of Bike stations appeared to be slightly higher compared to those within the Abatiku stations. No difference was observed among sites in the mean density and mean biomass of finfish among back- and outer-reef habitats.

Of concern, the mean densities and biomass of several finfish families were found to be significantly lower than those observed during the PROCFish surveys conducted at Abemama Atoll by SPC in 2004. It should be noted that these surveys were not conducted at exactly the same locations, thus these results may be at least partially influenced by spatial differences in habitat cover or depth among survey locations. Further monitoring of the locations surveyed in this baseline assessment is required to determine whether these differences are consistent over time.

Invertebrate Surveys

Invertebrate resources and their supporting habitats were surveyed using three complementary approaches. Manta tows were used to assess invertebrate populations at broad spatial scales, while reef benthos transects and soft infaunal quadrat surveys were used to assess invertebrate resources associated at finer-spatial scales. A total of 12 manta tow stations (6 x 300 m replicates) were established during the baseline assessment, with seven manta tow stations established at the Abatiku site and five manta tow stations established at Bike. A total of ten species were observed during the manta tow surveys, with six species recorded within the Abatiku stations and seven species recorded within the Bike stations. Individual species observed in the highest mean densities during the manta tow surveys at the Abatiku site included the giant clam *Tridacna maxima* (483.73±304.77 individuals/ha), the gastropod *Conomurex luhuanus* (203.57±101.56 individuals/ha) and the bivalve *Anadara uropigimelana* (96.03±82.58 individuals/ha). The individual species observed in the highest densities at Bike were the sea cucumber *Holothuria atra* (255.56±117.55 individuals/ha) and the bivalve *A. uropigimelana* (111.11±111.11 individuals/ha) Mean densities of *T. maxima* and *C. luhuanus* were higher at the Abatiku stations than those at Bike, while the mean densities of *H. atra* and the urchin *Echinothrix diadema* were significantly higher at Bike than Abatiku. Mean densities of the sea cucumber *Holothuria atra*, the bivalves *Spondylus* sp. and *Spondylus squamosus*, and the gastropod *Conomurex luhuanus* were significantly higher during the PROCFish surveys of 2004 than the current survey. While these surveys were conducted in the same general habitats, they were not conducted at the same locations, and as such these results may be at least partially influenced by spatial differences among locations. Further monitoring of the stations established during this baseline event is required to determine whether these differences are consistent over time.

To monitor the status of reef-associated invertebrate resources at finer-spatial scales, reef-benthos transects (RBT) were used. A total of 10 RBT stations (6 x 40 m replicates) were established within the two monitoring sites: with five stations established at each of the Abatiku and Bike sites. A total of 15 species were observed during the RBT surveys at Abatiku, while nine species were observed during the RBT surveys at Bike. Within the Abatiku stations, *Dendropoma maximum* had the highest density, with 13208.33±6277.88 individuals/ha, followed by *Conomurex luhuanus* (2241.67±2231.26 individuals/ha), and *Tridacna maxima* (2441.67±1040.80 individuals/ha). At Bike, the individual species with the highest mean densities were the bivalve *Tridacna maxima* (791.67±296.68

individuals/ha) and the gastropods *Dendropoma maximum* (258.33±153.88 individuals/ha) and *Monetaria annulus* (166.67±166.67 individuals/ha). Mean densities of *D. maximum* were significantly higher at Bike stations than those at Abatiku. Mean densities of the giant clam *Tridacna maxima* observed during RBT were significantly lower during the current survey than the PROCFish (2004) surveys, while mean densities of the gastropods *Dendropoma maximum* and *Conomurex luhuanus*, and the urchin *Diadema savignyi*, were significantly greater in the current survey than the PROCFish survey. Again, it should be noted that while these surveys were conducted in the same general habitats, they were not conducted at the same locations, and as such these results may be at least partially influenced by spatial differences among locations. Further monitoring of the stations established during this baseline event is required to determine whether these differences are consistent over time.

Soft-infaunal quadrats (SIQ) were used to monitoring the status of invertebrate resources associated with soft sediment habitats. A total of 12 SIQ stations were established, with six stations established in each of the Abatiku and Bike sites. Six invertebrate species were observed during the SIQ surveys at Abatiku, while 13 species were observed during the SIQ surveys at Bike. Within the Abatiku stations, the bivalve *Anadara uropigimelana* had the highest mean density, with 60,000.00±6324.55 individuals/ha, followed by *Gafrarium pectinatum* (57,500.00±39,322.38 individuals/ha) and *Holothuria atra* (16,666.67±9632.12 individuals/ha). The individual species observed in the highest mean densities at Bike included the sea cucumber *Holothuria atra* (247,500±156,598 individuals/ha), the bivalve *Anadara uropigimelana* (85,833±69,599 individuals/ha) and the gastropod *Conomurex luhuanus* (15,000±15,000 individuals/ha). No significant differences in mean density were observed among the sites. Similarly, no significant differences in mean density were observed for any invertebrate species during the SIQ assessments of the PROCFish (2004) and current (2011) surveys.

Recommendations for Future Monitoring

The following recommendations are proposed for future monitoring events:

- Due to logistical difficulties at the time of survey, no back-reef transects were completed at the Abatiku monitoring site. As a priority, these transects should be established during follow-up surveys.
- The differences observed in densities and biomass of several finfish families and invertebrates common to the current study and the PROCFish survey is of considerable concern, as it indicates a significant reduction in coastal resources over a short-term period. Further monitoring of the locations surveyed in this baseline assessment is required to determine whether these differences are consistent over time.

- For this baseline study, manta tow surveys were conducted on back- and lagoon-reef habitats only. As various reef habitats, and the organisms they support, differ greatly in their vulnerability to climate change, it is recommended that manta tow monitoring stations be established on the outer reef of both Abatiku and Bike sites.
- During the baseline assessment, 10 RBT stations were established; with five RBT stations established at each site. To increase the power of these surveys to detect differences over time, it is recommended that additional reef benthos transects be established on both sites.

1. Introduction

Project Background

Considering the concerns of climate change and its impacts on coastal fisheries resources, SPC is implementing the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project with funding assistance from 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 are due to climate change as opposed to other causative factors.

The purpose of this project is to assist PICTs to:

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

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

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

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

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

The Approach

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

Five pilot sites were selected for monitoring: Federated States of Micronesia (Pohnpei), Kiribati (Abemama Atoll), Marshall Islands (Majuro Atoll), Papua New Guinea (Manus Province) and Tuvalu (Funafuti Atoll). Their selection was based on existing available data such as fish, invertebrate and socio-economic 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), as well as their geographical location.

This report presents the results of baseline field surveys for the project conducted in Abemama, Kiribati, between September and November 2011, by a team from SPC's Coastal Fisheries Science and Management Section and staff from Kiribati Fisheries Department. Recommendations for future monitoring events are also provided.

Kiribati

Background

Kiribati is located in the Central Pacific Ocean near the equator, stretching from 6^{o}N – 12^{o}S and 168^{o}E – 152^{o}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.

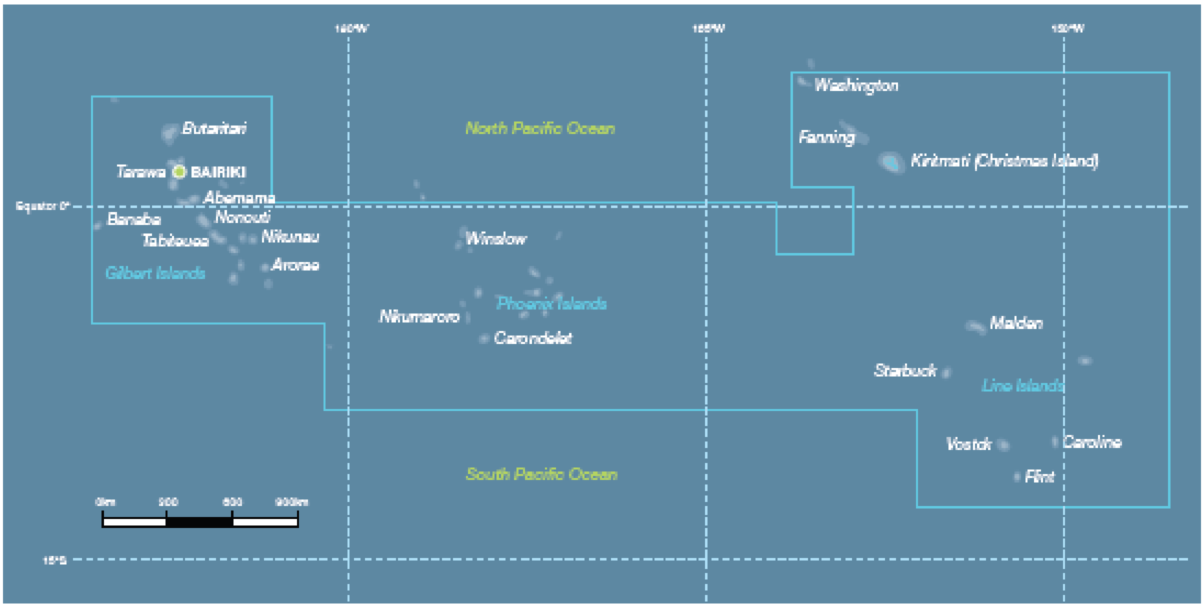

Figure 1: Kiribati (from PCCSP 2011).

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 1 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 are comprised of four 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 2 Estimated catch and value of coastal fisheries sectors in RMI, 2007 (Bell et al. 2011)

Coastal fishery category	Quantity (tonnes)	Contribution of catch (%)
Demersal finfish	15,075	73
Nearshore pelagic finfish	4250	20
Targeted invertebrates	60	< 1
Inter/subtidal invertebrates	1315	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).

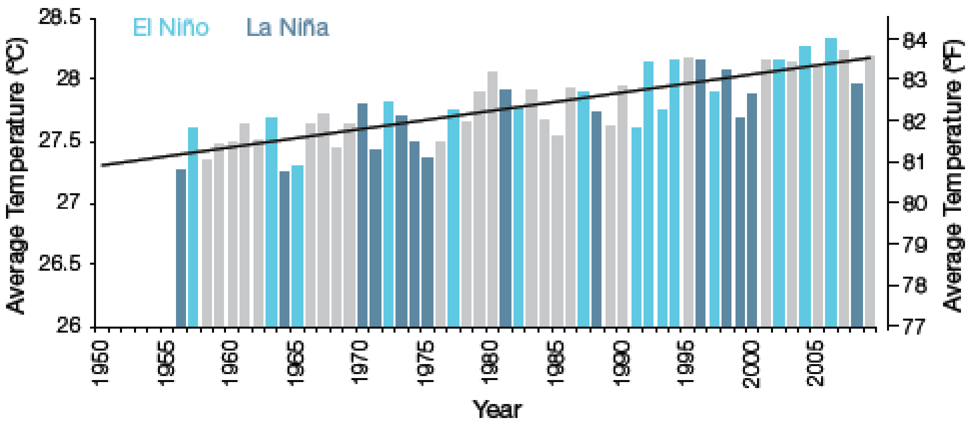

Figure 2 Mean annual air temperature at Tarawa (1956-2009) (from PCCSP 2011).

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 3).

Table 3 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^{o}C (relative to 1990 values) projected for 2030 for the Gilbert and Phoenix Islands; and +0.7, +0.8, and +0.7^{o}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 4).

Table 4 Projected sea-surface temperatures increases (in ^{o}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 CO_2 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 5). 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 6) (Bell et al. 2011). In contrast, fisheries for nearshore pelagic fish are projected to increase in productivity due to the redistribution of tuna to the east (Table 6) (Bell et al. 2011).

Table 5 Projected changes in coastal fish habitat in 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 6 Projected changes to coastal fisheries production in RMI 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 Marine Resource Division (KMRD). 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 Abiang Atolls (Donner et al. 2010), there is currently no ongoing monitoring of the corals reefs of Abemema. 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 islets is surrounded a deep lagoon. The eastern part of the atoll of Abemama is linked together 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).

For the purposes of the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project, monitoring sites were established in the waters surrounding Abatiku and Bike Islands in the southwest of Abemama Atoll (Figure 3). Abatiku Island was considered as an 'impacted' site as it has a large surrounding population, and relatively high levels of fishing pressure, while the Bike site has a no residing population, and low levels of fishing, effectively making it a 'control' site allowing for decoupling of the effects of over-fishing against other factors (i.e. climate change).

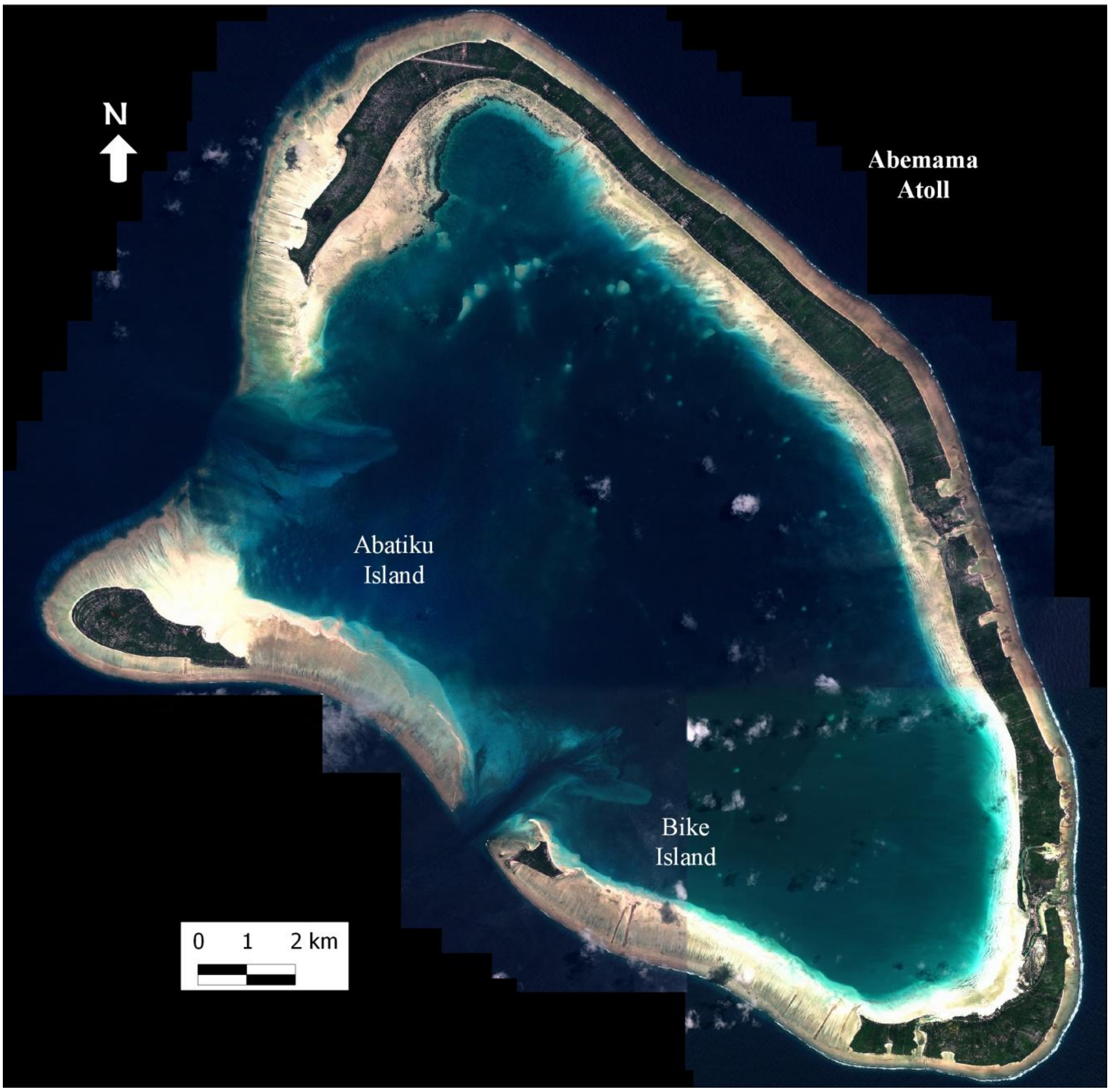

Figure 3 **Abemama Atoll indicating the Abatiku and Bike study regions.**

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-fish 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, 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). Finfish fishing in Abemama is performed mainly by males (Awira et al. 2008). Catch composition generally varies with the habitat fished, but catches are typically dominated by the families of Mugillidae, Carangidae, Lutjanidae, Lethrinidae and Acanthuridae (Awira et al. 2008).

By comparison, consumption of invertebrates was found to be 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).

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.

A Comparative Approach Only

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

3. Monitoring of Water Temperature

Methodologies

To monitor the water temperature in coastal areas SPC obtained type RBR TR-1060 temperature loggers. In October 2011, two temperature loggers were deployed in Abemama: one on the outer reef and one on the back reef of Abatiku Island (Figure 4). 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. Data retrieval and battery replacement is planned after a period ranging from six months (initial trial) to two years. The data will be stored on SPC servers and made available to networks of researchers, governmental services and conservation NGOs.

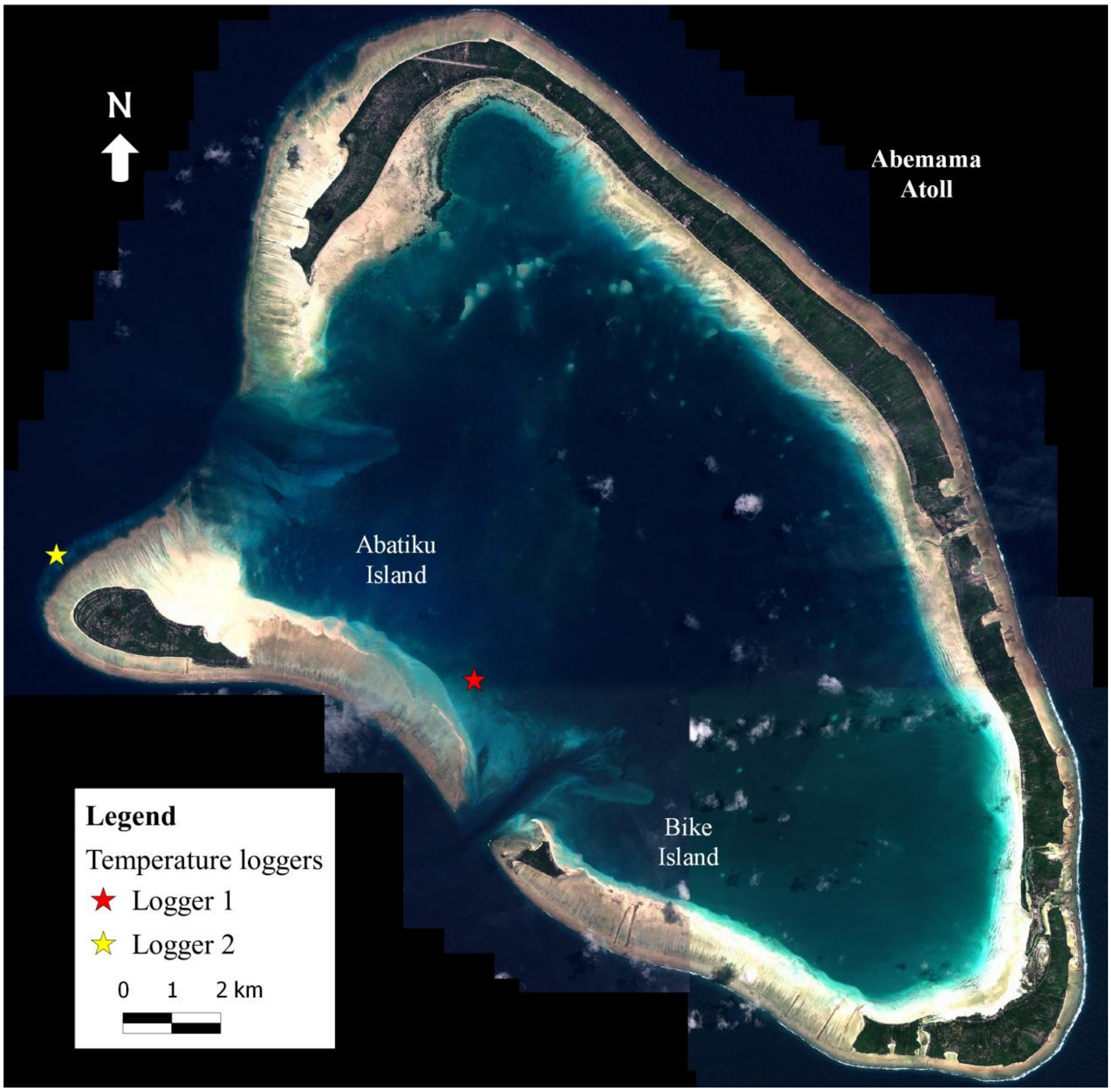

Figure 4 Location of the two water temperature loggers deployed at Abemama Atoll.

Table 7 Details of temperature loggers deployed at Abemama Atoll.

Details	Logger 1	Logger 2
Deployment date	15/10/2011	21/10/2011
Location	Lagoon	Outer reef
Habitat	Lagoon reef	Outer reef
Longitude (E)	173.83463	173.75792
Latitude (N)	0.37638	0.39956
Depth	10 m	10 m

Results

Results will be made available following collection and re-deployment of the temperature loggers.

4. Benthic Habitat Assessment

Methodologies

Data collection

For the assessments of benthic habitat and finfish resources, two survey stations were established at each of the Abatiku and Bike sites. Within each station, benthic habitat assessments were focused on three habitats: back-reefs, lagoon-reefs and outer-reefs (Figure 5), with a target of three replicate 50 m transects planned in each habitat for each station. To assess benthic habitats, up to 50 photographs of the benthos were taken per transect (with one photo taken approximately every metre) using a housed underwater camera and a quadrat frame measuring an area of 0.25 m^2. Photos were taken approximately 1 m above the benthos. Transects were laid parallel to the reef. A GPS position was recorded at the beginning of each replicate transect. In general, the same transects were used for both the benthic habitat and finfish assessments.

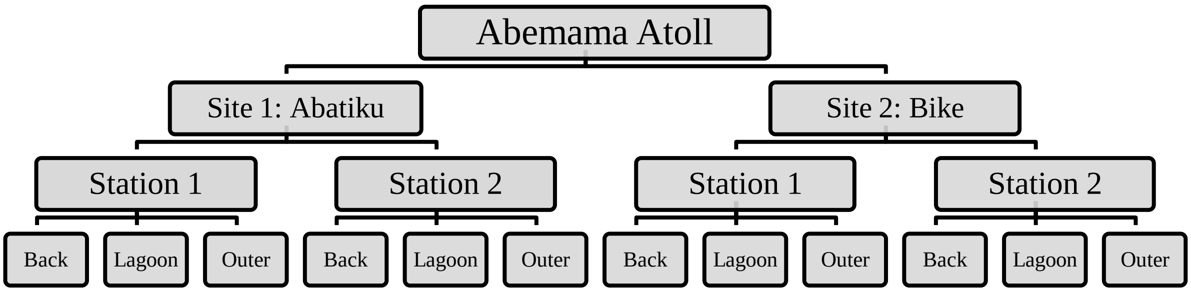

Figure 5 Survey design of the benthic habitat and finfish assessments in Abemama Atoll, Kiribati. Three replicate 50m transects were planned in each back-, lagoon- or outer-reef habitat.

Data processing and analysis

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

1. Hard coral – sum of the different types of hard coral, identified to genus level[1];
2. Other invertebrates – sum of invertebrate types including *Anemones*, *Ascidians*, *Cup sponge*, *Discosoma*, *Dysidea sponge*, *Gorgonians*, *Olive sponge*, *Terpios sponge*, *Other sponges*, *Soft coral*, *Zoanthids*, and *Other invertebrates* (other invertebrates not included in this list);

[1] Corals of the genus *Porites* were further divided into *Porites* (branching and encrusting forms), *Porites-rus* and *Porites*-massive categories.

3. Macroalgae – sum of different types of macroalgae *Asparagopsis*, *Blue-green algae*, *Boodlea*, *Bryopsis*, *Chlorodesmis*, *Caulerpa*, *Dicotyota*, *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;
6. Fleshy coralline algae;
7. Turf algae;
8. Seagrass – sum of seagrass genera *Enhalus*, *Halodule*, *Halophila*, *Syringodium*, *Thalassia*, *Thalassodendron*;
9. Chrysophyte;
10. Sand – 0.1 mm < hard particles < 30 mm;
11. Rubble – carbonated structures of heterogeneous sizes, broken and removed from their original locations; and
12. Pavement.

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

Results

Survey coverage

A total of 26 benthic habitat assessment transects were completed across the back-, lagoon- and outer-reef habitats of Abemama Atoll, with 12 transects completed at the Abatiku site and 14 transects completed at the Bike site (Figure 6;Table 8). Due to logistical issues, no back-reef transects could be completed at the Abatiku site. A list of GPS positions for each benthic habitat assessment transect is presented as Appendix 1.

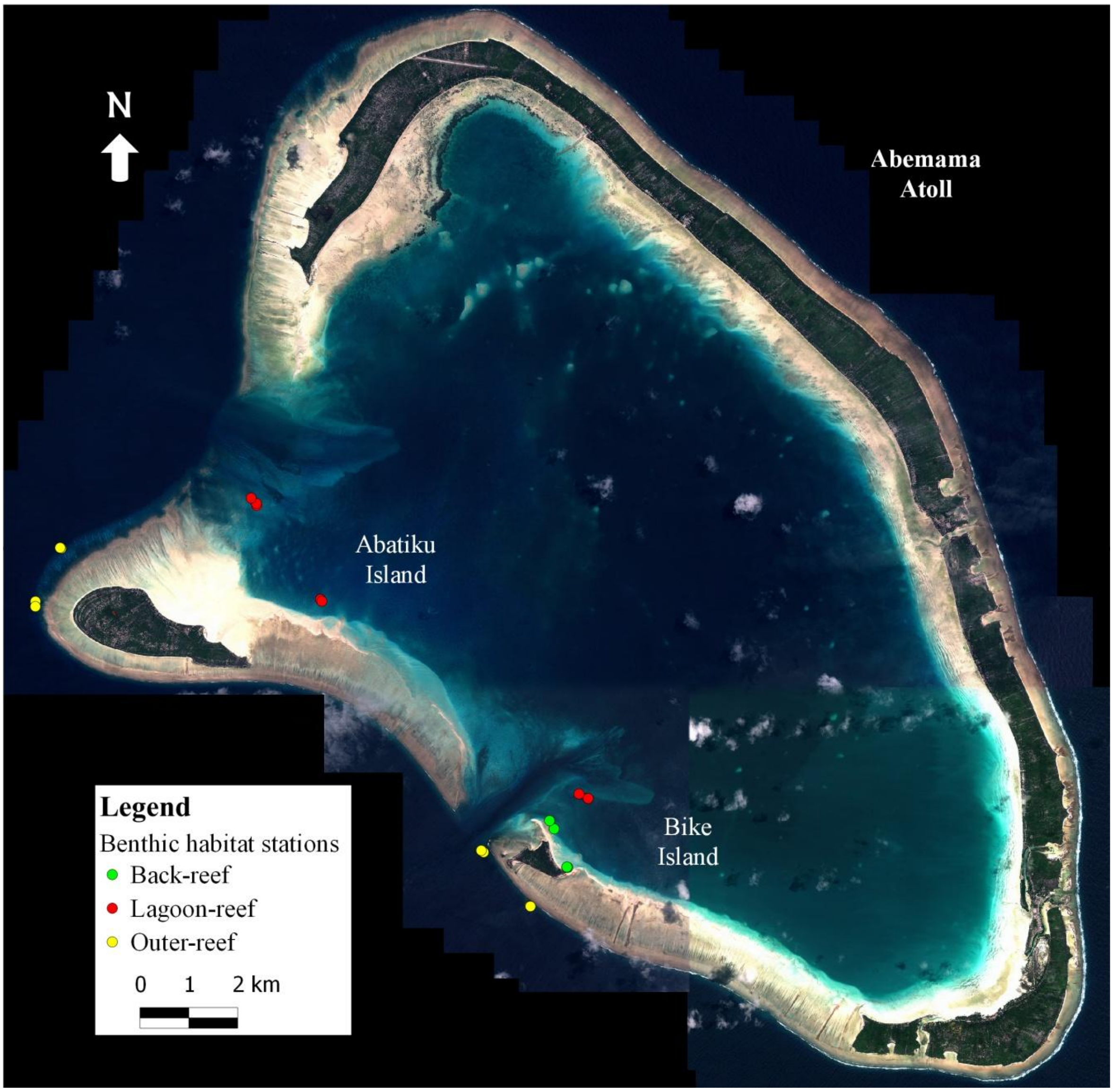

Figure 6 Location of benthic habitat assessment stations established at Abemama Atoll, 2011.

Table 8 Summary of benthic habitat assessment transects within the Abatiku and Bike monitoring sites, 2011

Site	Station	Habitat	No. of transects
Abatiku	Abatiku 1	Back-reef	0
		Lagoon-reef	3
		Outer-reef	3
	Abatiku 2	Back-reef	0
		Lagoon-reef	3
		Outer-reef	3
Bike	Bike 1	Back-reef	3
		Lagoon-reef	1
		Outer-reef	3
	Bike 2	Back-reef	3
		Lagoon-reef	1
		Outer-reef	3

Back-reef habitats

Back-reef habitats were only surveyed at the Bike site. The back-reefs of Bike were typically characterised by a high cover of sand and rubble, which constituted 57.3±6.55% and 24.2±4.8% of overall cover, respectively (Figure 8). While overall hard coral cover was relatively low (6.7±3.7%), hard coral diversity was comparatively high, with 13 types of hard coral observed (Figure 8). In terms of cover, *Porites*-massive and *Acropora* were the most common coral types within the back-reef habitats of the Bike site, representing 2.8±1.2 and 1.4±0.7% of overall cover, respectively (Figure 8). No bleached or recently dead corals were observed on the back-reefs habitats of Bike. Macroalgae abundance was similarly low (0.7±0.3% of overall cover). *Halimeda* was the most common macroalgae, representing 0.4±0.3% of overall cover.

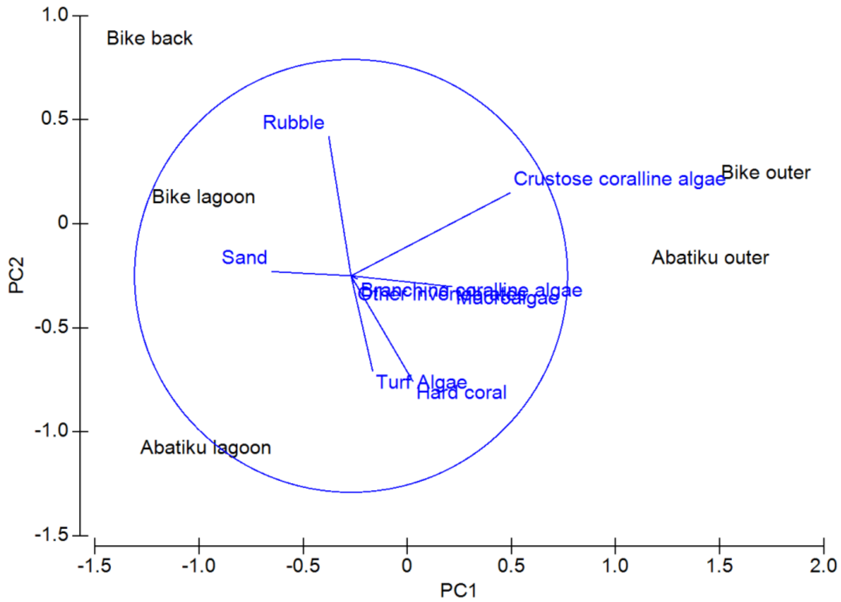

Figure 7 **Principle Component Analysis (PCA) of each major benthic substrate category for each site and habitat. Sites separate along a gradient of crustose coralline algae versus sand (PC1) and rubble versus hard coral (PC2).**

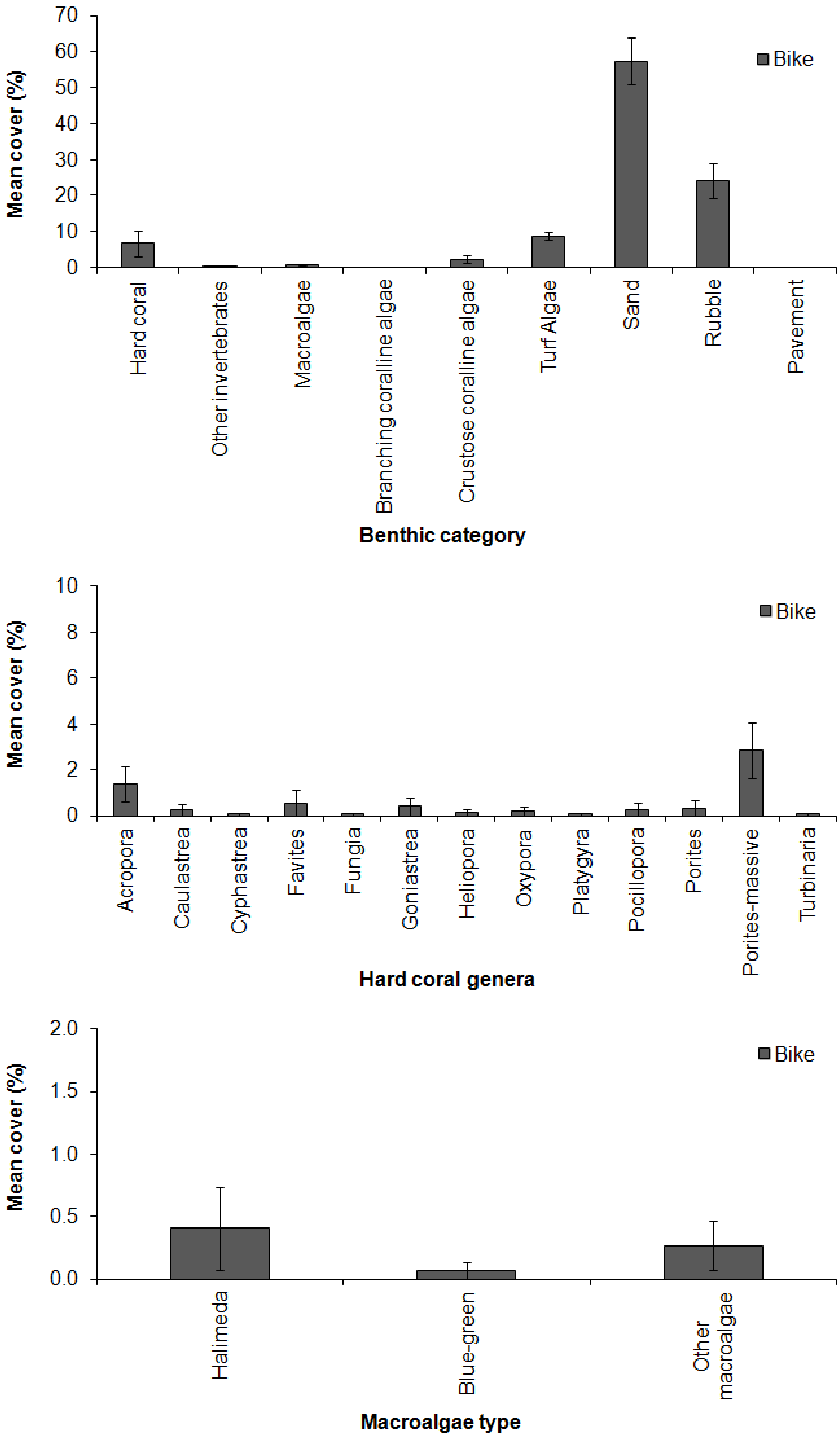

Figure 8 **Mean cover (± SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at back-reef habitats during benthic habitat assessments at the Bike monitoring stations, 2011.**

Lagoon-reef habitats

Lagoon-reef habitats of both the Abatiku and Bike monitoring stations were typically characterised by a high cover of sand, turf algae and rubble, and relatively low cover of hard coral (Figure 7; Figure 9). No significant differences were observed in mean percent cover of any major benthic category among lagoon-reef habitats of the Abatiku and Bike sites (Figure 9). The cover of macroalgae was low (< 2%) at both sites, with *Halimeda* the only macroalgae genera recorded at either site (Figure 9).

Hard coral diversity was slightly higher within the lagoon-reef habitats of the Abatiku site, where a total of 10 types of hard coral were recorded, compared to 8 types observed within the lagoon-reefs of the Bike site (Figure 9). The cover of hard corals was low at both sites, with hard corals constituting 22.1±4.4 and 10.8±7.9% of overall cover at Abatiku and Bike, respectively. *Acropora* and *Porites*-massive were the most common hard coral types within the lagoon-reefs of the Abatiku site, representing 9.3±4.7% and 7.6±3.6% of overall cover, respectively (Figure 9). *Favites* and *Goniastrea* were the dominant coral genera observed at the Bike site, representing 4.3±4.3% and 1.8±1.8% of overall cover, respectively (Figure 9). No bleached or recently dead corals were observed within the lagoon-reef habitats of either site.

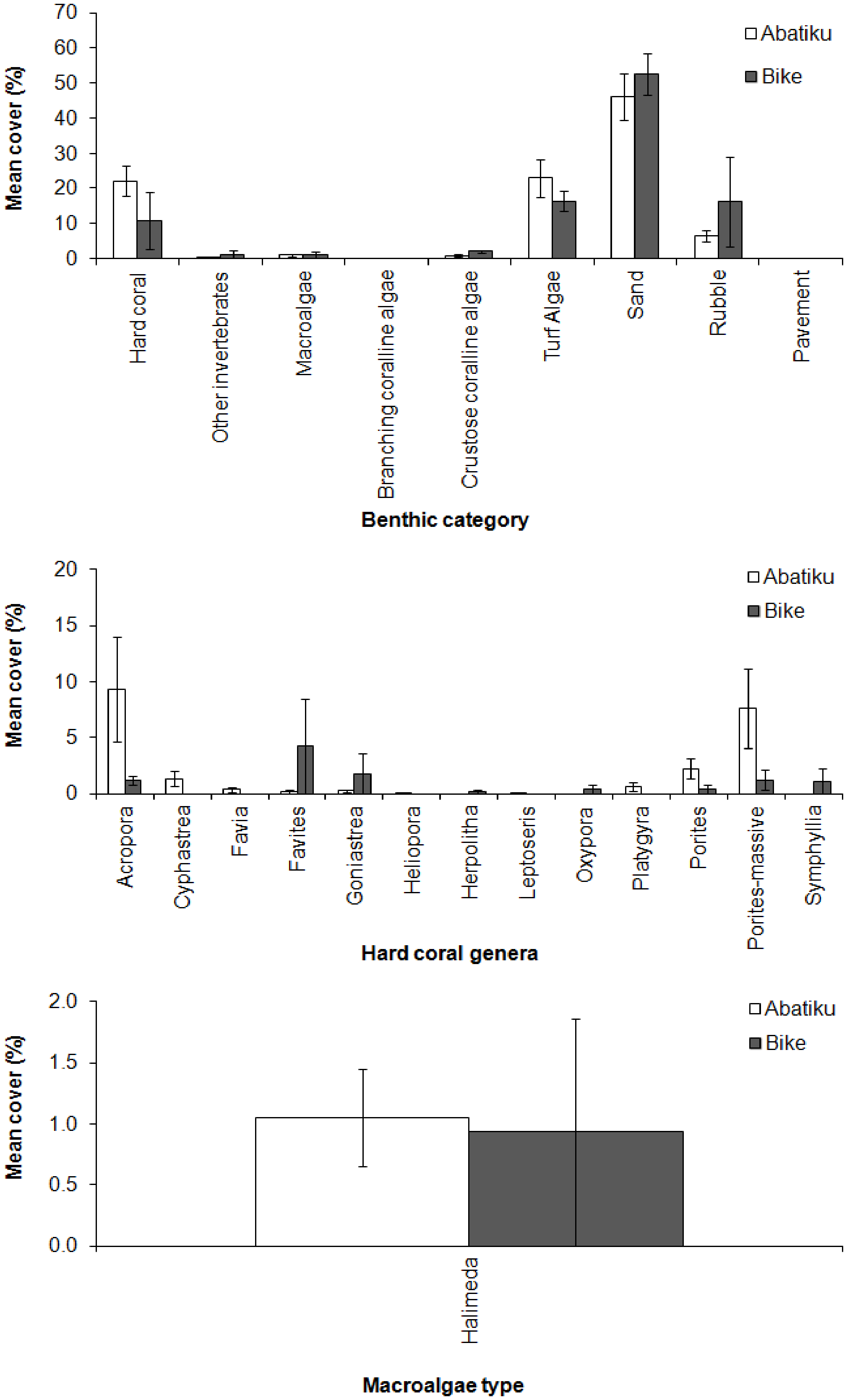

Figure 9 **Mean cover (± SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at lagoon-reef habitats during benthic habitat assessments at Abatiku and Bike, 2011.**

Outer-reef habitats

Outer-reef habitats of both the Abatiku and Bike monitoring sites were largely characterised by a high percent cover of crustose coralline algae and hard coral, and a low percent cover of sand, relative to the back- and lagoon-reefs habitats (Figure 7; Figure 10). No significant differences were observed in mean percent cover of any major benthic category among outer-reef habitats of the Abatiku and Bike sites (Figure 10). The cover of macroalgae on outer-reef habitats was relatively low (< 10%), with *Halimeda* the most common macroalgae observed at both sites (Figure 10).

Hard coral diversity was the highest within the outer-reef habitats, with 21 types of hard coral were recorded on the outer-reefs of Abatiku, and 18 on the outer-reefs of Bike (Figure 10). Hard corals constituted 22.3±3.5% and 28.3±4.1% of overall cover at the Abatiku and Bike sites, respectively (Figure 10). In terms of cover, *Porites*-massive, *Porites*, *Pocillopora and Platygyra* were the most common hard coral types within the outer-reefs of the Abatiku site, representing 5.4±1.1%, 3.2±1.1%, 2.4±1.1 and 2.3±1.0% of overall cover, respectively, while *Porites*-massive, *Pocillopora* and *Heliopora* were the most common corals on the outer-reef of the Bike site, representing 8.0±2.0%, 7.4±1.9% and 3.7±2.4% of overall cover at Bike, respectively (Figure 10). No bleached or recently dead corals were observed on the outer-reefs of the Abatiku site, while the cover of both bleached and recently dead corals at Bike was low, constituting 0.1±0.1% and 0.1%±0.1% of the overall mean cover of hard corals, respectively.

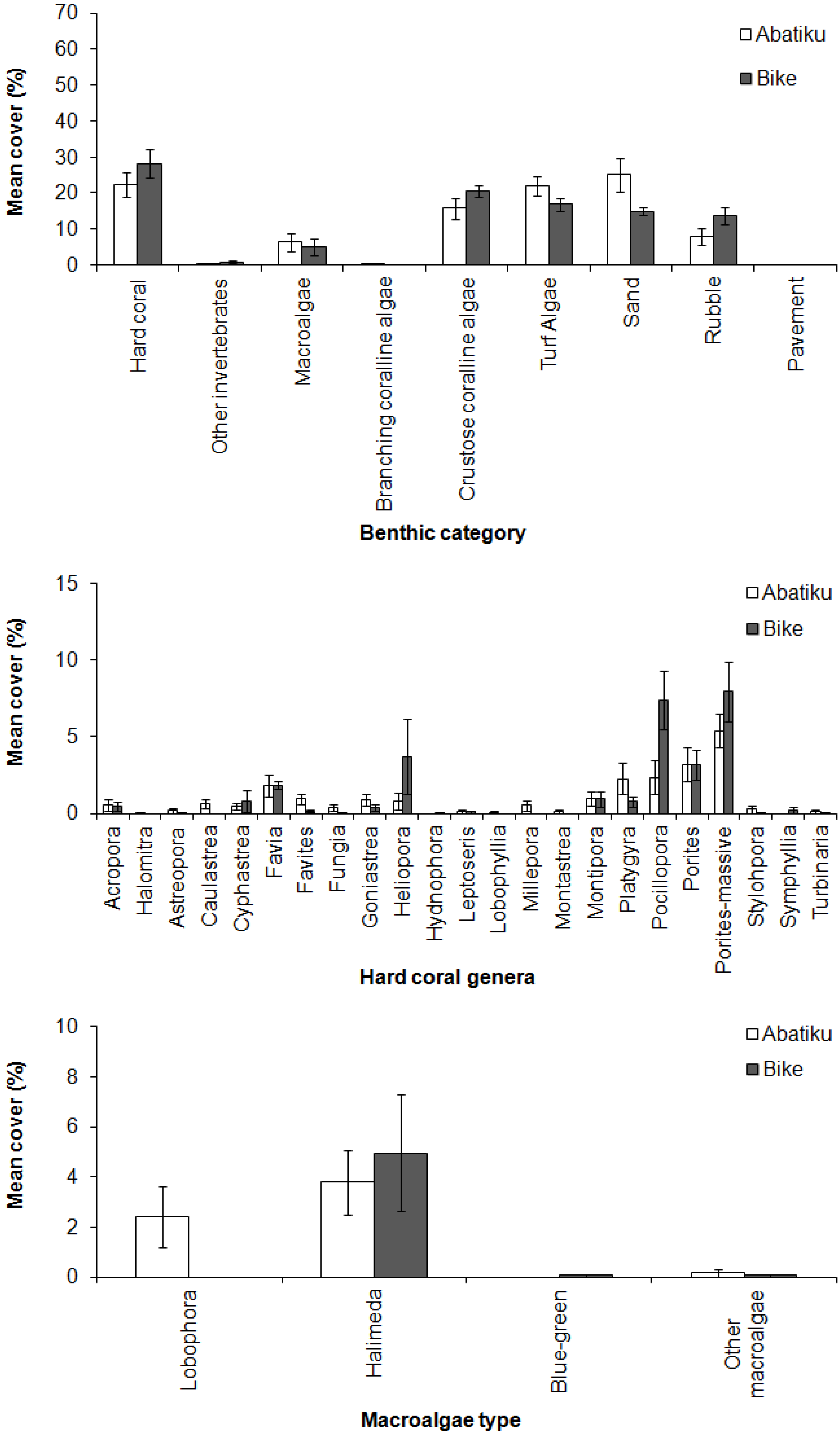

Figure 10 **Mean cover (± SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at outer-reef habitats during benthic habitat assessments at Abatiku and Bike, 2011.**

5. Finfish Surveys

Methods and Materials

Data collection

Finfish surveys

Fish on reef habitats were surveyed using distance-sampling underwater visual census (D-UVC) techniques. As per the benthic habitat assessments, three replicate 50 m transects were planned to be surveyed in the back-reef, lagoon-reef and outer-reef habitats at each of two stations within the Abatiku and Bike sites (Figure 5). Each transect census was completed by two SCUBA divers who recorded the species name, abundance and total length (TL) of all fish observed on a form (Appendix 2). The distance of the fish from the transect line was also recorded (Figure 11). The distance of the fish from the transect line was also recorded. Two distance measurements were recorded for a school of fish belonging to the same species and size: the distance from the transect tape to the nearest individual (D1) and the distance from the transect tape to the furthest individual (D2), while for individual fish only one distance was recorded (D1) (Figure 11). Regular review of identification books and cross-checks between divers after the dive ensured that accurate and consistent data were collected.

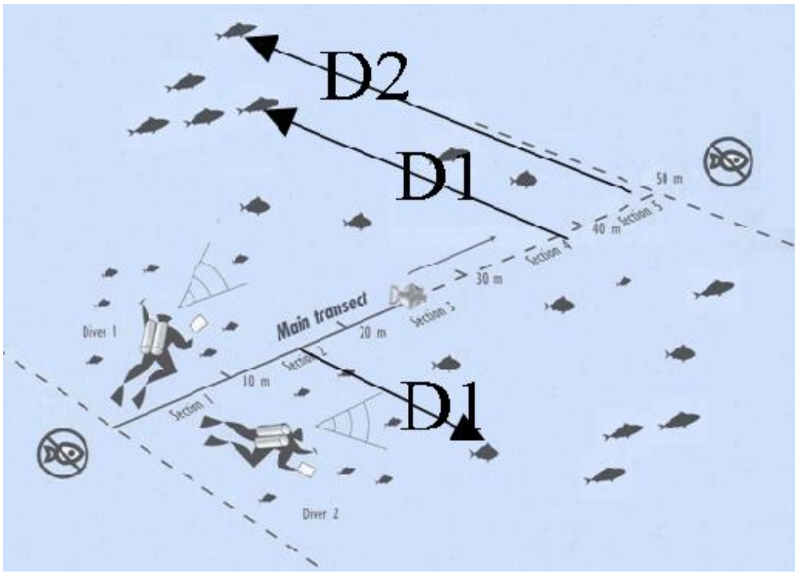

Figure 11 Diagram portraying the D-UVC method.

Habitats supporting finfish

Habitats supporting finfish were documented after the finfish survey using a modified version of the medium scale approach of Clua et al (2006). This component uses a separate form (Appendix 3) from that of the finfish assessment, collating 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 metre transect.

The substrate types were grouped into the following six categories:

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

Data analysis

Finfish surveys

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

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

level. This ratio can range from nearly zero when fish are very small to 100% when a given fish has reached the maximum size reported for the species;

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

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

Given the baseline nature of this report, relationships between environmental parameters and finfish resources have not been fully explored. Rather, the finfish resources are described and compared amongst habitats within sites and between the Abatiku and Bike sites. To explore differences among sites and reef environments, habitat category data and density, biomass, mean size and mean size ratio data of each of the 18 indicator families and five trophic groups in each individual transect were square-root transformed to reduce heterogeneity of variances and analysed by two-way analysis of variance (ANOVA) using Statistica 7.1, with site (Abatiku and Bike) and habitat as fixed factors in the analysis. A square-root transformation was used as preliminary analyses revealed it provided the greatest homogeneity of variances as compared to other transformation methods (e.g. log(x+1), 4^{th}-root). Tukey-Kramer post-hoc pairwise tests were used to identify specific differences between factors at $P = 0.05$. Where transformed data failed Cochran's test for homogeneity of variances ($P < 0.05$), an increased level of significance of $P = 0.01$ was used. Additionally, family-specific density and biomass data from both the Abatiku and Bike sites were combined and compared against those collected during the PROCFish surveys in Abemama Atoll in 2004 (Awira et al. 2008; Figure 12) using one-way ANOVA. While the PROCFish project collected data relating to species of interest to fisheries only, precluding comparisons of overall density and biomass and comparisons among trophic groups against the current study, data of commonly recorded families (Acanthuridae, Balistidae, Chaetodontidae, Holocentridae, Kyphosidae, Lethrinidae, Lutjanidae, Mullidae, Nemipteridae, Scaridae, Siganidae and Zanclidae) can nevertheless be compared, providing an important starting point from which to explore changes over time.

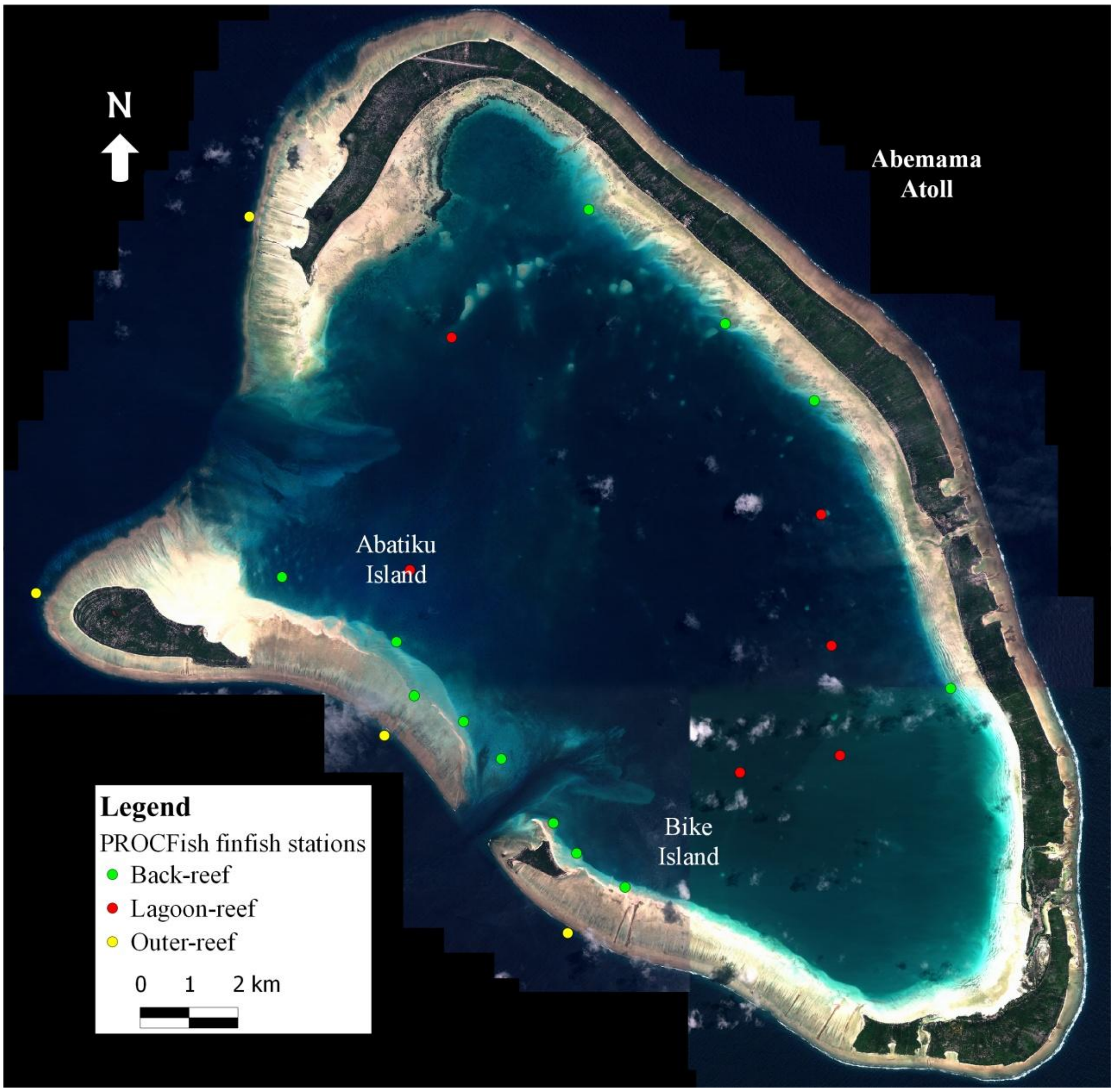

Figure 12 **Location of PROCFish finfish survey sites at Abemama Atoll used to compare against data collected during the current (2011) survey.**

Results

Coverage

A total of 26 D-UVC transects were completed during the baseline monitoring program, with 12 transects conducted at the Bike site and 14 at the Abatiku site (Figure 13; Table 9). A list of GPS coordinates for each D-UVC transect is presented as Appendix 4.

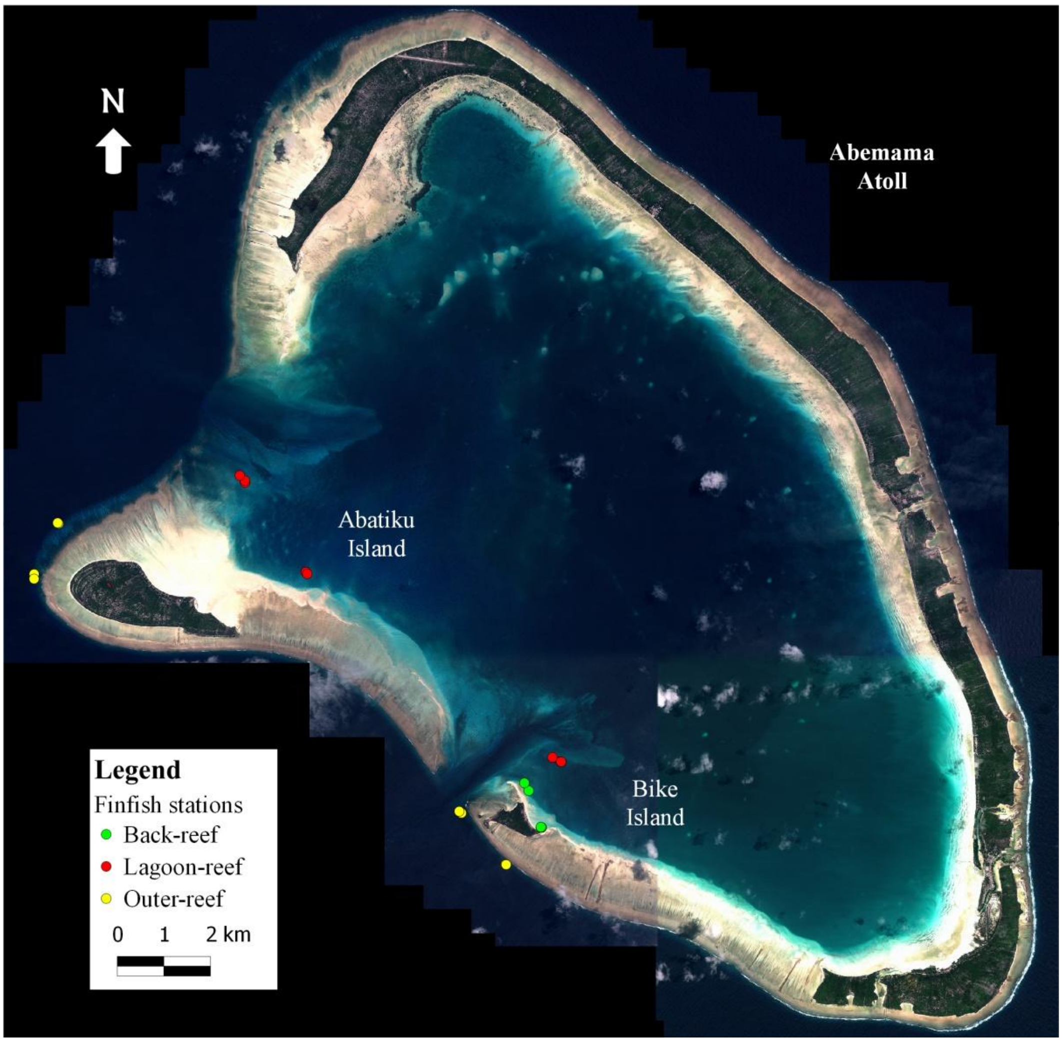

Figure 13 Location of finfish assessment stations established at Abatiku and Bike Islands, 2011.

Table 9 Summary of distance underwater visual census (D-UVC) transects among habitats for Abatiku and Bike monitoring sites, 2011.

Site	Habitat	No. of stations	No. of transects
Abatiku	Lagoon-reef	2	6
	Outer-reef	2	6
Bike	Back-reef	2	5
	Lagoon-reef	2	3
	Outer reef	2	6

Finfish surveys

Overall

A total of 23 families, 76 genera, 181 species and 30,485 individual fish were recorded from the 26 transects. Of these, 19 families, 61 genera, 117 species and 14,079 individual fish were recorded from the Abatiku monitoring stations, while 20 families, 64 genera, 138 species and 16,406 individual fish were recorded from the Bike monitoring stations. Within the Abatiku stations, overall mean density appeared higher within the outer-reef compared to the lagoon-reef habitats (Figure 14). Within the Bike stations, overall mean density appeared higher within the lagoon- and outer-reef habitats compared to the back-reef habitats, while no difference was observed between the lagoon- and outer-reef habitats. The overall mean density and mean biomass of finfish on the lagoon-reefs of Bike stations appeared slightly higher than those at Abatiku. No difference was observed in the mean density and mean biomass of finfish among back- and outer-reef habitats (Figure 14; Figure 15). Species diversity was typically highest within the lagoon- and outer-reef habitats of Bike, and lowest on the back-reefs (Table 10).

Table 10 Total number of families, genera and species, and diversity of finfish observed at back-, lagoon- and outer-reef habitats of Abatiku and Bike monitoring stations, 2011.

Parameter	Back-reef		Lagoon-reef		Outer-reef	
	Abatiku	Bike	Abatiku	Bike	Abatiku	Bike
No. of families	-	15	15	18	20	20
No. of genera	-	26	40	42	55	57
No. of species	-	44	80	78	103	122
Diversity	-	8.8	13.3	26	17.2	20.3

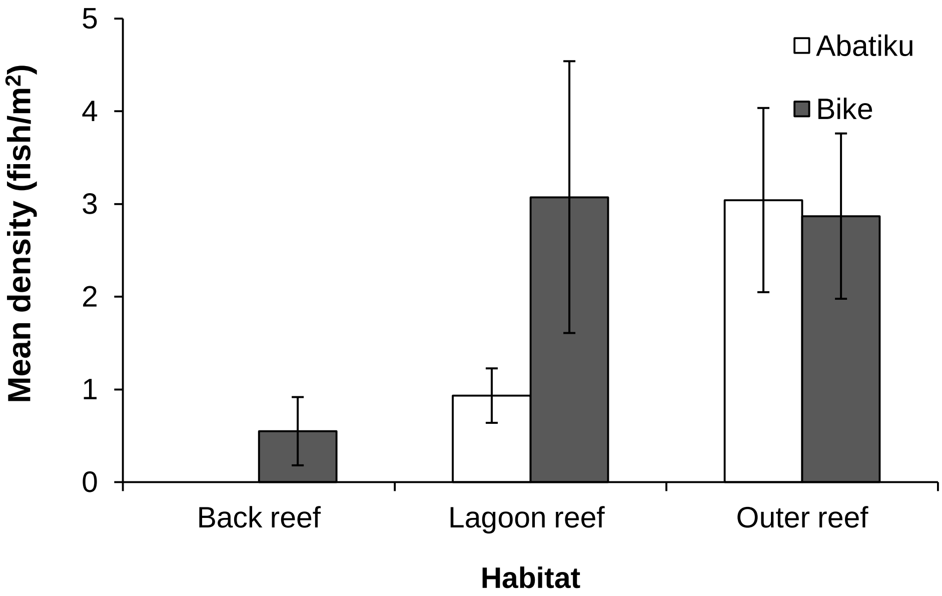

Figure 14 **Overall mean density of finfish (± SE) within the back-, lagoon- and outer-reef habitats of the Abatiku and Bike monitoring stations, 2011.**

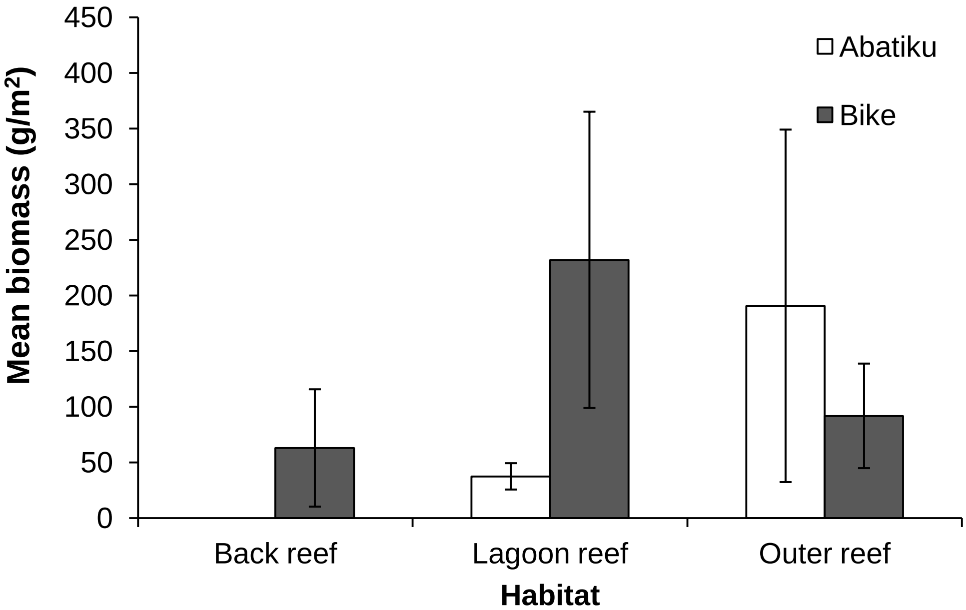

Figure 15 **Overall mean biomass of finfish (± SE) within the back-, lagoon- and outer-reef habitats of the Abatiku and Bike monitoring stations, 2011.**

Back-reef habitats

Habitat

Back-reef habitats were the D-UVC transects were carried out at Bike were largely characterised by a high cover of sand (46.3±10.2%) (Figure 16). There were few live corals observed within the Bike stations; consisting of massive (10.4±4.6%), sub-massive (3.5±1.9%), encrusting (1.1±0.6%) and branching (0.2±0.2%) coral growth forms (Figure 16).

Finfish surveys

A total of 15 families, 26 genera, 44 species and 1,400 individual fish were recorded from back-reef habitats of the Bike monitoring stations (Table 10). Of the 18 selected 'indicator' families, Pomacentridae occurred in the greatest mean density within the back-reef environments of Bike (0.24±0.19 fish/m^2), followed to a lesser extent by members of the families Lutjanidae (0.12±0.09 fish/m^2), Labridae (0.10±0.04 fish/m^2), Mullidae (0.03±0.02) and Acanthuridae (0.02±0.01 fish/m^2) (Figure 17). The species observed in the highest densities within the back-reef habitats of the Bike site were the pomacentrid *Pomacentrus coelestis*, the lutjanid *Lutjanus gibbus*, the labrids *Halichoeres trimaculatus* and *H. hortulanus* and the mullid *Parupeneus multifasciatus* (Table 11). A full list of densities by family and individual species can be found in Appendices 5 to 8, respectively.

Within the back reef habitat of the Bike stations, members of the Lutjanidae had the greatest biomass, comprising 42.10±36.45 g/m^2 of the total observed biomass, followed by members of the families Labridae (11.51±10.01 g/m^2), Acanthuridae (2.31±2.12 g/m^2), Mullidae (1.75±1.06 g/m^2) and Balistidae (1.57±0.39 g/m^2) (Figure 17). The individual species observed in the highest biomass within the back-reef habitats of the Bike site were the lutjanids *Lutjanus gibbus* and *L. fulvus*, the labrid *Halichoeres hortulanus*, the acanthurid *Acanthurus achilles*, and the balistid *Rhinecanthus aculeatus* (Table 12). A full list of biomass by family and individual species can be found in Appendices 5 to 8, respectively.

In terms of trophic structure, carnivores and herbivores were observed in the highest mean densities within the back-reef habitats of the Bike site, with 0.27±0.15 fish/m^2 and 0.26±0.21 fish/m^2, respectively. Similarly, carnivores had the greatest biomass, comprising 58.40±47.84 g/m^2 of the total observed biomass of the indicator families, followed by herbivores (3.94±3.37 g/m^2). Piscivores and planktivores comprised a biomass of < 1% of the overall biomass. No detritivores were observed within the back-reef habitats of the Bike stations (Figure 18).

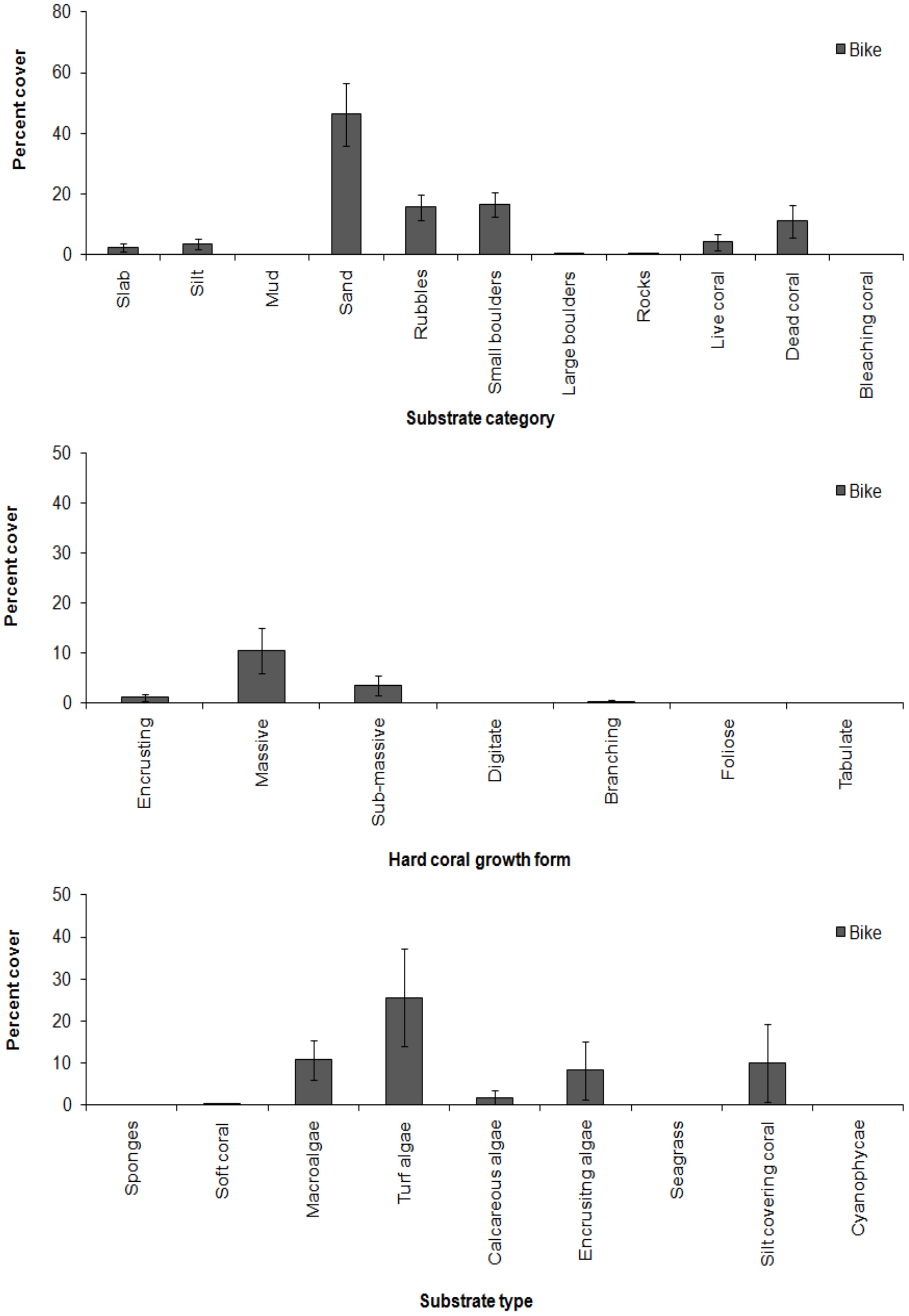

Figure 16 **Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate type (bottom) present at back-reef habitats during finfish surveys at Bike monitoring stations, 2011.**

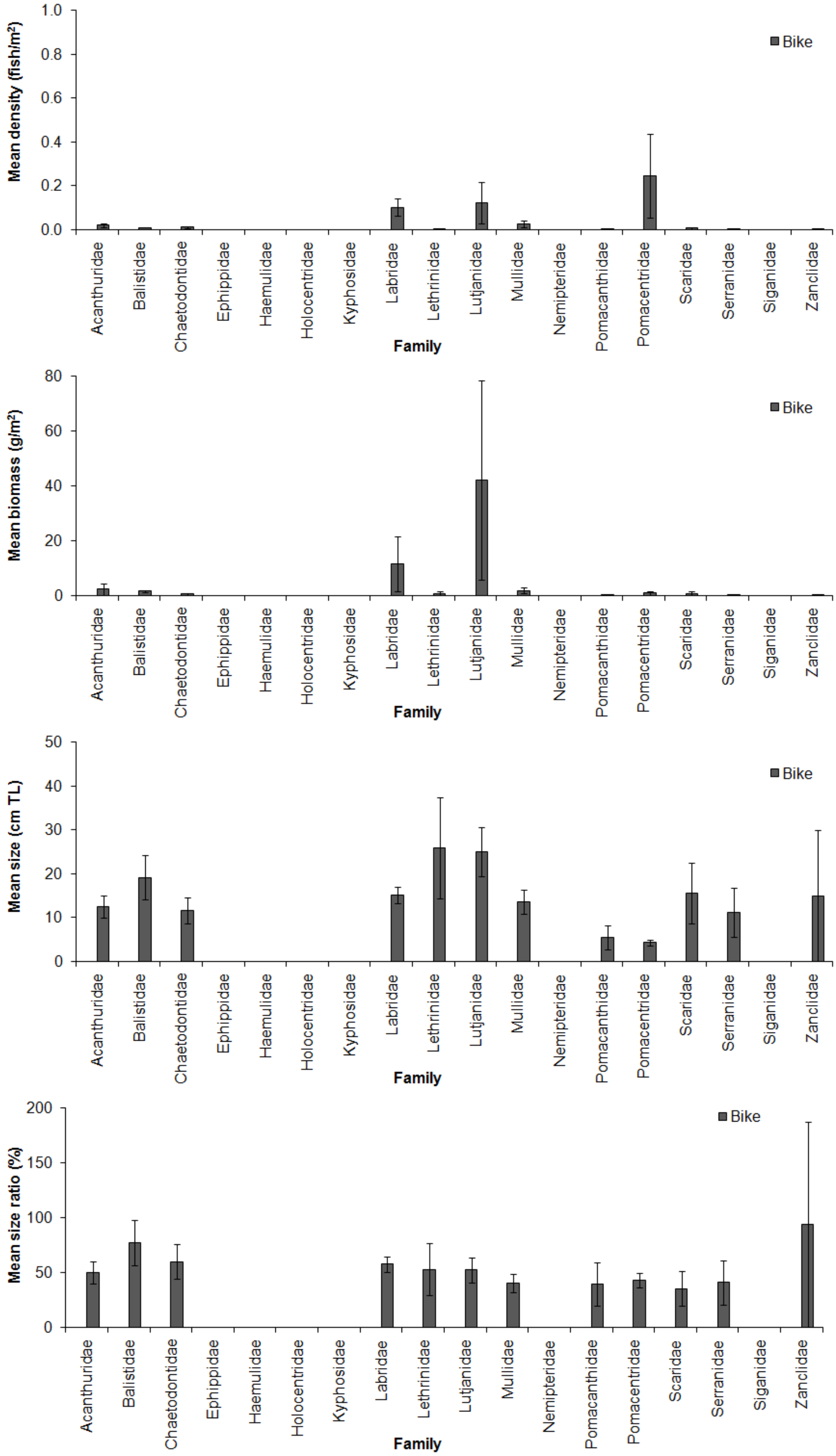

Figure 17 Profile of finfish indicator families in back-reef habitats of Bike monitoring stations, 2011.

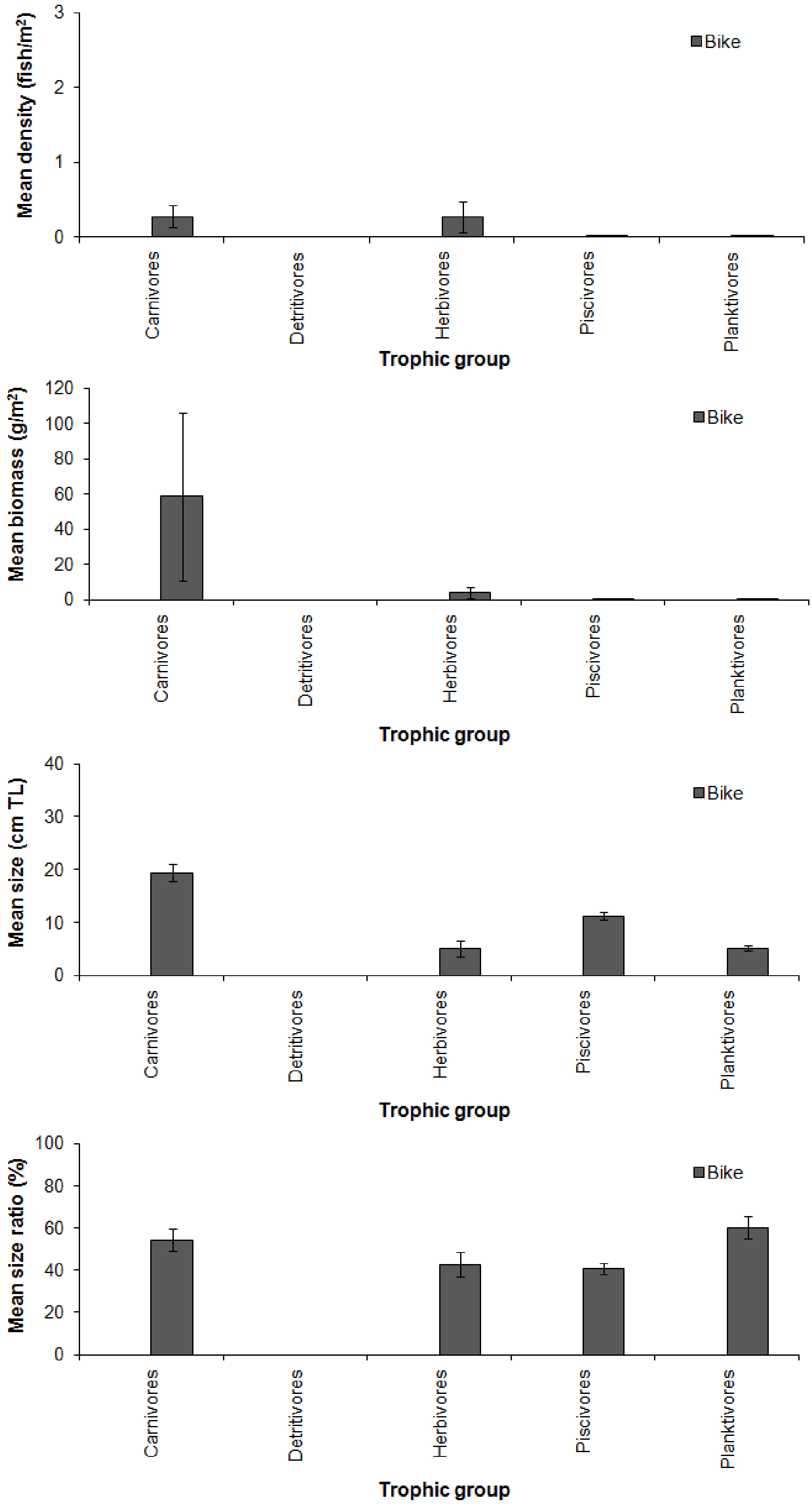

Figure 18 Profile of finfish by trophic level in back-reef habitats of Bike monitoring stations, 2011.

Table 11 Finfish species observed in the highest densities in back-reef habitats of Bike monitoring sites, 2011. See Appendix 7 and 8 for a full list of densities of individual fish species.

Site	Species	Family	Density (fish/m^2±SE)
Bike	*Pomacentrus coelestis*	Pomacentridae	0.22±0.19
	Lutjanus gibbus	Lutjanidae	0.10±0.08
	Halichoeres trimaculatus	Labridae	0.05±0.02
	Halichoeres hortulanus	Labridae	0.04±0.03
	Parupeneus multifasciatus	Mullidae	0.02±0.01

Table 12 Finfish species with the highest biomass in back-reef habitats of Bike monitoring sites, 2011. See Appendix 7 and 8 for a full list of biomass of individual fish species.

Site	Species	Family	Biomass (g/m^2±SE)
Bike	*Lutjanus gibbus*	Lutjanidae	33.00±27.80
	Halichoeres hortulanus	Labridae	10.18±10.17
	Lutjanus fulvus	Lutjanidae	9.10±8.69
	Acanthurus achilles	Acanthuridae	1.47±1.47
	Rhinecanthus aculeatus	Balistidae	1.35±1.35

Comparisons with PROCFish surveys

Observed mean densities of Chaetodontidae, Lethrinidae and Zanclidae, and mean biomass of Balisitdae, Scaridae and Zanclidae, on back-reefs of Abemama were significantly higher during the PROCFish surveys than the current (2011) survey ($P < 0.05$) (Figure 19). It should be noted that these surveys were not conducted at exactly the same locations, thus these results may be at least partially influenced by spatial differences in habitat cover or depth among survey locations. Further monitoring of the stations established during this baseline event is required to determine whether these differences are consistent over time.

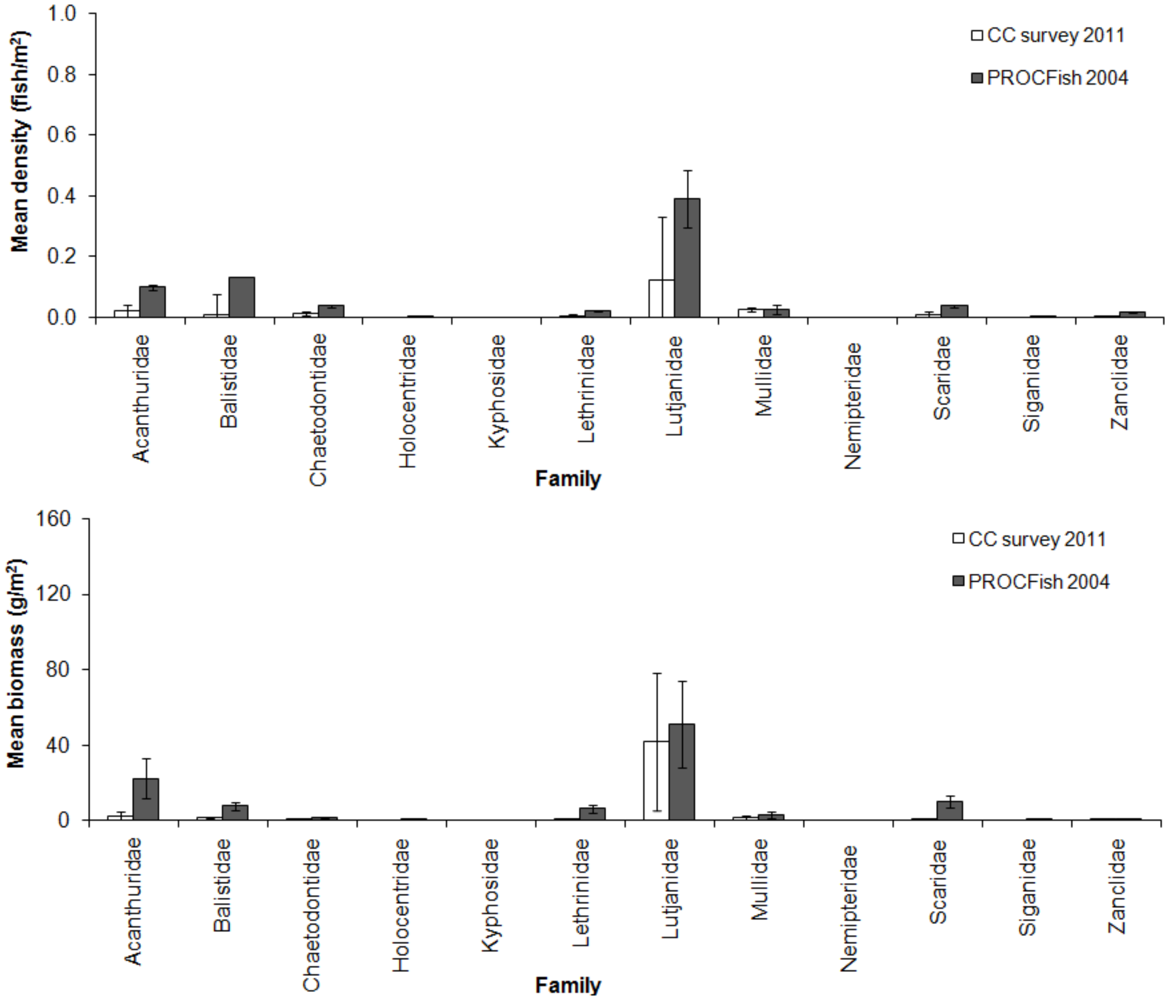

Figure 19: Comparison of mean density (top) and mean biomass (bottom) of finfish families (± SE) recorded from back-reef habitats of Abemama Atoll in the current (2011) survey and during PROCFish surveys in 2004.

Lagoon reef habitats

Habitat

Lagoon-reef habitats where the D-UVC transects were established at both sites were largely characterised by sand, live corals and dead corals. Within the lagoon-reef habitats of Abatiku stations, sand constituted 24.8±3.6% of the overall cover, followed by live corals (23.2±4.0%), and dead corals (17.1±4.9) (Figure 20). Similarly within the Bike monitoring stations, sand constituted 30.4±5.9% of the total substrate cover, followed by live corals (27.9±8.8%), and long dead corals (26.1±17.7%) (Figure 20). Tabulate, massives and sub-massives were the most common coral growth forms on the lagoon-reef habitats of both the Abatiku and Bike monitoring stations. While the lagoon-reef transects at Bike were significantly deeper than those at Abatiku, no significant differences in the cover of any substrate categories were evident among sites (Figure 20).

Finfish surveys

Lagoon-reef habitats supported a moderate diversity of finfish, with 15 families, 40 genera, 80 species and 2,919 individual fishes recorded from lagoon-reef habitats of the Abatiku monitoring stations, while 18 families, 42 genera, 78 species and 4,657 individual fishes were recorded from lagoon-reef habitats of the Bike monitoring stations (Table 10). At Abatiku, the families that occurred in the greatest mean densities were the Pomacentridae (0.55±0.17 fish/m^2), Labridae (0.10±0.0.02 fish/m^2) and Scaridae (0.10±0.04 fish/m^2). At Bike, Pomacentridae had the greatest mean density of (1.57±0.46 fish/m^2), followed by Serranidae (0.23±0.18 fish/m^2) and Lethrinidae (0. 22±0.20 fish/m^2) (Figure 21). The mean densities of Balistidae, Chaetodontidae and Mullidae were significantly higher on the lagoon-reefs of the Bike stations compared to those at Abatiku ($P < 0.05$). The individual species observed in the highest densities within the lagoon-reef habitats of Abatiku site were the pomacentrids *Pomacentrus coelestis, Dascyllus aruanus, Pomacentrus vaiuli, Chromis viridis* and scarid *Chlorurus sordidus*, while the individual species observed in the highest densities within the lagoon-reef habitats of the Bike site were the pomacentrids *Chromis margaritifer, C. weberi, C.viridis, Pomacentrus coelestis* and the lethrinid *Gnathodentex aureolineatus* (Table 13). A full list of densities by family and individual species can be found in Appendices 5 to 8, respectively.

The families that occurred in the greatest biomass within the lagoon-reef habitats of Abatiku sites were the Scaridae (17.29±5.75 g/m^2) Acanthuridae (10.41±2.65 g/m^2), Labridae (2.68±0.53 g/m^2) and Pomacentridae (1.92±0.48 g/m^2). At Bike, Acanthuridae had the highest mean biomass (68.84±21.17 g/m^2), followed by Balistidae (28.82±20.07 g/m^2), Pomacentridae (20.80±16.22 g/m^2) and Scaridae (17.58±10.41 g/m^2) (Figure 21). The mean biomass of Acanthuridae, Balistidae, Chaetodontidae, Mullidae, Pomacanthidae and Serranidae were significantly higher on the lagoon-reef habitats of the Bike stations than those at Abatiku ($P < 0.05$). The individual species of the 18 indicator families that occurred in the greatest biomass within the lagoon-reef habitats of Abatiku sites were the scarids *Chlorurus sordidus, Scarus ghobban, Hipposcarus longiceps,* and the acanthurids *Ctenochaetus striatus,* and *Acanthurus triostegus.* The species with the greatest biomass within the lagoon-reef habitats of Bike sites were the acanthurid *Acanthurus blochii,* the pomacentrid *Chromis weberi,* the balistid *Pseudobalistes flavimarginatus,* the lethrinid *Gnathodentex aureolineatus* and the scarid *Scarus ghobban* (Table 14). A full list of biomass by family and individual species can be found in Appendices 5 to 8, respectively.

No significant differences in mean size or mean size ratio were evident for any of the 18 indicator families among the lagoon-reef habitats of the Abatiku and Bike sites (Figure 21).

In terms of trophic group, herbivores occurred in the greatest mean density within the lagoon-reef of Abatiku monitoring stations with 0.48±0.08 g/m^2 (54.33% of the overall density), followed by planktivores and carnivores. At Bike, planktivores occurred in the greatest mean density (1.50±0.41 g/m^2, comprising 55.58% of the overall density), followed by herbivores and carnivores (Figure 22). The mean densities of carnivores, piscivores and planktivores, and mean biomass of piscivores and planktivores, were significantly higher on the lagoon-reefs of Bike than those at Abatiku ($P < 0.05$). No significant differences in mean size or mean size ratio were evident among sites for any trophic group (Figure 22).

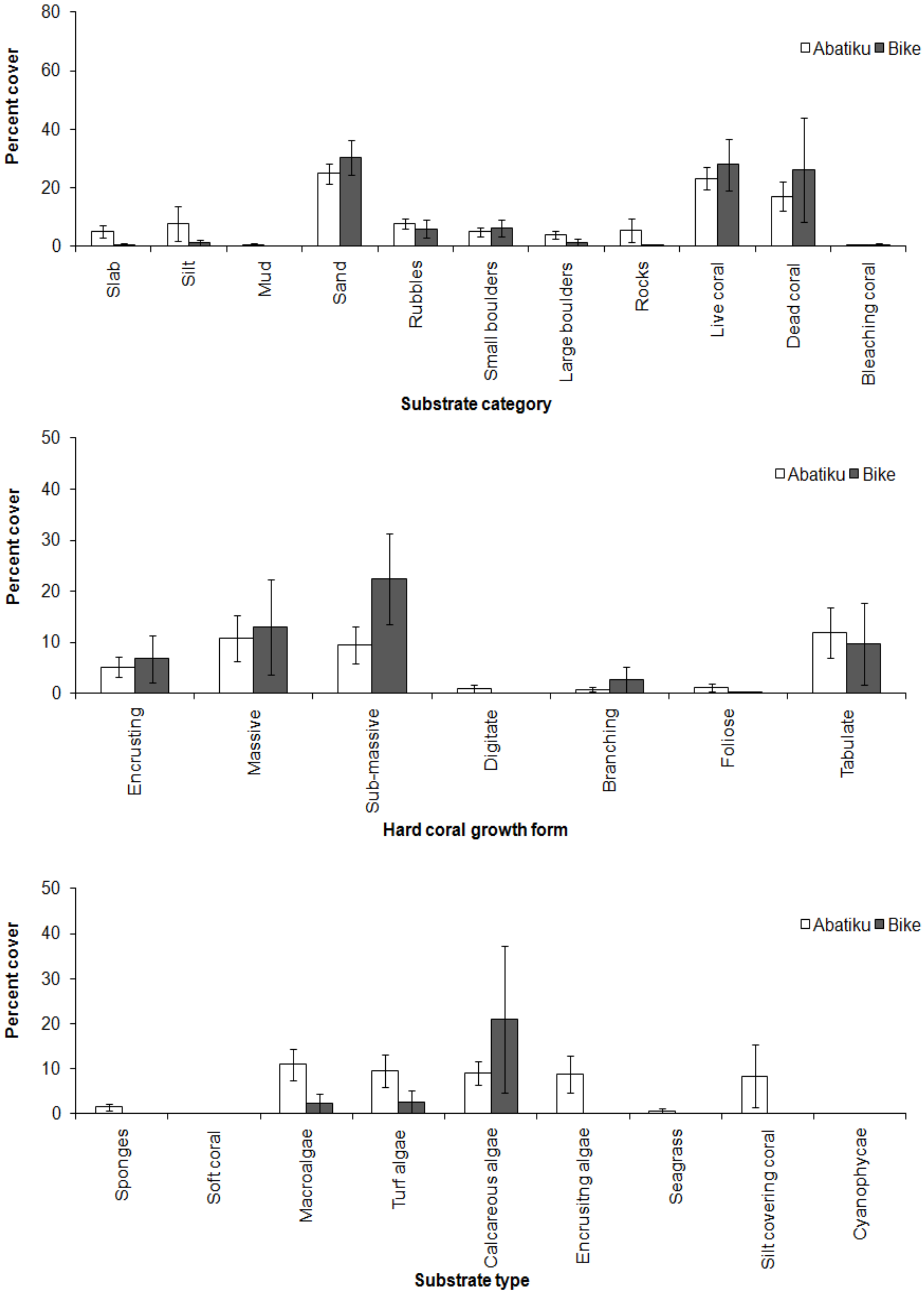

Figure 20 **Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate type (bottom) present at lagoon-reef habitats during finfish surveys at Abatiku and Bike monitoring stations, 2011.**

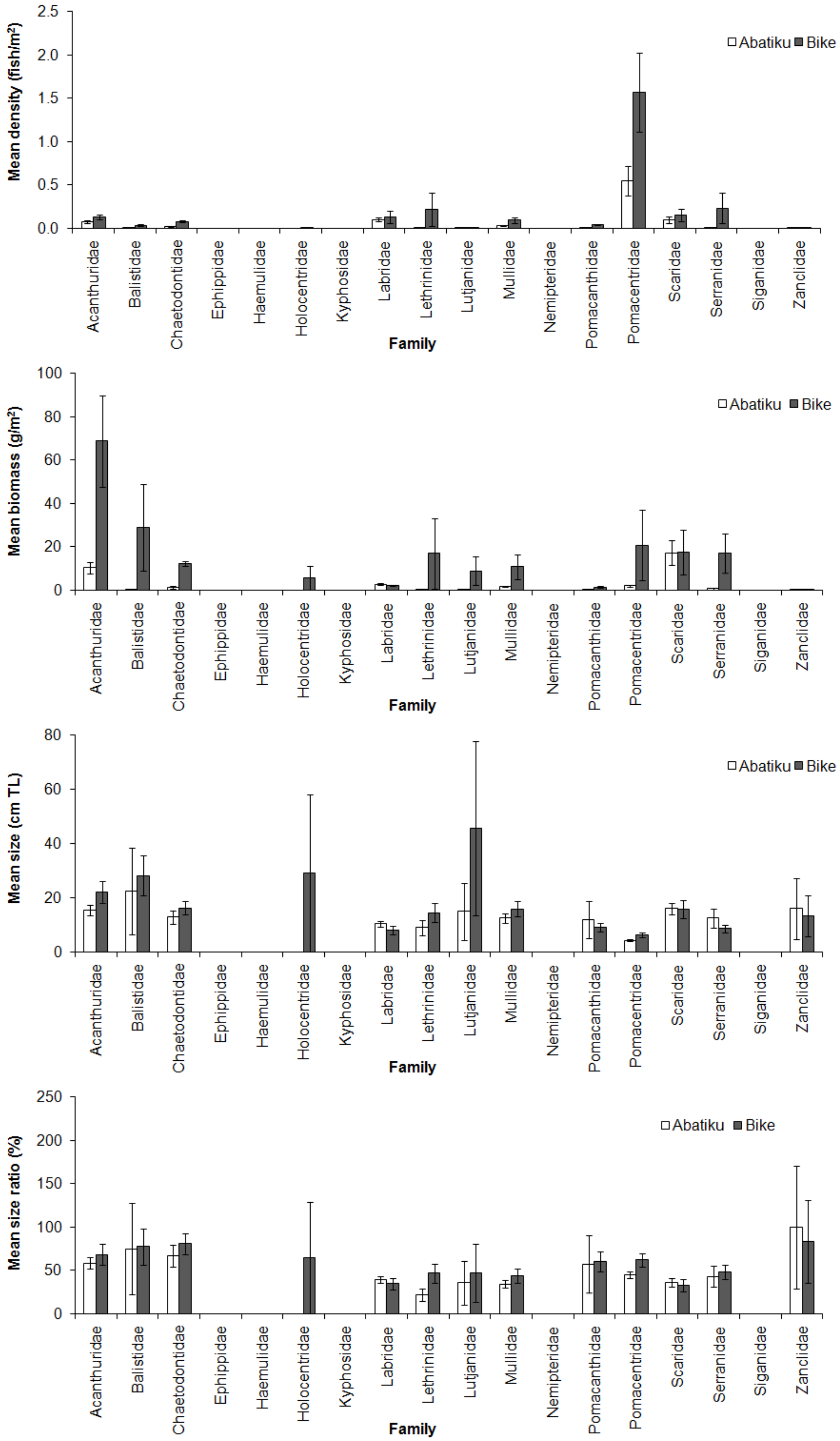

Figure 21 Profile of finfish indicator families in lagoon-reef habitats of Abatiku and Bike monitoring stations, 2011.

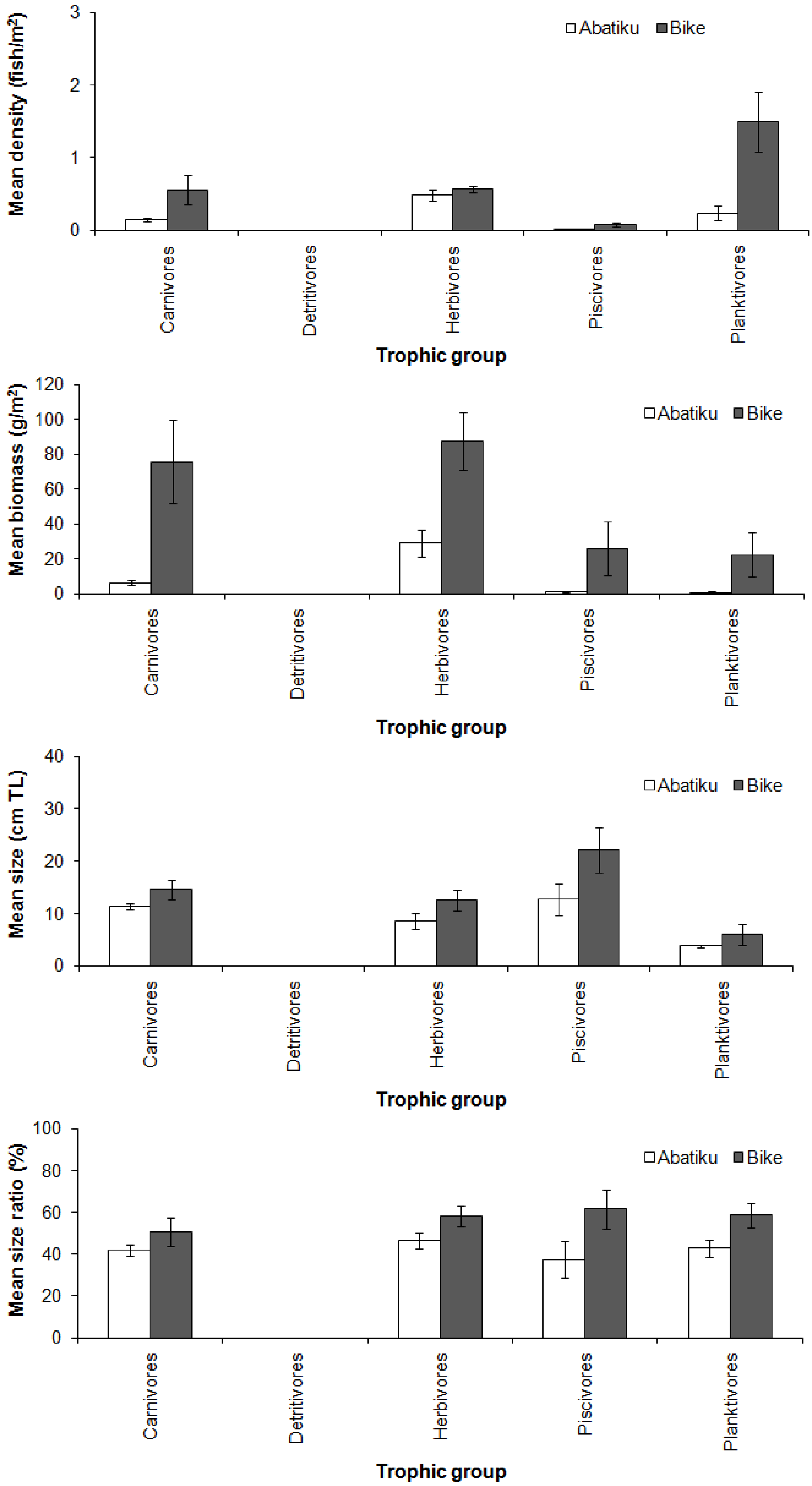

Figure 22 Profile of finfish by trophic level in lagoon-reef habitats of Abatiku and Bike monitoring stations, 2011.

Table 13 Finfish species observed in the highest densities in lagoon-reef habitats of Abatiku and Bike monitoring sites, 2011. See Appendix 7 and 8 for a full list of densities of individual fish species.

Site	Species	Family	Density (fish/m^2±SE)
Abatiku	*Pomacentrus coelestis*	Pomacentridae	0.21±0.10
	Dascyllus aruanus	Pomacentridae	0.09±0.04
	Pomacentrus vaiuli	Pomacentridae	0.07±0.04
	Chlorurus sordidus	Scaridae	0.04±0.01
	Chromis viridis	Pomacentridae	0.04±0.04
Bike	*Chromis weberi*	Pomacentridae	0.51±0.39
	Chromis margaritifer	Pomacentridae	0.40±0.06
	Pomacentrus coelestis	Pomacentridae	0.25±0.07
	Gnathodentex aureolineatus	Lethrinidae	0.20±0.19
	Chromis viridis	Pomacentridae	0.17±0.16

Table 14 Finfish species with the highest biomass in lagoon-reef habitats of Abatiku and Bike monitoring sites, 2011. See Appendix 7 and 8 for a full list of biomass of individual fish species.

Site	Species	Family	Biomass (g/m^2±SE)
Abatiku	*Chlorurus sordidus*	Scaridae	7.18±4.20
	Ctenochaetus striatus	Acanthuridae	6.72±1.89
	Scarus ghobban	Scaridae	4.39±2.54
	Hipposcarus longiceps	Scaridae	3.66±3.66
	Acanthurus triostegus	Acanthuridae	1.44±1.44
Bike	*Acanthurus blochii*	Acanthuridae	40.97±32.24
	Pseudobalistes flavimarginatus	Balistidae	20.25±20.25
	Chromis weberi	Pomacentridae	14.14±13.29
	Gnathodentex aureolineatus	Lethrinidae	13.91±13.67
	Scarus ghobban	Scaridae	8.78±6.44

Comparisons with PROCFish surveys

Observed mean densities and biomass of Balistidae, Lutjanidae and Zanclidae on lagoon-reefs of Abemama Atoll sites were significantly higher during the PROCFish surveys than the current survey ($P < 0.05$) (Figure 23). In contrast, the mean density of Scaridae during the current (2011) survey was slightly higher than the PROCFish surveys ($P < 0.05$). As with the back-reef habitats, it should be noted that these surveys were not conducted at exactly the same locations, thus these results may be at least partially influenced by spatial differences in habitat cover or depth among survey locations. Further monitoring of the stations established during this baseline event is required to determine whether these differences are consistent over time.

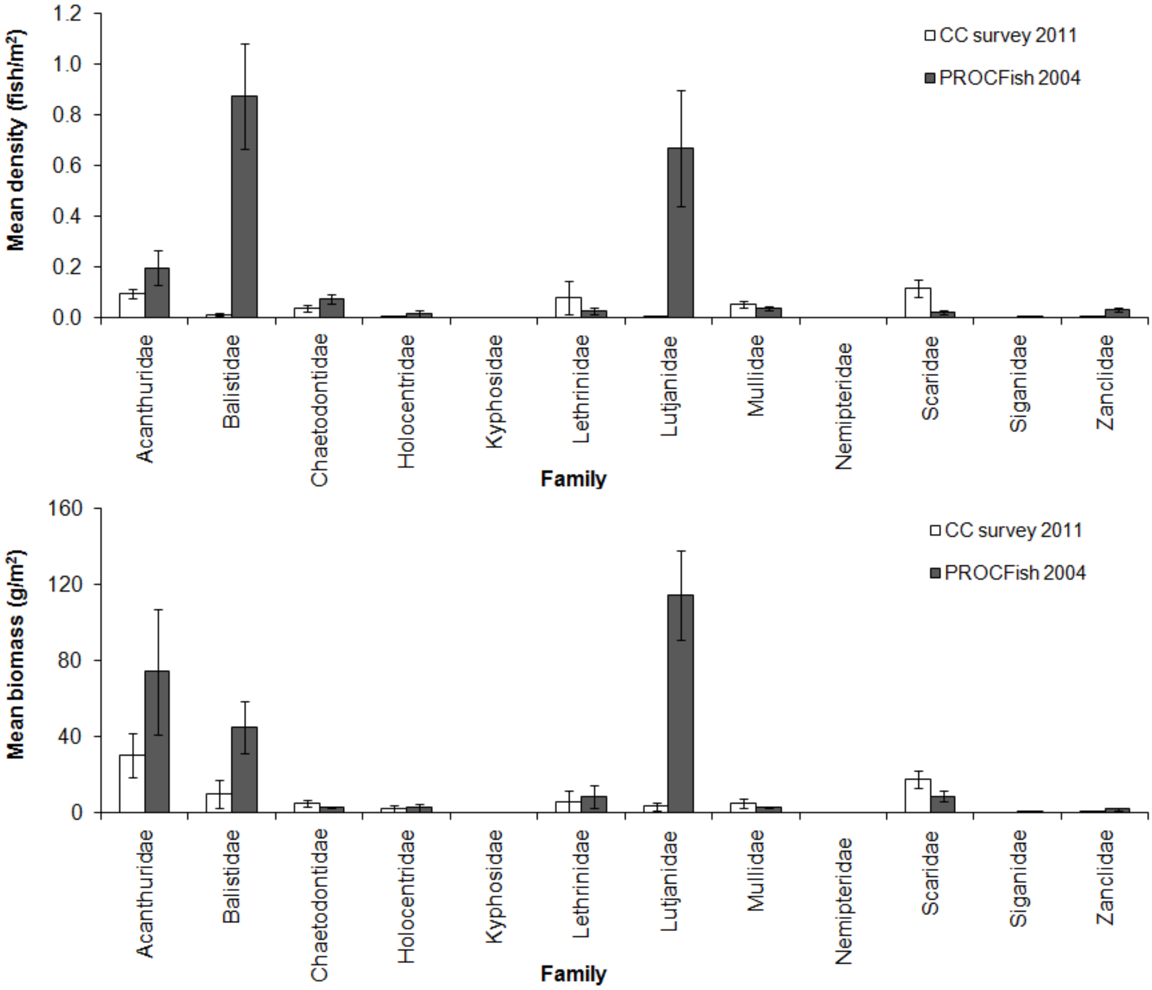

Figure 23: Comparison of mean density (top) and mean biomass (bottom) of finfish families (± SE) recorded from lagoon-reef habitats of Abemama atoll in the current (2011) survey and during PROCFish surveys in 2004.

Outer-reef habitats

Habitat

The substrate of the outer-reefs at the Abatiku and Bike stations were typically characterised by a relatively high cover of live and dead corals, with a low cover of slab, rubble, sand and small boulders (Figure 24). Within the outer-reef habitats of Abatiku stations, live corals constituted 40.2±10.2% of the overall cover, followed by dead corals (24.5±4.1%), slab (13.5±3.0%), sand (8.2±4.3%) and small boulders (5.1±1.6%), while at Bike, live coral constituted 34.0±6.7% of the overall substrate, followed by dead corals (24.6±4.0%), slab (12.8±3.9%), rubble (9.2±2.5%) and sand (7.5±1.3%) (Figure 24). Sub-massive, massive and encrusting corals were the most common coral growth forms at both sites (Figure 24).

Finfish surveys

Outer-reef habitats supported the greatest diversity of finfish, with 20 families, 55 genera, 103 species and 11,160 individual fishes recorded from outer-reef habitats of the Abatiku monitoring stations, while 20 families, 57 genera, 122 species and 10,352 individual fishes were recorded from outer-reef habitats of the Bike monitoring stations (Table 10). At Abatiku, Pomacentridae occurred in the highest mean density (1.70±0.16 fish/m^2, comprising 56.02% of the overall density at this site), followed by Serranidae (0.45±0.29 fish/m^2) and Acanthuridae (0.09±0.02 fish/m^2). Similarly, within the Bike stations Pomacentridae had the highest mean density of 1.90±0.38 fish/m^2, followed by Serranidae (0.36±0.24 fish/m^2) and Acanthuridae (0.19±0.07 fish/m^2) (Figure 25). No differences in mean density of any of the 18indicator families were observed among sites ($P > 0.05$). The individual species observed in the highest densities within the outer-reef habitats of the Abatiku station were the pomacentrids *Chromis margaratifer, C. vanderbilti, C. ternatensis, Pomacentrus coelestis,* and the serranid *Pseudanthias dispar*. The individual species observed in the highest densities within the outer-reef habitats of the Bike stations were the pomacentrids *Chromis margaritifer, C. vanderbilti, C. ternatensis* and *C. weberi,* and the serranid *Pseudanthias dispar* (Table 15). A full list of densities by family and individual species can be found in Appendices 5 to 8, respectively.

The families that occurred in the greatest biomass within the outer-reef habitats of the Abatiku stations were the Labridae (18.89±17.74 g/m^2), Acanthuridae (12.99±6.31 g/m^2), Balistidae (10.41±5.43 g/m^2) and Pomacentridae (6.53±1.36 g/m^2). At the Bike stations, Acanthuridae had the highest mean biomass of 38.12±19.06 g/$m^{2,}$ followed by Scaridae (8.87±3.38 g/m^2), Serranidae (7.39±2.62 g/m^2), and Pomacentridae (7.12±2.34 g/m^2) (Figure 25). No differences were observed in the mean biomass of any families among sites ($P > 0.05$). The individual species that occurred in the greatest biomass within the outer-reef habitats of the Abatiku stations were the acanthurid *Ctenochaetus striatus,* the labrid *Cheilinus undulatus,* the balistid *Balistoides viridescens,* the lethrinid *Gnathodentex* *aureolineatus,* and the serranid *Cephalopholis argus.* The individual species with the greatest biomass within the outer-reef habitats of the Bike stations were the acanthurids *Ctenochaetus striatus, Acanthurus blochii, Acanthurus nigrofuscus,* the serranid *Cephalopholis argus*, and the scarid *Chlorurus sordidus* (Table 16). A full list of biomass by family and individual species can be found in Appendices 5 to 8, respectively.

No difference in either mean size or mean size ratio was apparent for any of the 18 indicator families on the outer-reefs of the Abatiku and Bike sites (Figure 25).

In terms of trophic group, planktivores occurred in the greatest mean density within the outer-reef of both Abatiku and Bike monitoring stations, with 1.57±0.36 fish/m^2 and 1.98±0.40 fish/m^2, respectively, followed by herbivores and carnivores (Figure 26). No differences in mean density were observed for any trophic group among the two sites. In terms of mean biomass, carnivores (33.21±23.80 g/m^2) and herbivores (16.57±6.87g/m^2) were the dominant trophic groups within the Abatiku stations, while herbivores (7.63±5.53 g/m^2) and carnivores (3.14±1.99 g/m^2) had the greatest biomass at the Bike stations. No significant differences in mean density, biomass, size or size ratio were evident among sites for any trophic group (Figure 26).

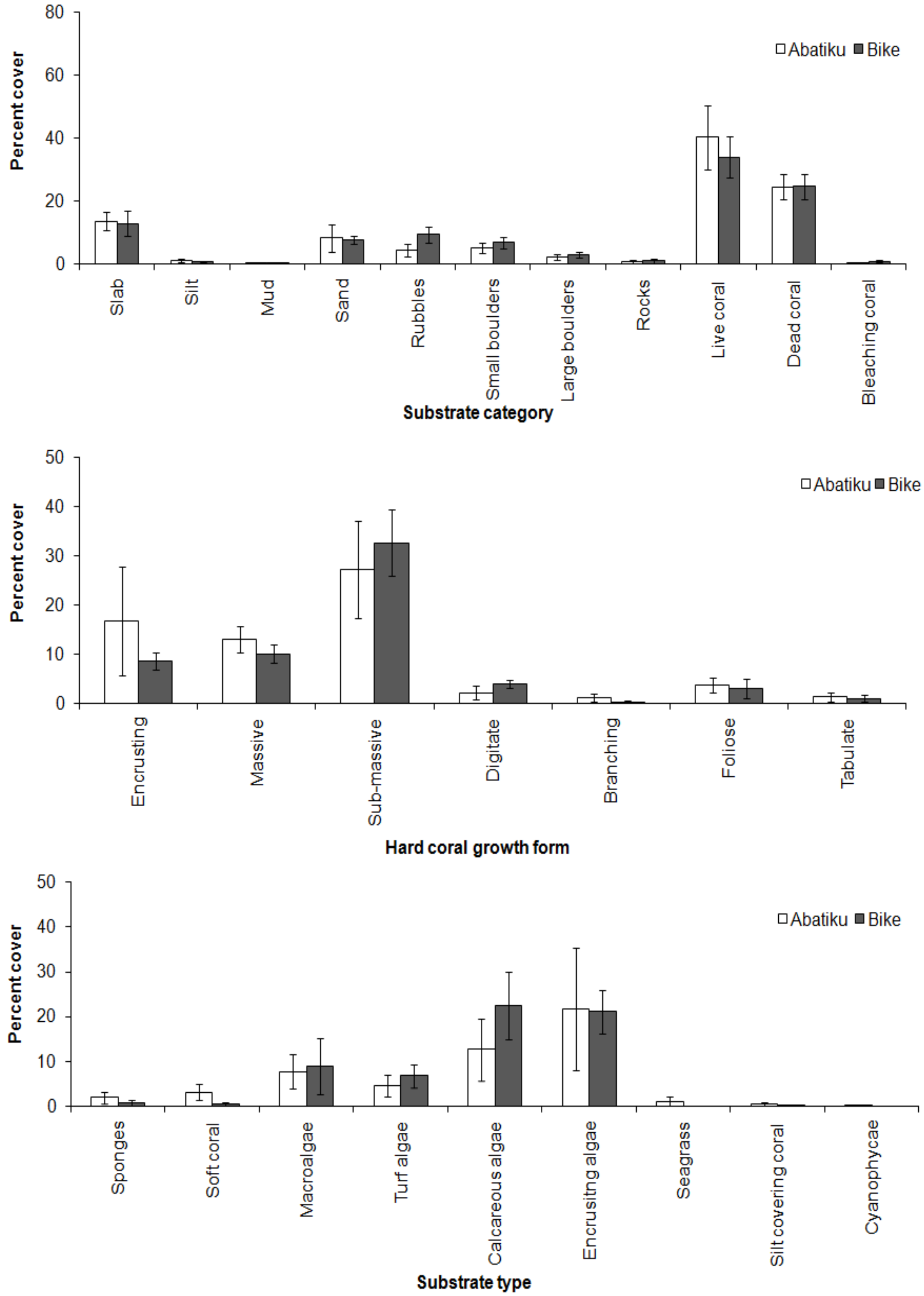

Figure 24 **Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate type (bottom) present at outer-reef habitats during finfish surveys at Abatiku and Bike monitoring stations, 2011.**

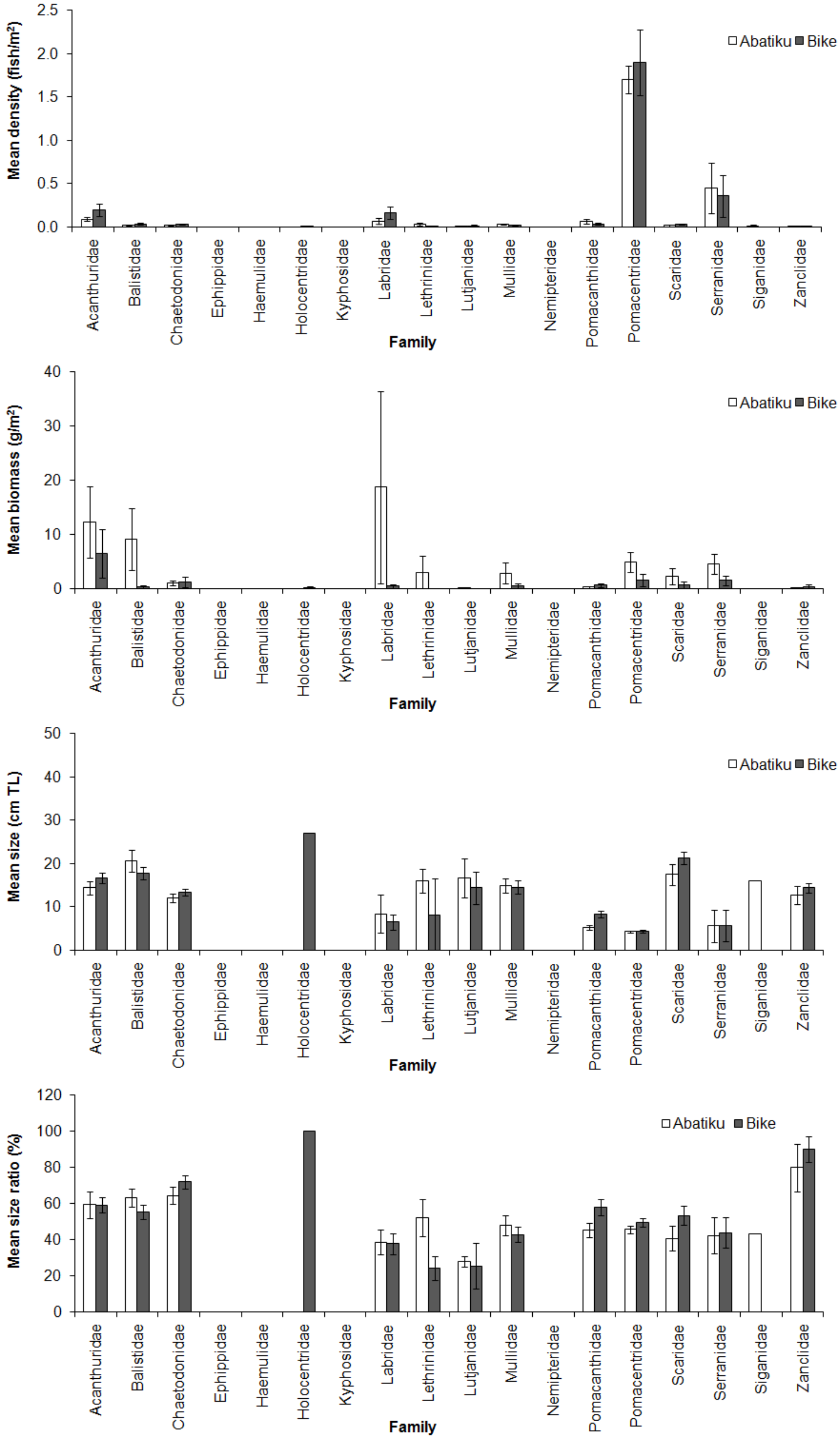

Figure 25 Profile of finfish indicator families in outer-reef habitats of Abatiku and Bike monitoring stations, 2011.

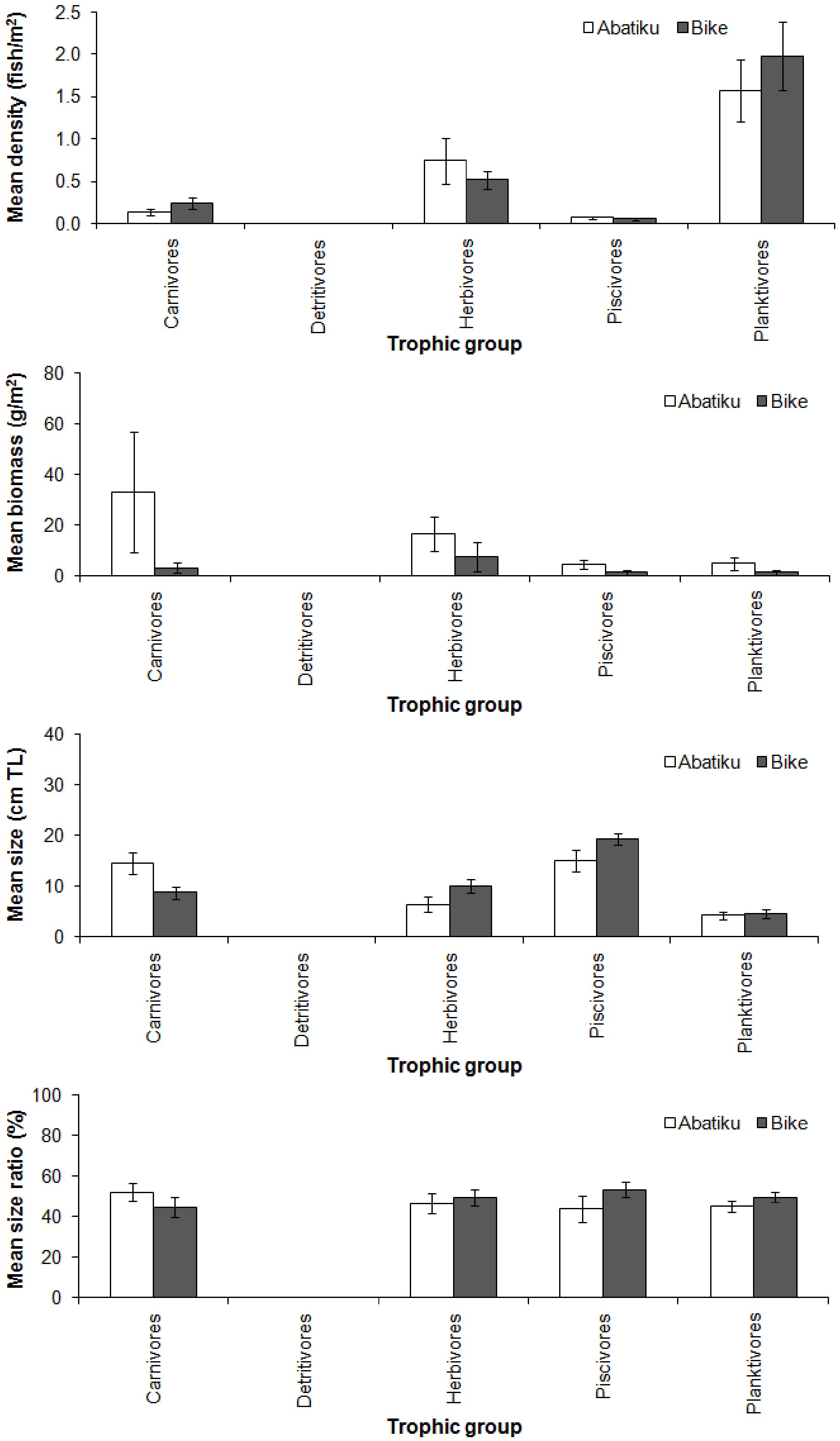

Figure 26 Profile of finfish by trophic level in outer-reef habitats of Abatiku and Bike monitoring stations, 2011.

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

Site	Species	Family	Density (fish/m²±SE)
Abatiku	*Chromis margaritifer*	Pomacentridae	0.46±0.12
	Pomacentrus coelestis	Pomacentridae	0.45±0.24
	Pseudanthias dispar	Serranidae	0.38±0.29
	Chromis vanderbilti	Pomacentridae	0.24±0.15
	Chromis ternatensis	Pomacentridae	0.17±0.09
Bike	*Chromis margaritifer*	Pomacentridae	0.62±0.15
	Chromis vanderbilti	Pomacentridae	0.42±0.18
	Pseudanthias dispar	Serranidae	0.32±0.24
	Chromis ternatensis	Pomacentridae	0.27±0.18
	Chromis weberi	Pomacentridae	0.19±0.10

Table 16 Finfish species with the highest biomass in outer-reef habitats of Abatiku and Bike monitoring sites, 2011. See Appendix 7 and 8 for a full list of biomass of individual fish species.

Site	Species	Family	Biomass (g/m²±SE)
Abatiku	*Cheilinus undulatus*	Labridae	17.86±17.86
	Ctenochaetus striatus	Acanthuridae	8.16±5.18
	Balistoides viridescens	Balistidae	6.04±6.04
	Gnathodentex aureolineatus	Lethrinidae	3.38±2.91
	Cephalopholis argus	Serranidae	3.01±1.43
Bike	*Ctenochaetus striatus*	Acanthuridae	16.11±9.48
	Acanthurus blochii	Acanthuridae	10.46±10.13
	Chlorurus sordidus	Scaridae	4.90±2.81
	Cephalopholis argus	Serranidae	3.91±1.83
	Acanthurus nigrofuscus	Acanthuridae	2.91±2.43

Comparisons with PROCFish surveys

Observed mean densities of Acanthuridae, Balistidae, Chaetodontidae, Lethrinidae, Lutjanidae, Scaridae and Zanclidae, and mean biomass of Balistidae, Chaetodontidae, Lethrinidae, Lutjanidae, and Scaridae, on outer-reefs were significantly higher during the PROCFish surveys than the current survey ($P < 0.05$) (Figure 27). As with both the back- and lagoon-reef comparisons, it should be noted that the PROCFish and current surveys were not conducted at exactly the same locations, thus these results may be at least partially influenced by spatial differences in habitat cover or depth among survey locations. Further monitoring of the stations established during this baseline event is required to determine whether these differences are consistent over time.

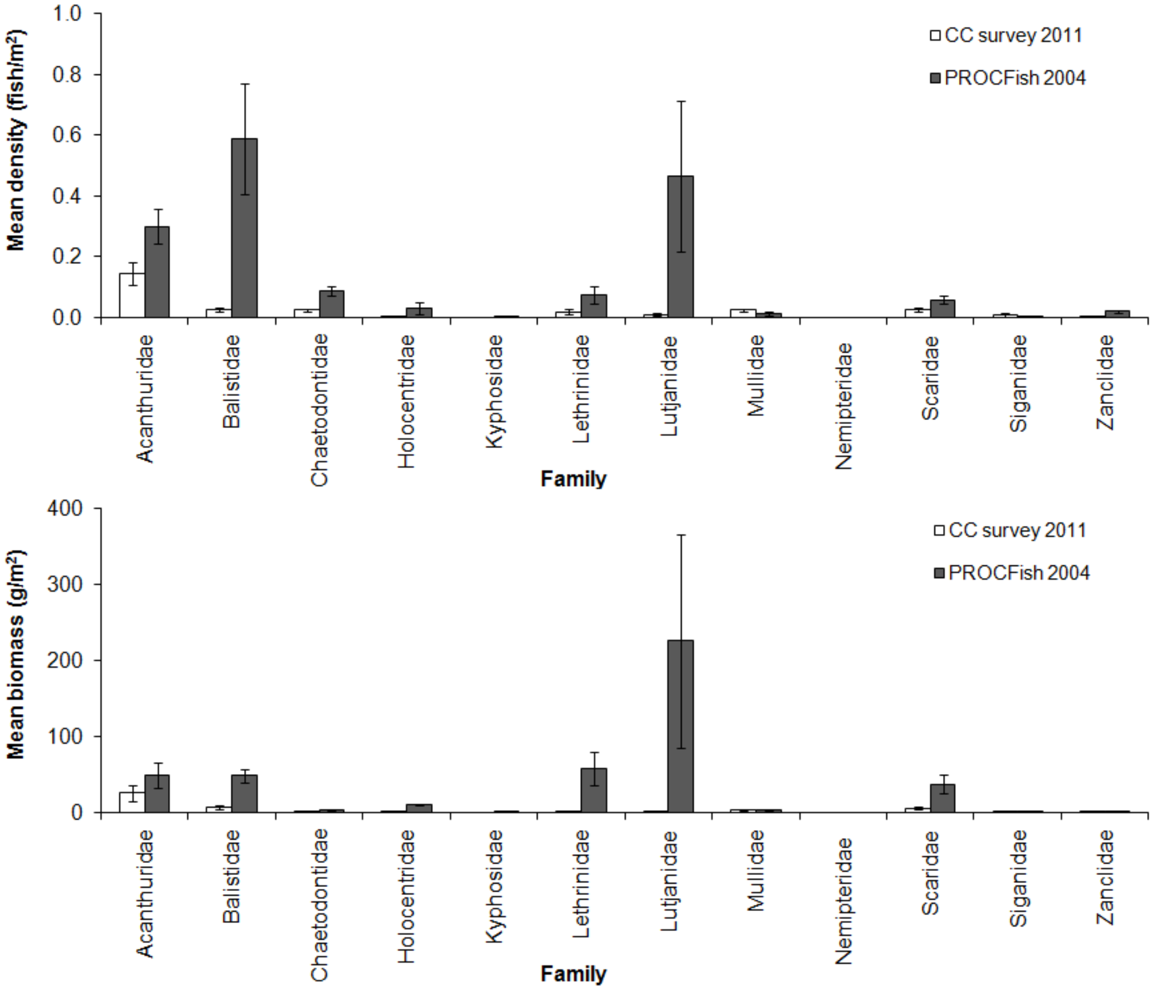

Figure 27: Comparison of mean density (top) and mean biomass (bottom) of finfish families (± SE) recorded from outer-reef habitats of Abemama atoll in the current (2011) survey and during PROCFish surveys in 2004.

6. Invertebrate Surveys

Methods and Materials

Data collection

Invertebrates

Three survey methods were used to assess the abundance, size and condition of invertebrate resources and their habitat at Abemama Atoll. Manta tows were used to provide a broad-scale assessment of invertebrate resources associated with reef areas. 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 28). Hand tally counters were also mounted on the manta board to assist with enumerating the common species on site. The snorkeler's observation belt was two metres wide and tows were conducted in depths typically ranging from one to ten metres. Each tow replicate was 300 m in length and was calibrated using the odometer function within the trip computer option of a Garmin 76Map GPS. Six x 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 within ten metres.

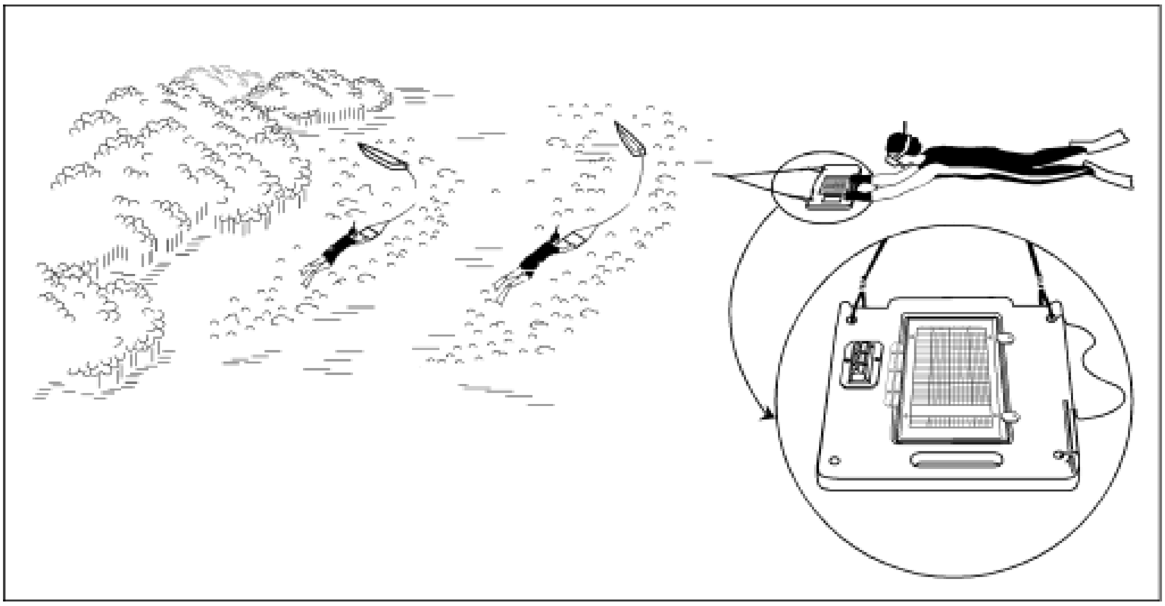

Figure 28 Broad-scale method: manta tow survey

To assess the abundance, size and condition of reef-associated invertebrate resources and their habitat at finer-spatial scales, reef-benthos transects (RBT) were conducted. Reef-benthos transects were conducted by two snorkelers 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 metres long with a one metre wide observation belt, conducted in depths ranging from one to three metres. The two snorkelers conducted three transects each, totalling six 40 m transects for each RBT station (Figure 29). The GPS position of each station was recorded in the centre of the station.

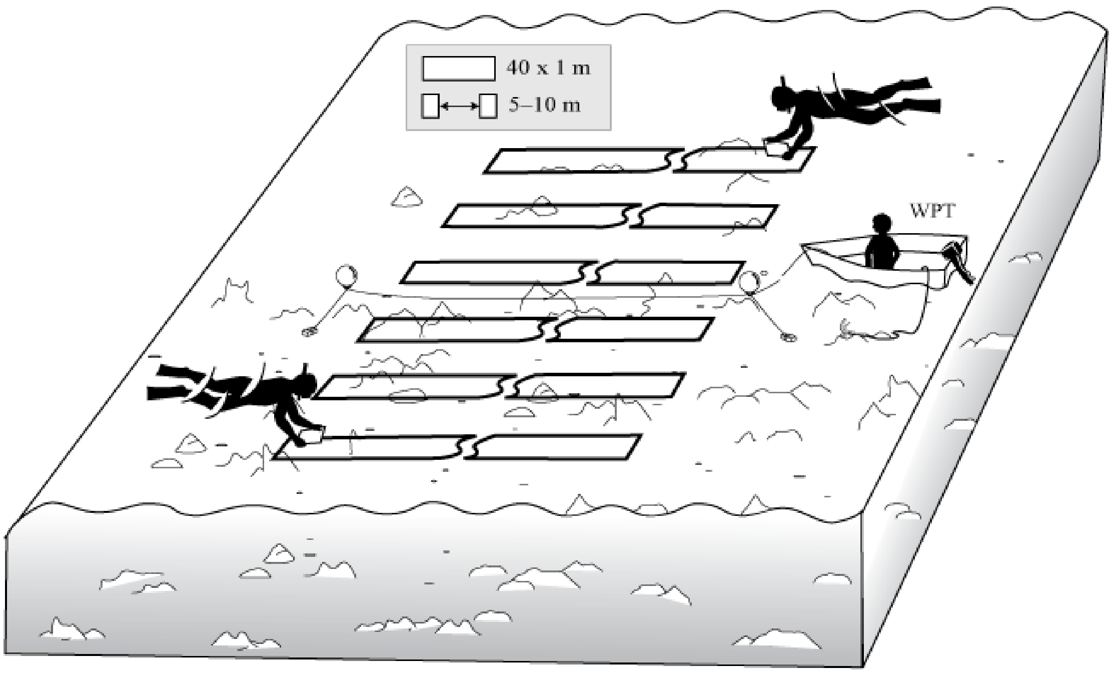

Figure 29 Fine-scale method: reef-benthos transects

To assess the range, abundance and size of infaunal invertebrates in soft sediment areas, infaunal quadrats assessments were conducted. Three people conducted the survey; two surveyors and a recorder (Figure 30). Eight sets of four randomly spaced quadrats were sampled every 5 to 6 metres along a 40 m transect line. The quadrats (25 x 25 cm) were thrown randomly either side of the line, and the sediment within the quadrat retrieved by hand down to approx 5-8 cm. Collected species were measured and recorded. This method targets invertebrates such as *Anadara* species and sea cucumber species associated with soft sediment and seagrass habitats.

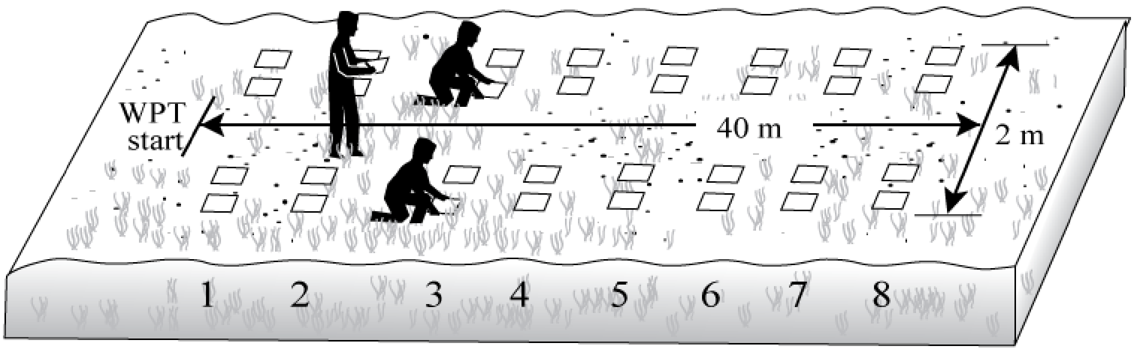

Figure 30 Soft-infaunal quadrat: fine-scale method

Habitats supporting invertebrates

Manta tow, reef benthos transects and soft benthos transects used the same survey form (Appendix 9) which also includes a section for substrate cover record (medium scale approach). Habitat is recorded in seven broad categories:

1. Relief and complexity
    - Relief – describes average height variation for hard and soft benthos (scale 1–5, with 1 = low relief and 5 = high relief);
    - Complexity – describes average surface variation for substrates (relative to places for animals to find shelter; scale 1–5, with 1= low complexity and 5 = high complexity);
2. Ocean influence – describes the distance and influence of area to open sea (scale 1–5, with 1 = low ocean influence and 5 = high ocean influence);
3. Depth – average depth of the surveyed area (in metres);
4. Substrate categories (totalling to 100%):
    - Soft sediments including (1) *mud*, (2) *mud and sand*, (3) *sand* and (4) *coarse sand*;
    - (5) *rubble* - small fragments of coral between 0.5 and 15 cm;
    - (6) *boulders* - detached big pieces of coral stone more than 30 cm;
    - (7) c*onsolidated rubble* - cemented pieces of coral and limestone debris,
    - (8) *pavement* - solid fixed flat limestone;
    - (9) *coral live* any live hard coral; and
    - (10) *coral dead* any dead carbonated edifices that are still in place and retain a general coral shape;
5. Other substrate types (recorded in occurrences not totalling 100%)
    - (11) s*oft coral*;
    - (12) *sponges*; and,
    - (13) *fungids*;
    - (14) *crustose coralline algae*;
    - (15) *coralline algae* (e.g. *Halimeda*);
    - (16) *other algae* - includes all fleshy macroalgae not having calcium carbonate deposits; and
    - (17) *seagrass* (e.g. *Halophila*);
6. Epiphytes and silt
    - Epiphytes – describes the coverage of filamentous algae such as turf algae on hard substrate (scale 1–5, with 1 = no cover and 5 = high cover);
    - Silt – easily suspended fine particles (scale 1–5, as 1 = no silt and 5 = high silt);
7. Bleaching - the percentage of bleached live coral.

Data analysis

In this report, the status of invertebrate resources 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 species per habitat and site divided by the number of stations;
3) mean density per station (individuals/ha);
4) mean size (mm).

As with the finfish analyses, relationships between environmental parameters and invertebrate resources have not been fully explored in this baseline report. To explore differences in invertebrate densities and their habitats among sites, density data for each individual invertebrate species, and habitat categorical data, of each transect was square-root transformed to reduce heterogeneity of variances and analysed by one-way ANOVA at $P = 0.05$, using Statistica 7.1. Where transformed data failed Cochran's test for homogeneity of variances ($P < 0.05$), an increased level of significance of $P = 0.01$ was used. Additionally, density data from the current study were compared against that collected during the PROCFish surveys in Abemama Atoll region in 2004 (Awira et al. 2008) for both manta tow and RBT methodologies using one-way ANOVA. As the PROCFish data was collected from across Abemama Atoll, the data for Abatiku and Bike collected during the present study were combined for these analyses. Comparisons were conducted based on data from similar habitat types only (i.e. reef-flat and back-reefs) (Figure 36).

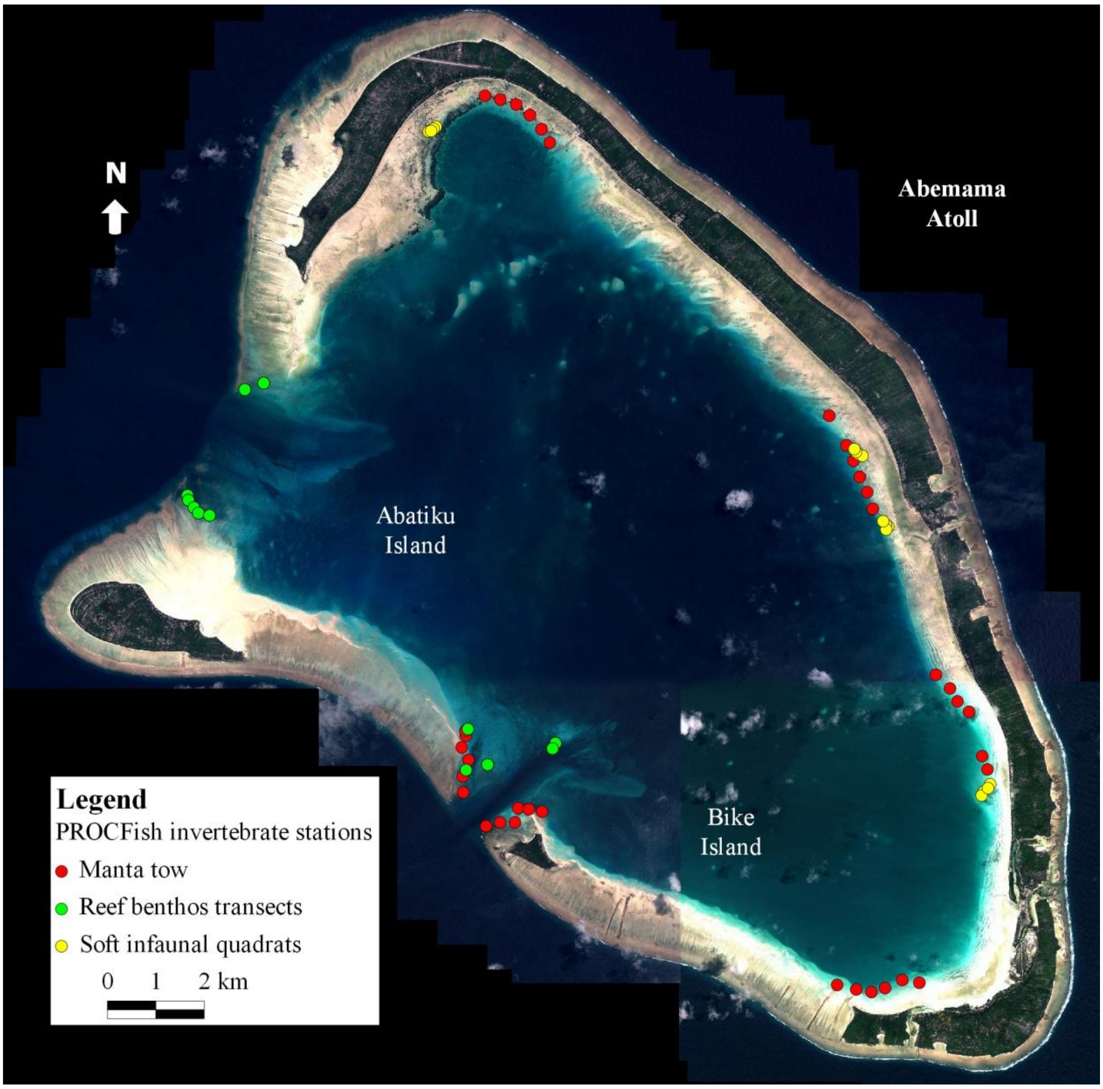

Figure 31 Location of PROCFish invertebrate survey sites at Abemama Atoll used to compare against data collected during the current (2011) study.

Results

Manta tow

Survey coverage

A total of 12 manta tow stations were established during the baseline assessment, with seven manta tow stations established at the Abatiku site and five manta tow stations established at Bike. All manta tows were conducted in reef flat and back-reef habitats of Abemama Atoll, covering more than 40,000 m^2 (Figure 32; Table 17).

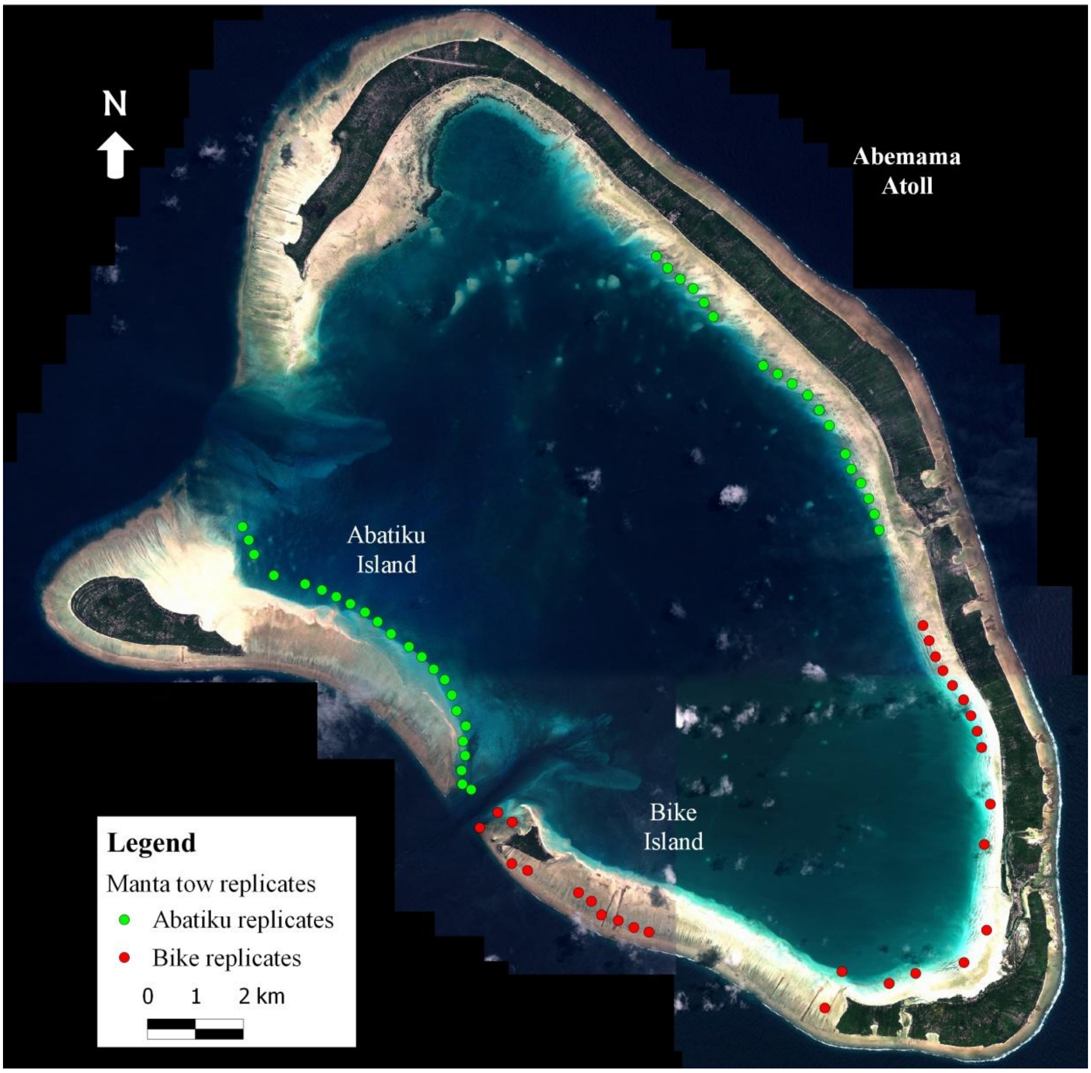

Figure 32 Locations of manta tow replicates established at the Abatiku and Bike monitoring stations, 2011.

Table 17 Summary of manta tow stations established within the Abatiku and Bike monitoring sites, 2011

Site	Number of stations	Total number of replicates	Area surveyed (m^2)
Abatiku	7	47	28,200
Bike	5	28	16,800

Habitats supporting invertebrates

Within both the Abatiku and Bike monitoring sites, the substrate was comprised largely of sand, followed by live corals, rubbles and dead corals (Figure 33). Habitats where manta tows were conducted at Abatiku had a slightly greater relief, complexity and oceanic influence, and a higher cover of live corals and other algae than those at Bike, while habitats at Bike had a greater cover of coralline algae and seagrass than those at Abatiku ($P < 0.05$) (Figure 33). A full list of percent cover of each habitat variable recorded during the manta tow surveys can be found in Appendix 12.

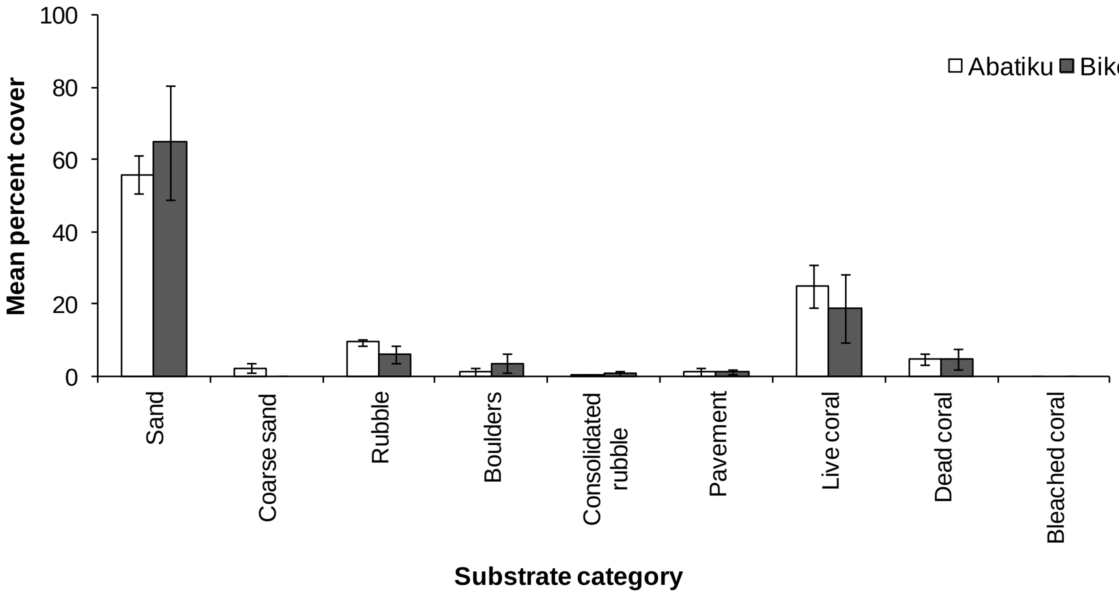

Figure 33 Mean percent cover of each major substrate category of manta tow survey stations at Abatiku and Bike monitoring stations, 2011.

Invertebrate surveys

A total of ten species were observed during the manta tow surveys, with six species recorded within the Abatiku stations and seven species recorded within the Bike stations. Individual species observed in the highest mean densities during the manta tow surveys at the Abatiku site included the giant clam *Tridacna maxima* (483.73±304.77 individuals/ha), the gastropod *Conomurex luhuanus*[2] (203.57±101.56 individuals/ha) and the bivalve *Anadara uropigimelana*[3] (96.03±82.58 individuals/ha). The individual species observed in the highest densities at Bike were the sea cucumber *Holothuria atra* (255.56±117.55 individuals/ha) and the bivalve *A. uropigimelana* (111.11±111.11 individuals/ha) (Figure 34). Mean densities of *T. maxima* and *C. luhuanus* were higher at the Abatiku stations than those at Bike, while the mean densities of *H. atra* and the urchin *Echinothrix diadema* were significantly higher at Bike than Abatiku ($P < 0.05$). A full list of densities for individual species can be found in Appendix 13.

[2] This species was formerly known as *Strombus luhuanus*
[3] This species was formerly known as *Anadara holoserica*

Table 18 Total number of genera and species, and diversity, of invertebrates observed during manta tow surveys at Abatiku and Bike monitoring stations, 2011.

Parameter	Site	
	Abatiku	Bike
No. of genera	6	6
No. of species	6	7
Diversity	0.9	1.4

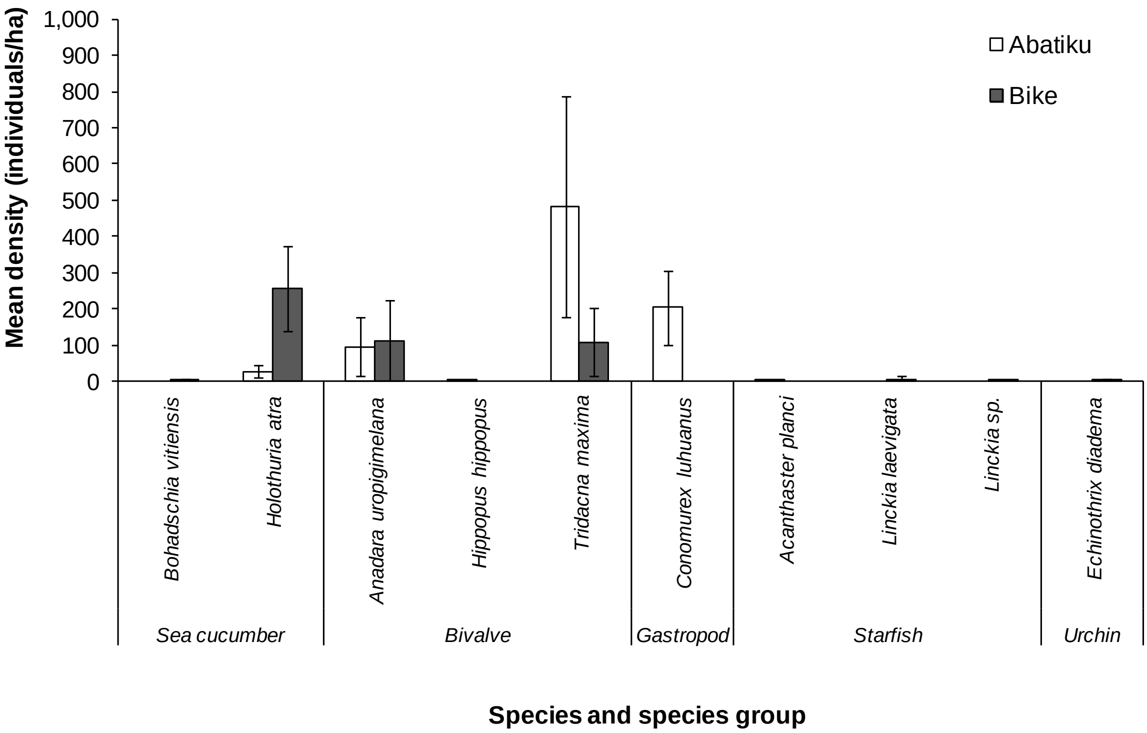

Figure 34 Overall mean density (± SE) of invertebrates species observed during manta tow surveys within the Abatiku and Bike monitoring stations, 2011.

Comparisons with PROCFish (2004) surveys

Mean densities of the sea cucumber *Holothuria atra*, the bivalves *Spondylus* sp. and *Spondylus squamosus*, and the gastropod *Conomurex luhuanus* were significantly higher during the PROCFish (2004) surveys than the current (2011) survey ($P < 0.05$) (Figure 35). It should be noted that while these surveys were conducted in the same general habitats, they were not conducted at the same locations, and as such these results may be at least partially influenced by spatial differences among locations. Further monitoring of the stations established during this baseline event is required to determine whether these differences are consistent over time.

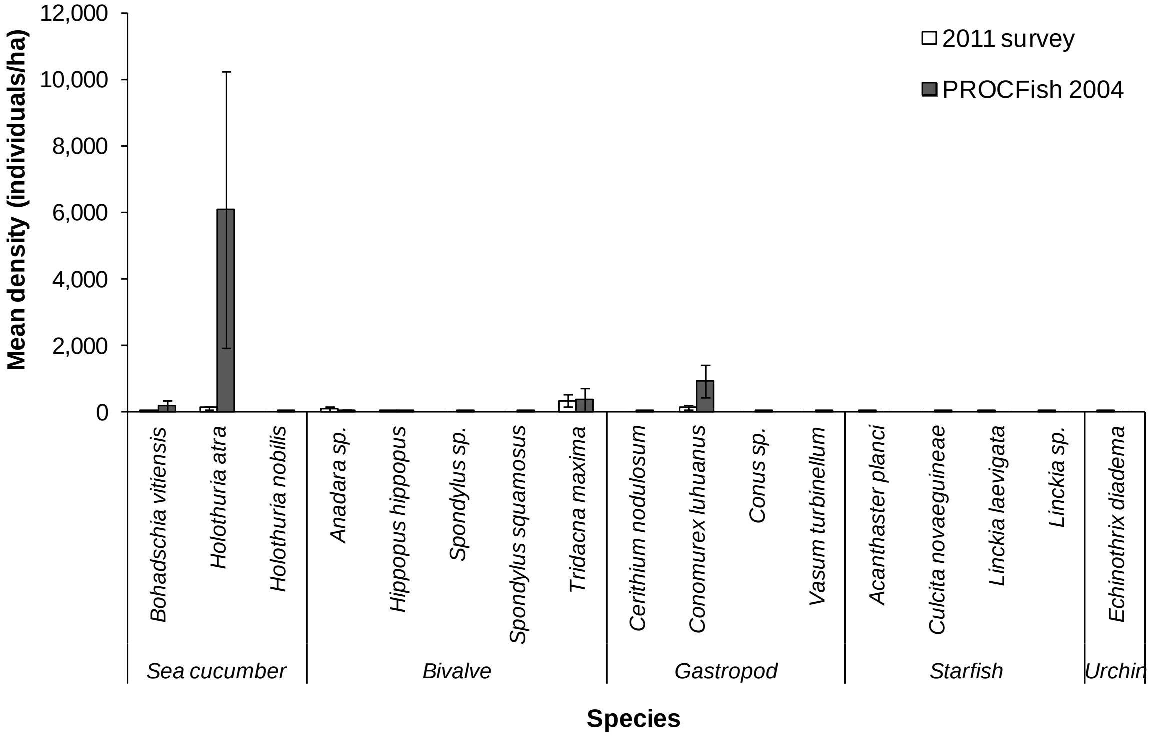

Figure 35 **Comparison of mean density (± SE) of invertebrates recorded from during manta tow surveys at Abemama Atoll during the current (2011) and PROCFish (2006) surveys.**

Reef-benthos transects

Survey coverage

A total of 10 RBT stations were established within the two monitoring sites: with five stations established at each of the Abatiku and Bike sites (Figure 36). GPS positions of all RBT stations are tabulated in Appendix 11.

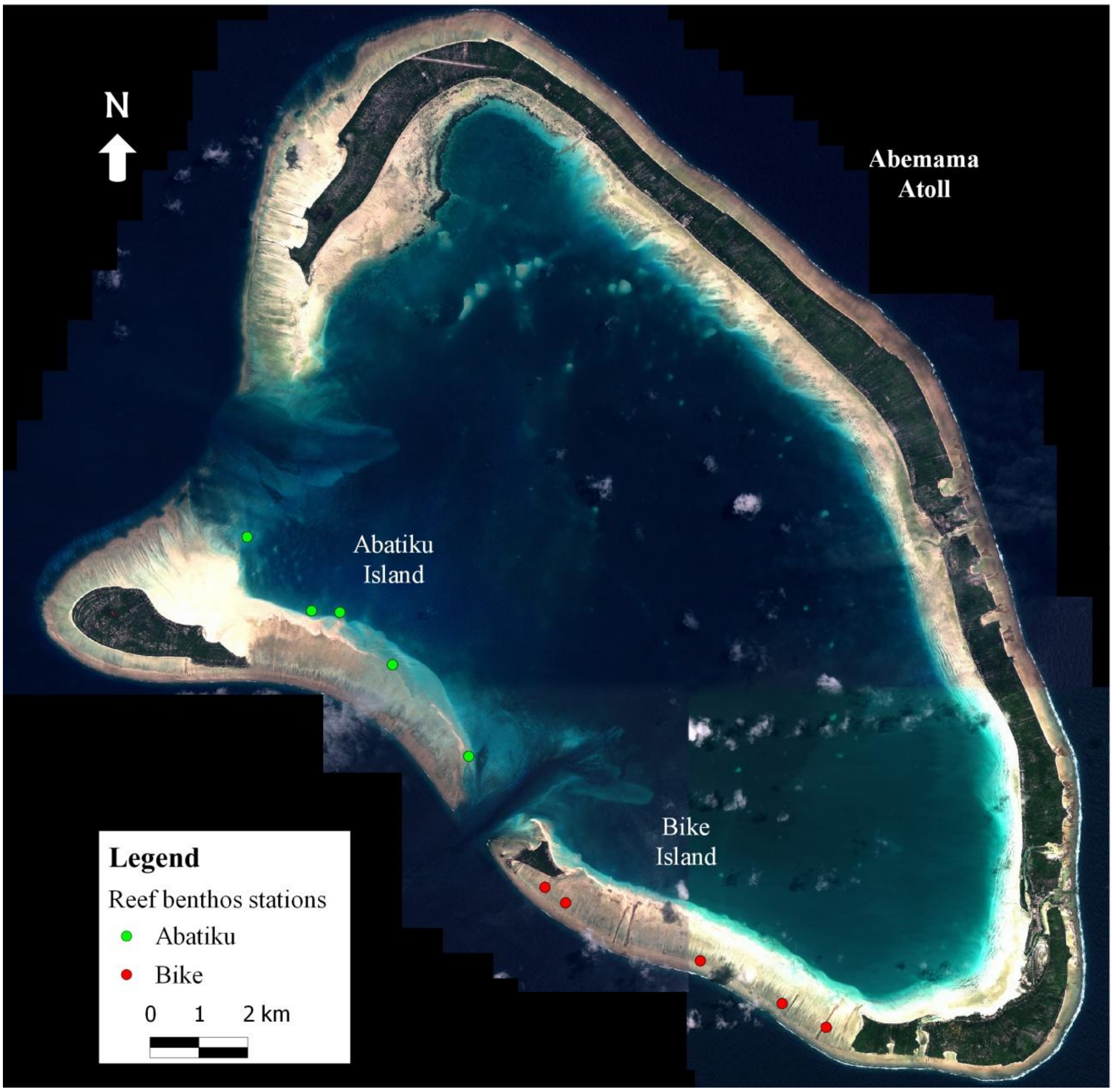

Figure 36 **Locations of reef-benthos transect (RBT) stations established at the Abatiku and Bike monitoring sites, 2011. Six x 40 m replicate transects were completed at each RBT station.**

Table 19 **Summary of reef-benthos transect stations established within the Abatiku and Bike monitoring sites, 2011**

Site	Number of stations	Total number of replicates	Area surveyed (m^2)
Abatiku	5	30	1,200
Bike	5	30	1,200

Habitats supporting invertebrates

Sand was the dominant substrate type where the RBT stations were established at both Abatiku and Bike, followed by live corals, dead corals, rubbles and boulders (Figure 37). Habitats where RBT stations were established at Abatiku had a slightly greater complexity, and a higher cover of live corals than those at Bike, while habitats at Bike had a greater cover of boulders than those at Abatiku ($P < 0.05$) A full list of percent cover of each habitat variable recorded during the RBT surveys can be found in Appendix 14.

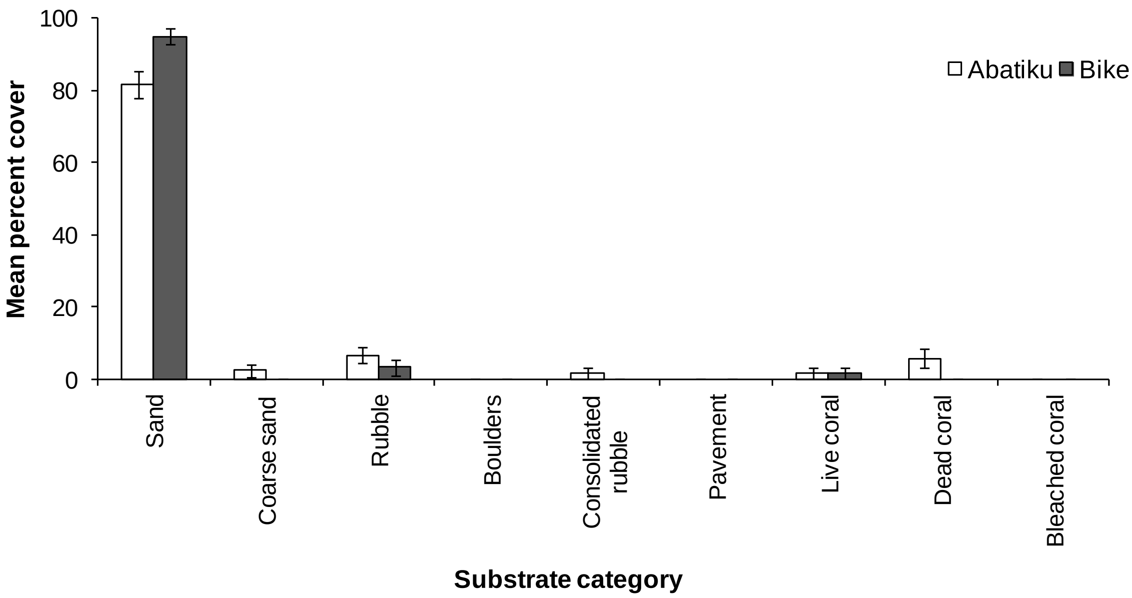

Figure 37 Mean percent cover (± SE) of each major substrate category of RBT survey stations at Abatiku and Bike monitoring stations, 2011.

Invertebrate surveys

A total of 15 species were observed during the RBT surveys at Abatiku, while nine species were observed during the RBT surveys at Bike (Table 20). Within the Abatiku stations, *Dendropoma maximum* had the highest density, with 13208.33±6277.88 individuals/ha, followed by *Conomurex luhuanus* (2241.67±2231.26 individuals/ha), and *Tridacna maxima* (2441.67±1040.80 individuals/ha). At Bike, the individual species with the highest mean densities were the bivalve *Tridacna maxima* (791.67±296.68 individuals/ha) and the gastropods *Dendropoma maximum* (258.33±153.88 individuals/ha) and *Monetaria annulus*[4] (166.67±166.67 individuals/ha) (Figure 38). Mean densities of *D. maximum* were significantly higher at Bike stations than those at Abatiku ($P < 0.05$). *Tridacna maxima* within the Abatiku stations were slightly larger compared to those within the Bike monitoring stations (Table 21). No differences in mean size were apparent for any other species common to both Abatiku and Bike monitoring sites (Table 21). A full list of densities of individual species can be found in Appendix 15.

[4] This species was formerly known as *Cypraea annulus*

Table 20 Total number of genera and species, and diversity of invertebrates observed during RBT surveys at Abatiku and Bike monitoring stations, 2011.

Parameter	Site	
	Abatiku	Bike
No. of genera	12	8
No. of species	15	9
Diversity	3.0	1.8

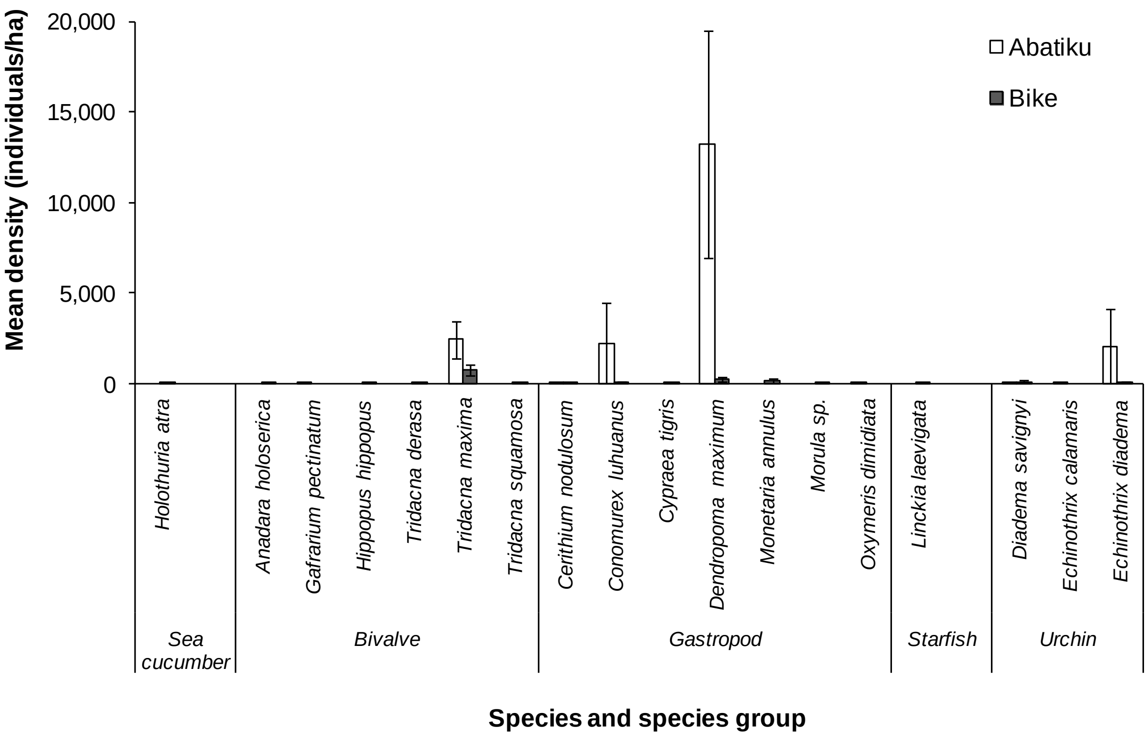

Figure 38 Overall mean density (± SE) of invertebrates species observed during reef benthos transects at the Abatiku and Bike monitoring stations, 2011.

Table 21 Mean size (± SE) of measured invertebrates during reef-benthos transects at Abatiku and Bike, 2011.

Group	Species	Mean size (mm)	
		Abatiku	Bike
Bivalve	*Tridacna maxima*	91.2±2.9	67.3±2.8
Gastropod	*Cerithium nodulosum*	69.0±4.0	80.0±0.0
Gastropod	*Conomurex luhuanus*	41.8±1.1	41.7±5.4
Gastropod	*Oxymeris dimidiata*[5]	37.5±12.5	-

[5] This species was formerly known as *Terebra dimidiata*

Comparisons with PROCFish (2004) surveys

Mean densities of the giant clam *Tridacna maxima* were significantly higher during the PROCFish (2004) surveys than the current (2011) survey (P < 0.05) (Figure 39). In contrast, mean densities of the gastropods *Dendropoma maximum* and *Conomurex luhuanus*, and the urchin *Diadema savignyi*, were significantly greater in the current survey than the PROCFish survey (P < 0.05) (Figure 39). It should be noted that while these surveys were conducted in the same general habitats, they were not conducted at the same locations, and as such these results may be at least partially influenced by spatial differences among locations. Further monitoring of the stations established during this baseline event is required to determine whether these differences are consistent over time.

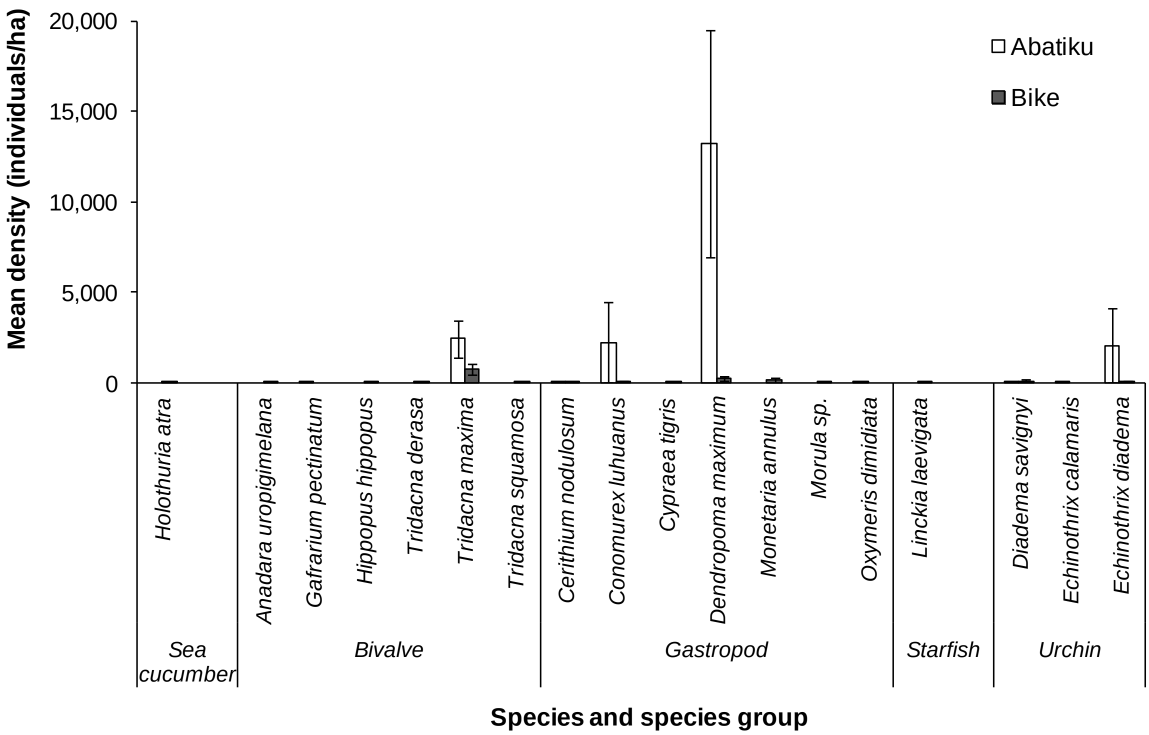

Figure 39 **Comparison of mean density (± SE) of invertebrates recorded during reef benthos transect surveys at Abemama Atoll during the current (2011) and PROCFish (2004) surveys.**

Soft-infaunal quadrats

Survey coverage

A total of 12 soft infaunal quadrat (SIQ) stations were established, with 6 stations established in each of the Abatiku and Bike sites (Figure 40; Table 22). GPS positions of all SIQ stations are tabulated in Appendix 11.

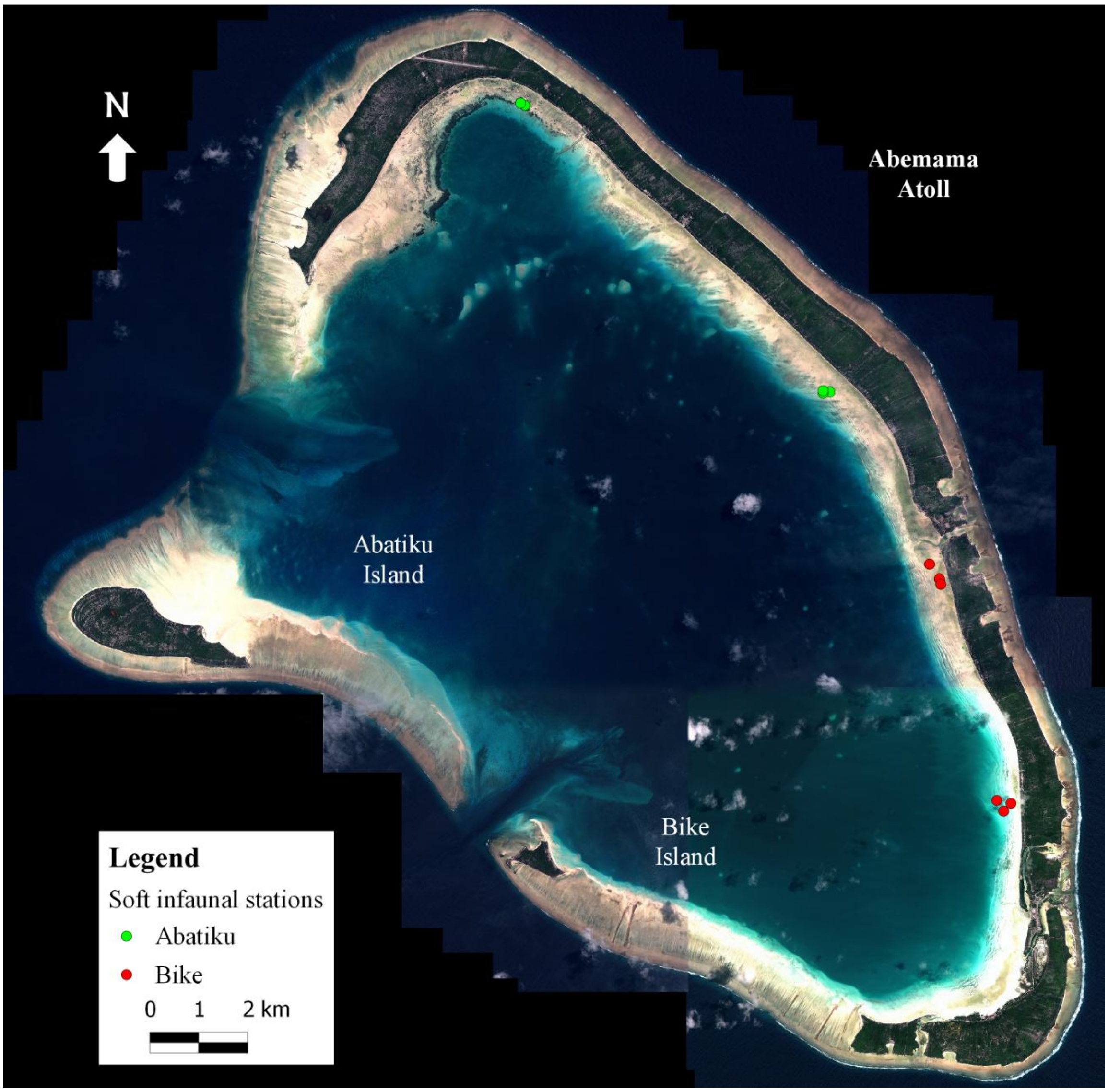

Figure 40 Locations of soft-infaunal quadrat (SIQ) stations established at the Abatiku and Bike monitoring sites, 2011.

Table 22 Summary of soft infaunal quadrat stations established within the Abatiku and Bike monitoring sites, 2011

Site	Number of stations	Total number of replicates	Area surveyed (m^2)
Abatiku	6	6	12
Bike	6	6	12

Habitat supporting invertebrates

Sand was the dominant substrate cover where the SIQ stations were established at both the Abatiku and Bike monitoring sites. There were fragments of rubble, live and dead corals present within both Abatiku and Bike stations (Figure 41). The mean cover of sand within the Bike stations was slightly higher than those of Abatiku ($P < 0.05$). A full list of percent cover of each habitat variable recorded during the SIQ surveys can be found in Appendix 16.

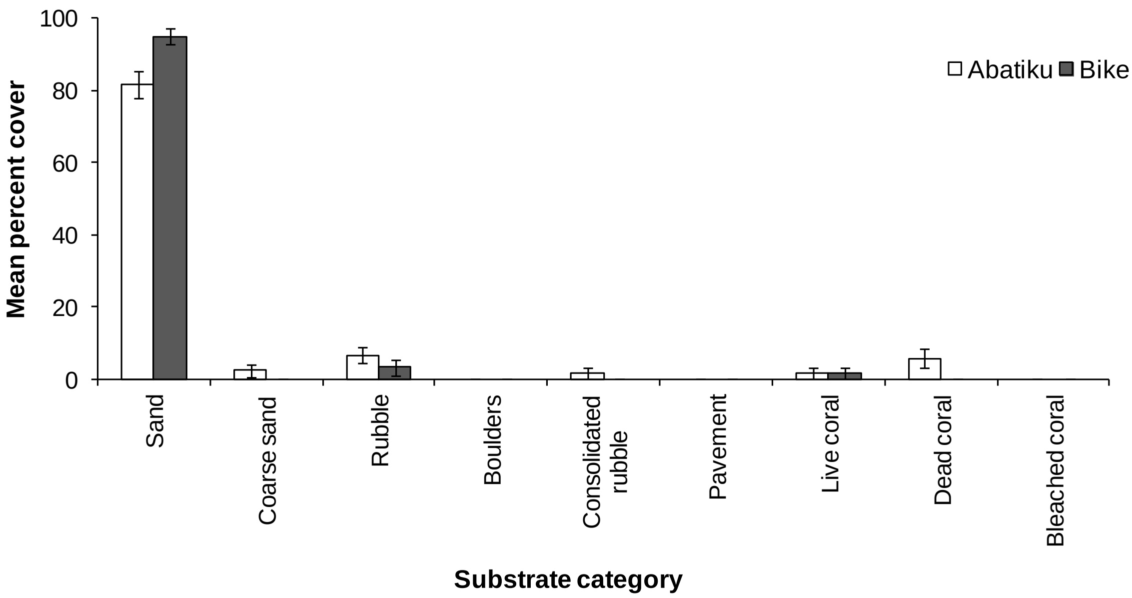

Figure 41 Mean percent cover (± SE) of each major substrate category of SIQ survey stations at Abatiku and Bike monitoring stations, 2011.

Invertebrate survey

Six invertebrate species were observed during the SIQ surveys at Abatiku, while 13 species were observed during the SIQ surveys at Bike (Table 23). Within the Abatiku stations, the bivalve *Anadara uropigimelana* had the highest mean density, with 60,000.00±6324.55 individuals/ha, followed by *Gafrarium pectinatum* (57,500.00±39,322.38 individuals/ha) and *Holothuria atra* (16,666.67±9632.12 individuals/ha). The individual species observed in the highest mean densities at Bike included the sea cucumber *Holothuria atra* (247,500±156,598 individuals/ha), the bivalve *Anadara uropigimelana* (85,833±69,599 individuals/ha) and the gastropod *Conomurex luhuanus* (15,000±15,000 individuals/ha) (Figure 42). No significant differences in mean density were observed among the sites. A full list of density by individual species can be found in Appendix 17. *Holothuria atra* within the Abatiku stations were larger compared to the Bike monitoring stations, with a mean size of 93.5±7.4 mm vs. 47.7±2.62 mm, respectively, while the bivalve *Gafrarium pectinatum* and the gastropod *Conomurex luhuanus* were slightly larger at Bike than Abatiku. No differences in mean size were apparent for any other species common to both

Abatiku and Bike monitoring sites. A full list of densities of individual species can be found in Appendix 17.

Table 23 Total number of genera and species, and diversity, of invertebrates observed during soft-infaunal quadrat assessments at Abatiku and Bike monitoring stations, 2011.

Parameter	Site	
	Abatiku	Bike
No. of genera	6	12
No. of species	6	13
Diversity	1	2.17

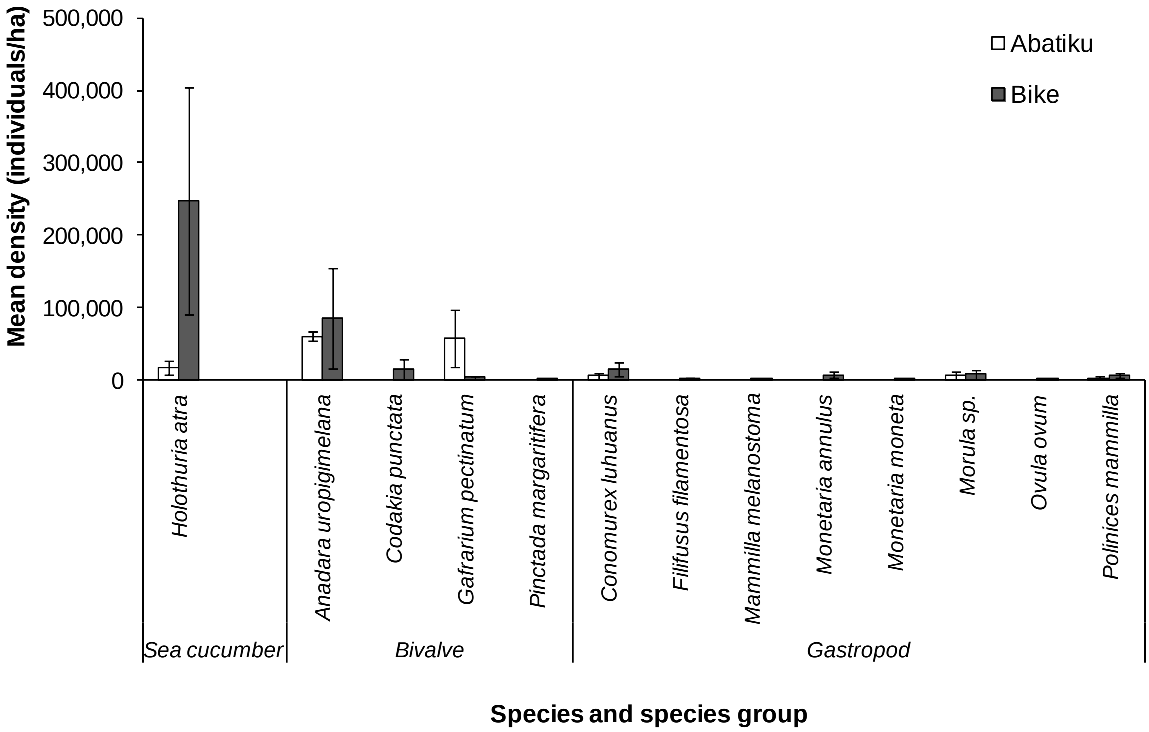

Figure 42 Mean density (± SE) of invertebrates species observed during soft infaunal quadrat surveys at the Abatiku and Bike monitoring stations, 2011.

Table 24 Mean size (± SE) of measured invertebrates during soft-infaunal quadrats at Abatiku and Bike, 2011.

Group	Species	Mean size	
		Abatiku	Bike
Sea cucumber	*Holothuria atra*	93.5±7.4	47.7±2.6
Bivalve	*Anadara uropigimelana*	39.1±1.7	43.1±2.0
	Gafrarium pectinatum	26.1±1.0	33.0±3.4
Gastropod	*Conomurex luhuanus*	36.4±1.4	39.6±0.6
	Filifusus filamentosus[6]	-	37.0±7.0
	Monetaria annulus	-	17.5±1.1
	Morula sp.	13.3±1.7	14.5±0.5
	Polinices mammilla	25.0±0	27.0±1.4

Comparisons with PROCFish (2004) surveys

No significant differences in mean density were observed for any invertebrate species during the SIQ assessments of the PROCFish (2004) and current (2011) surveys (Figure 43).

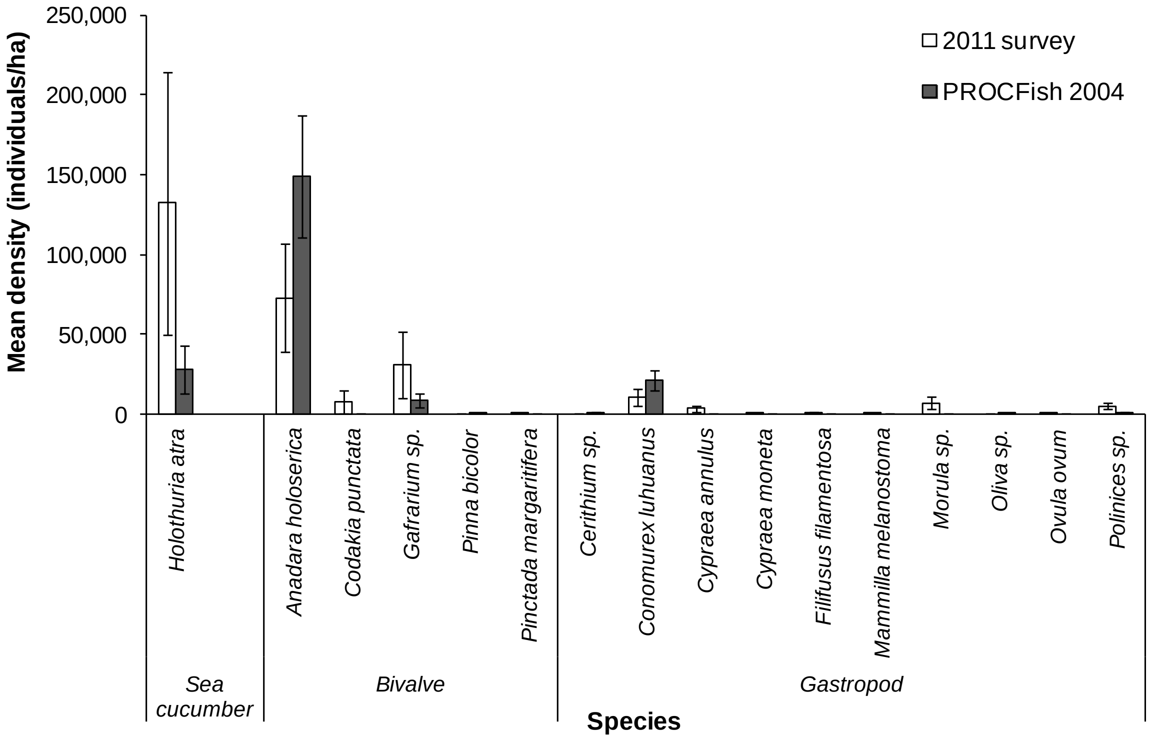

Figure 43 Comparison of mean density (± SE) of invertebrates recorded during reef benthos transect surveys at Abemama Atoll during the current (2011) and PROCFish (2004) surveys.

[6] This species was formerly known as *Pleuroploca filamentosa*

7. Capacity Building

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

A week of training was conducted before the actual baseline assessment for both finfish and invertebrate surveys. A total of nine people were trained: six officers from Fisheries headquarters in Tarawa and three fisheries officers from Provincial Fisheries of Arorae, Nonouti and Maiana (Table 25). The training initially consisted of classroom sessions where assessment methods and survey forms were explained in detail and slideshows of local species were presented to assist with identification. This was followed by field activities where the trainees practiced a method, as well as species identification (Figure 44). Only when the results of the trainees were consistent with senior project staff were the trainees able to participate in the baseline assessment.

Table 25 List of trainees who participated in the baseline assessment

Names	Title	Organisation
Taamwaa Batiromaio	Fisheries Assistant	Nonouti Island
Iakoba Ierutia	Fisheries Assistant	Fisheries HQ
Samuelu Ioane	Fisheries Assistant	Arorae Island
Max Peter	Fisheries Assistant	MFMRD HQ
Tukee Teema	Senior Fisheries Officer	Fisheries HQ
Toaea Beiateuea	Senior Fisheries Research Assistant	Fisheries HQ
Timon Ribanti	Fisheries Assistant	Fisheries HQ
Erietera Aram	Fisheries Assistant	Maiana Island
Favae Nauto	Fisheries Assistant	Fisheries HQ

Figure 44 Kiribati participants undertaking habitat assessment survey training at Abemama Atoll.

8. Recommendations for Future monitoring

The following recommendations are proposed for future monitoring events:

- Due to logistical difficulties at the time of survey, no back-reef transects were completed at the Abatiku monitoring site. As a priority, these transects should be established during follow-up surveys.

- The differences observed in densities and biomass of several finfish families and invertebrates common to the current study and the PROCFish (2004) survey is of considerable concern, as it indicates a significant reduction in coastal resources over a short-term period. Further monitoring of the locations surveyed in this baseline assessment is required to determine whether these differences are consistent over time.

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

- During the baseline assessment, 10 RBT stations were established; with five RBT stations established at each site. To increase the power of these surveys to detect differences over time, it is recommended that additional reef benthos transects be established on both sites.

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Appendix 1 GPS positions of benthic habitat assessment transects

Site	Habitat	Station ID	Latitude	Longitude
Abatiku 1	Lagoon-reef	TRA07	173.80647	0.39133
	Lagoon-reef	TRA08	173.80647	0.39133
	Lagoon-reef	TRA09	173.80672	0.39100
	Outer-reef	TRA04	173.75882	0.40078
	Outer-reef	TRA05	173.75863	0.40090
	Outer-reef	TRA06	173.75863	0.40090
Abatiku 2	Lagoon-reef	TRA10	173.79475	0.40872
	Lagoon-reef	TRA11	173.79470	0.40908
	Lagoon-reef	TRA12	173.79373	0.41008
	Outer-reef	TRA16	173.75407	0.39102
	Outer-reef	TRA17	173.75410	0.39097
	Outer-reef	TRA18	173.75408	0.39003
Bike 1	Back-reef	TRA26	173.84937	0.34888
	Back-reef	TRA27	173.84853	0.35038
	Outer-reef	TRA19	173.83605	0.34488
	Outer-reef	TRA20	173.83642	0.34455
	Outer-reef	TRA21	173.83598	0.34488
Bike 2	Back-reef	TRA29	173.85188	0.34175
	Back-reef	TRA30	173.85170	0.34173
	Back-reef	TRA31	173.85172	0.34182
	Lagoon-reef	TRA32	173.85550	0.35453
	Lagoon-reef	TRA33	173.85562	0.35450
	Lagoon-reef	TRA34	173.85395	0.35535
	Outer-reef	TRA22	173.84490	0.33460
	Outer-reef	TRA23	173.84502	0.33453
	Outer-reef	TRA24	173.84502	0.33453

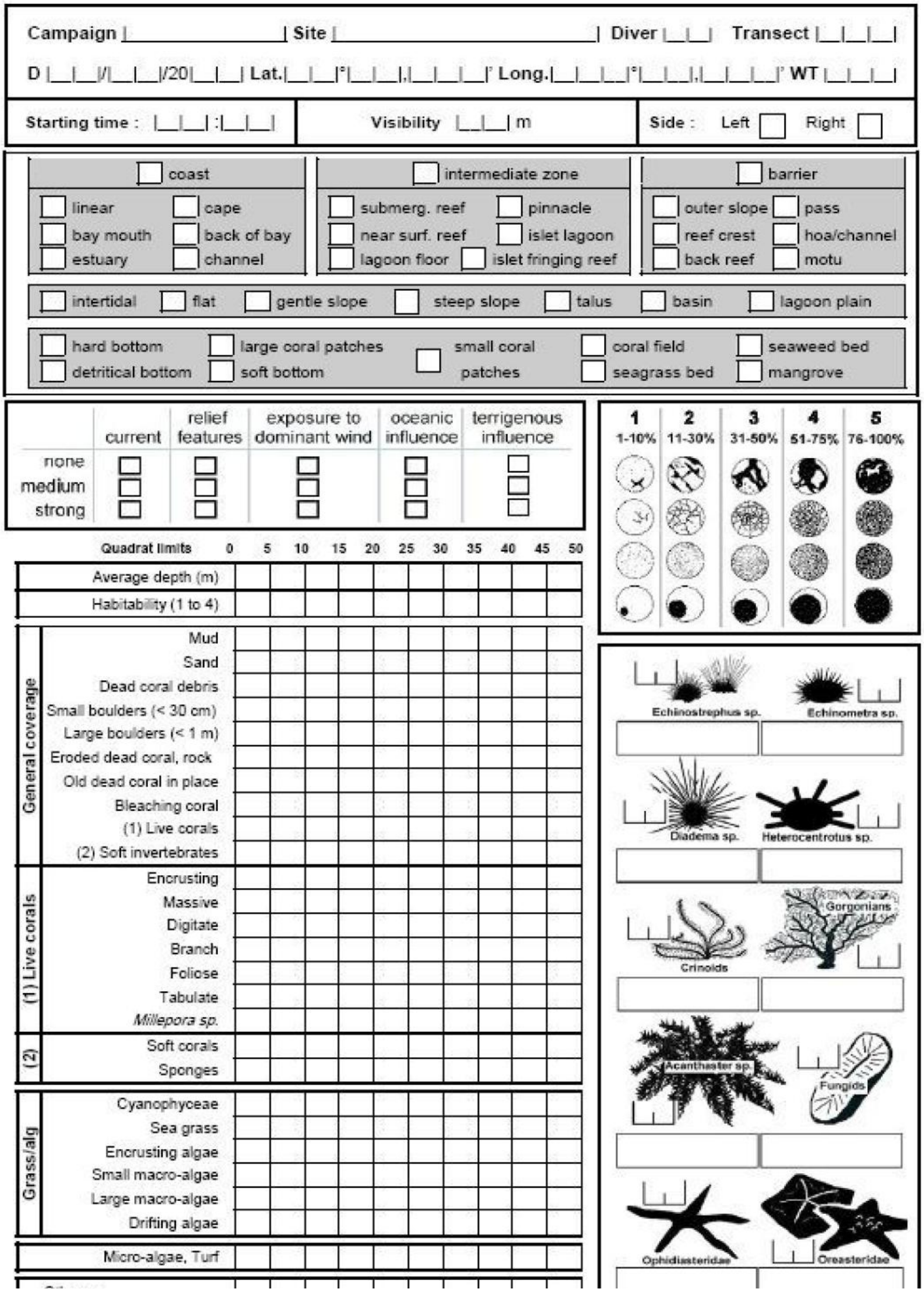
Appendix 2: Finfish distance-sampling underwater visual census (D-UVC) survey form

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

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

ST	SCIENTIFIC NAME	NBER	LGT	D1	D2	COMMENTS

Appendix 3: Form used to assess habitats supporting finfish



Campaign |________| Site |________| Diver |_|_| Transect |_|_|_|

D |_|_|/|_|_|/20|_|_| Lat.|_|_|°|_|_|,|_|_|_|' Long.|_|_|_|°|_|_|,|_|_|_|' WT |_|_|_|

Starting time : |_|_| :|_|_| Visibility |_|_| m Side : Left ☐ Right ☐

☐ coast: ☐ linear ☐ cape ☐ bay mouth ☐ back of bay ☐ estuary ☐ channel

☐ intermediate zone: ☐ submerg. reef ☐ pinnacle ☐ near surf. reef ☐ islet lagoon ☐ lagoon floor ☐ islet fringing reef

☐ barrier: ☐ outer slope ☐ pass ☐ reef crest ☐ hoa/channel ☐ back reef ☐ motu

☐ intertidal ☐ flat ☐ gentle slope ☐ steep slope ☐ talus ☐ basin ☐ lagoon plain

☐ hard bottom ☐ detritical bottom ☐ large coral patches ☐ soft bottom ☐ small coral patches ☐ coral field ☐ seagrass bed ☐ seaweed bed ☐ mangrove

	current	relief features	exposure to dominant wind	oceanic influence	terrigenous influence
none	☐	☐	☐	☐	☐
medium	☐	☐	☐	☐	☐
strong	☐	☐	☐	☐	☐

1	2	3	4	5
1-10%	11-30%	31-50%	51-75%	76-100%

	Quadrat limits	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
	Average depth (m)										
	Habitability (1 to 4)										
General coverage	Mud										
	Sand										
	Dead coral debris										
	Small boulders (< 30 cm)										
	Large boulders (< 1 m)										
	Eroded dead coral, rock										
	Old dead coral in place										
	Bleaching coral										
	(1) Live corals										
	(2) Soft invertebrates										
(1) Live corals	Encrusting										
	Massive										
	Digitate										
	Branch										
	Foliose										
	Tabulate										
	Millepora sp.										
(2)	Soft corals										
	Sponges										
Grass/alg	Cyanophyceae										
	Sea grass										
	Encrusting algae										
	Small macro-algae										
	Large macro-algae										
	Drifting algae										
	Micro-algae, Turf										

Appendix 4: GPS positions of finfish survey transects

Site	Habitat	Station ID	Latitude	Longitude
Abatiku 1	Lagoon-reef	TRA07	173.80647	0.39133
	Lagoon-reef	TRA08	173.80647	0.39133
	Lagoon-reef	TRA09	173.80672	0.39100
	Outer-reef	TRA04	173.75882	0.40078
	Outer-reef	TRA05	173.75863	0.40090
	Outer-reef	TRA06	173.75863	0.40090
Abatiku 2	Lagoon-reef	TRA10	173.79475	0.40872
	Lagoon-reef	TRA11	173.79470	0.40908
	Lagoon-reef	TRA12	173.79373	0.41008
	Outer-reef	TRA16	173.75407	0.39102
	Outer-reef	TRA17	173.75410	0.39097
	Outer-reef	TRA18	173.75408	0.39003
Bike 3	Back-reef	TRA26	173.84937	0.34888
	Back-reef	TRA27	173.84853	0.35038
	Outer-reef	TRA19	173.83605	0.34488
	Outer-reef	TRA20	173.83642	0.34455
	Outer-reef	TRA21	173.83598	0.34488
Bike 4	Back-reef	TRA29	173.85188	0.34175
	Back-reef	TRA30	173.85170	0.34173
	Back-reef	TRA31	173.85172	0.34182
	Lagoon-reef	TRA32	173.85550	0.35453
	Lagoon-reef	TRA33	173.85562	0.35450
	Lagoon-reef	TRA34	173.85395	0.35535
	Outer-reef	TRA22	173.84490	0.33460
	Outer-reef	TRA23	173.84502	0.33453
	Outer-reef	TRA24	173.84502	0.33453

Appendix 5: Mean density and biomass (± SE) of finfish families recorded at Abatiku by habitat

Habitat	Family	Density (fish/m²)	SE Density	Biomass (g/m²)	SE Biomass
Lagoon reef	Acanthuridae	0.073	0.019	10.414	2.653
Lagoon reef	Balistidae	0.001	0.001	0.183	0.183
Lagoon reef	Caesionidae	0.043	0.029	0.321	0.262
Lagoon reef	Chaetodontidae	0.016	0.004	1.409	0.594
Lagoon reef	Gobiidae	0.000	0.000	0.001	0.001
Lagoon reef	Labridae	0.100	0.023	2.679	0.527
Lagoon reef	Lethrinidae	0.007	0.004	0.268	0.188
Lagoon reef	Lutjanidae	0.002	0.002	0.222	0.145
Lagoon reef	Mullidae	0.032	0.004	1.712	0.327
Lagoon reef	Pomacanthidae	0.001	0.001	0.140	0.136
Lagoon reef	Pomacentridae	0.547	0.166	1.923	0.476
Lagoon reef	Scaridae	0.096	0.036	17.288	5.747
Lagoon reef	Serranidae	0.010	0.004	0.666	0.419
Lagoon reef	Tetraodontidae	0.001	0.001	0.001	0.001
Lagoon reef	Zanclidae	0.001	0.001	0.168	0.168
Outer reef	Acanthuridae	0.091	0.019	12.995	6.311
Outer reef	Balistidae	0.022	0.006	10.412	5.430
Outer reef	Belonidae	0.028	0.028	0.174	0.174
Outer reef	Caesionidae	0.460	0.337	81.801	78.900
Outer reef	Carangidae	0.028	0.028	39.258	38.637
Outer reef	Chaetodontidae	0.019	0.004	1.270	0.398
Outer reef	Cirrhitidae	0.006	0.002	0.283	0.176
Outer reef	Gobiidae	0.001	0.001	0.012	0.012
Outer reef	Labridae	0.066	0.033	18.889	17.741
Outer reef	Lethrinidae	0.034	0.019	3.487	2.891
Outer reef	Lutjanidae	0.004	0.003	0.630	0.418
Outer reef	Mullidae	0.032	0.010	3.238	1.834
Outer reef	Pomacanthidae	0.063	0.031	0.488	0.206
Outer reef	Pomacentridae	1.704	0.156	6.534	1.357
Outer reef	Scaridae	0.017	0.008	2.761	1.381
Outer reef	Serranidae	0.449	0.294	7.207	1.440
Outer reef	Siganidae	0.014	0.014	0.989	0.989
Outer reef	Tetraodontidae	0.001	0.001	0.002	0.002
Outer reef	Zanclidae	0.002	0.001	0.179	0.071

Appendix 6: Mean density and biomass (± SE) of finfish families recorded at Bike by habitat

Habitat	Family	Density (fish/m^2)	SE Density	Biomass (g/m^2)	SE Biomass
Back reef	Acanthuridae	0.020	0.010	2.309	2.119
Back reef	Balistidae	0.010	0.001	1.573	0.395
Back reef	Carangidae	0.000	0.000	0.443	0.443
Back reef	Chaetodontidae	0.011	0.005	0.587	0.310
Back reef	Cirrhitidae	0.002	0.002	0.004	0.004
Back reef	Labridae	0.101	0.039	11.511	10.012
Back reef	Lethrinidae	0.002	0.002	0.819	0.550
Back reef	Lutjanidae	0.121	0.094	42.103	36.447
Back reef	Mullidae	0.026	0.016	1.748	1.064
Back reef	Pomacanthidae	0.002	0.002	0.025	0.025
Back reef	Pomacentridae	0.244	0.191	0.876	0.645
Back reef	Scaridae	0.006	0.004	0.783	0.592
Back reef	Serranidae	0.002	0.001	0.035	0.021
Back reef	Tetraodontidae	0.000	0.000	0.036	0.036
Back reef	Zanclidae	0.000	0.000	0.054	0.054
Lagoon reef	Acanthuridae	0.131	0.030	68.840	21.166
Lagoon reef	Apogonidae	0.007	0.007	0.054	0.054
Lagoon reef	Balistidae	0.034	0.013	28.816	20.073
Lagoon reef	Caesionidae	0.367	0.366	19.172	19.114
Lagoon reef	Carangidae	0.001	0.001	0.907	0.907
Lagoon reef	Chaetodontidae	0.079	0.012	12.134	1.114
Lagoon reef	Cirrhitidae	0.001	0.001	0.006	0.006
Lagoon reef	Holocentridae	0.010	0.010	5.606	5.606
Lagoon reef	Labridae	0.128	0.071	2.335	0.206
Lagoon reef	Lethrinidae	0.220	0.196	17.049	16.287
Lagoon reef	Lutjanidae	0.006	0.005	8.878	6.575
Lagoon reef	Mullidae	0.092	0.032	10.841	5.783
Lagoon reef	Pomacanthidae	0.040	0.008	1.462	0.462
Lagoon reef	Pomacentridae	1.571	0.460	20.796	16.219
Lagoon reef	Scaridae	0.152	0.076	17.581	10.412
Lagoon reef	Serranidae	0.233	0.179	17.179	9.016
Lagoon reef	Tetraodontidae	0.001	0.001	0.061	0.061
Lagoon reef	Zanclidae	0.002	0.000	0.197	0.070
Outer reef	Acanthuridae	0.194	0.068	38.119	19.060
Outer reef	Apogonidae	0.000	0.000	0.004	0.004
Outer reef	Balistidae	0.033	0.011	4.514	1.379
Outer reef	Caesionidae	0.040	0.040	0.044	0.044
Outer reef	Carangidae	0.002	0.002	10.954	10.129
Outer reef	Chaetodontidae	0.030	0.005	2.707	0.770
Outer reef	Cirrhitidae	0.004	0.002	0.194	0.115
Outer reef	Hemiramphidae	0.030	0.030	3.312	3.312

Habitat	Family	Density (fish/m^2)	SE Density	Biomass (g/m^2)	SE Biomass
Outer reef	Holocentridae	0.000	0.000	0.200	0.200
Outer reef	Labridae	0.166	0.069	2.402	0.871
Outer reef	Lethrinidae	0.004	0.003	0.089	0.065
Outer reef	Lutjanidae	0.015	0.009	1.832	1.185
Outer reef	Microdesmidae	0.002	0.001	0.000	0.000
Outer reef	Mullidae	0.017	0.002	1.893	0.660
Outer reef	Pomacanthidae	0.036	0.009	1.351	0.472
Outer reef	Pomacentridae	1.901	0.384	7.122	2.338
Outer reef	Scaridae	0.032	0.010	8.875	3.385
Outer reef	Serranidae	0.356	0.243	7.391	2.616
Outer reef	Zanclidae	0.006	0.003	0.746	0.381

Appendix 7: Mean density and biomass (± SE) of all fish recorded at Abatiku by habitat

Habitat	Family	Species	Density (fish/m²)	SE Density	Biomass (g/m²)	SE density
Lagoon	Acanthuridae	*Acanthurus blochii*	0.006	0.005	0.563	0.560
Lagoon	Acanthuridae	*Acanthurus lineatus*	0.001	0.001	0.112	0.112
Lagoon	Acanthuridae	*Acanthurus nigricans*	0.004	0.002	0.663	0.284
Lagoon	Acanthuridae	*Acanthurus nigricauda*	0.003	0.003	0.138	0.138
Lagoon	Acanthuridae	*Acanthurus nigrofuscus*	0.007	0.005	0.499	0.344
Lagoon	Acanthuridae	*Acanthurus nigroris*	0.002	0.002	0.219	0.219
Lagoon	Acanthuridae	*Acanthurus triostegus*	0.011	0.011	1.442	1.442
Lagoon	Acanthuridae	*Ctenochaetus marginatus*	0.001	0.001	0.063	0.063
Lagoon	Acanthuridae	*Ctenochaetus striatus*	0.038	0.005	6.716	1.893
Lagoon	Balistidae	*Balistapus undulatus*	0.001	0.001	0.183	0.183
Lagoon	Caesionidae	*Caesio caerulaurea*	0.027	0.027	0.268	0.268
Lagoon	Caesionidae	*Pterocaesio trilineata*	0.017	0.017	0.053	0.053
Lagoon	Chaetodontidae	*Chaetodon auriga*	0.007	0.002	0.629	0.254
Lagoon	Chaetodontidae	*Chaetodon ephippium*	0.001	0.001	0.317	0.223
Lagoon	Chaetodontidae	*Chaetodon kleinii*	0.000	0.000	0.002	0.002
Lagoon	Chaetodontidae	*Chaetodon lunula*	0.001	0.001	0.143	0.137
Lagoon	Chaetodontidae	*Chaetodon lunulatus*	0.002	0.002	0.155	0.155
Lagoon	Chaetodontidae	*Chaetodon ornatissimus*	0.002	0.001	0.027	0.019
Lagoon	Chaetodontidae	*Chaetodon trifascialis*	0.001	0.001	0.017	0.013
Lagoon	Chaetodontidae	*Chaetodon vagabundus*	0.001	0.001	0.100	0.089
Lagoon	Chaetodontidae	*Forcipiger flavissimus*	0.001	0.001	0.020	0.020
Lagoon	Gobiidae	*Amblygobius phalaena*	0.000	0.000	0.001	0.001
Lagoon	Labridae	*Anampses melanurus*	0.003	0.003	0.078	0.078
Lagoon	Labridae	*Bodianus axillaris*	0.000	0.000	0.004	0.004
Lagoon	Labridae	*Cheilinus undulatus*	0.008	0.007	0.158	0.143
Lagoon	Labridae	*Choerodon fasciatus*	0.001	0.001	0.258	0.258
Lagoon	Labridae	*Epibulus insidiator*	0.000	0.000	0.011	0.011
Lagoon	Labridae	*Gomphosus varius*	0.006	0.003	0.086	0.039
Lagoon	Labridae	*Halichoeres biocellatus*	0.000	0.000	0.005	0.005
Lagoon	Labridae	*Halichoeres hortulanus*	0.004	0.002	0.325	0.172
Lagoon	Labridae	*Halichoeres leucurus*	0.007	0.006	0.020	0.016
Lagoon	Labridae	*Halichoeres melanurus*	0.002	0.002	0.051	0.051
Lagoon	Labridae	*Halichoeres trimaculatus*	0.027	0.010	0.821	0.415
Lagoon	Labridae	*Labroides dimidiatus*	0.004	0.001	0.006	0.002
Lagoon	Labridae	*Macropharyngodon meleagris*	0.000	0.000	0.003	0.003
Lagoon	Labridae	*Stethojulis bandanensis*	0.001	0.000	0.003	0.002
Lagoon	Labridae	*Thalassoma amblycephalum*	0.004	0.004	0.001	0.001
Lagoon	Labridae	*Thalassoma hardwicke*	0.004	0.001	0.156	0.047
Lagoon	Labridae	*Thalassoma lunare*	0.025	0.006	0.654	0.257
Lagoon	Labridae	*Thalassoma lutescens*	0.002	0.002	0.032	0.032
Lagoon	Labridae	*Thalassoma purpureum*	0.001	0.001	0.006	0.006

Habitat	Family	Species	Density (fish/m²)	SE Density	Biomass (g/m²)	SE density
Lagoon	Lethrinidae	*Gnathodentex aureolineatus*	0.004	0.004	0.033	0.033
Lagoon	Lethrinidae	*Monotaxis grandoculis*	0.003	0.001	0.235	0.194
Lagoon	Lutjanidae	*Lutjanus fulvus*	0.002	0.002	0.087	0.087
Lagoon	Lutjanidae	*Lutjanus gibbus*	0.000	0.000	0.135	0.135
Lagoon	Mullidae	*Mulloidichthys flavolineatus*	0.011	0.003	0.405	0.130
Lagoon	Mullidae	*Parupeneus barberinus*	0.001	0.001	0.121	0.099
Lagoon	Mullidae	*Parupeneus bifasciatus*	0.001	0.001	0.056	0.045
Lagoon	Mullidae	*Parupeneus cyclostomus*	0.005	0.003	0.436	0.399
Lagoon	Mullidae	*Parupeneus multifasciatus*	0.014	0.002	0.671	0.162
Lagoon	Mullidae	*Parupeneus pleurostigma*	0.001	0.001	0.023	0.023
Lagoon	Pomacanthidae	*Centropyge flavissimus*	0.001	0.001	0.003	0.003
Lagoon	Pomacanthidae	*Pygoplites diacanthus*	0.000	0.000	0.137	0.137
Lagoon	Pomacentridae	*Amphiprion clarkii*	0.001	0.001	0.002	0.002
Lagoon	Pomacentridae	*Chromis acares*	0.014	0.014	0.018	0.018
Lagoon	Pomacentridae	*Chromis margaritifer*	0.033	0.012	0.051	0.016
Lagoon	Pomacentridae	*Chromis ternatensis*	0.020	0.020	0.014	0.014
Lagoon	Pomacentridae	*Chromis vanderbilti*	0.006	0.006	0.019	0.019
Lagoon	Pomacentridae	*Chromis viridis*	0.040	0.036	0.045	0.031
Lagoon	Pomacentridae	*Chromis xanthura*	0.010	0.007	0.055	0.042
Lagoon	Pomacentridae	*Chrysiptera biocellata*	0.003	0.003	0.015	0.013
Lagoon	Pomacentridae	*Dascyllus aruanus*	0.095	0.041	0.344	0.260
Lagoon	Pomacentridae	*Plectroglyphidodon dickii*	0.010	0.004	0.036	0.010
Lagoon	Pomacentridae	*Plectroglyphidodon lacrymatus*	0.004	0.003	0.016	0.012
Lagoon	Pomacentridae	*Pomacentrus coelestis*	0.210	0.104	0.759	0.348
Lagoon	Pomacentridae	*Pomacentrus pavo*	0.016	0.016	0.153	0.153
Lagoon	Pomacentridae	*Pomacentrus vaiuli*	0.077	0.039	0.366	0.166
Lagoon	Pomacentridae	*Stegastes albifasciatus*	0.007	0.007	0.032	0.032
Lagoon	Scaridae	*Chlorurus sordidus*	0.045	0.011	7.186	4.203
Lagoon	Scaridae	*Hipposcarus longiceps*	0.023	0.023	3.657	3.657
Lagoon	Scaridae	*Scarus ghobban*	0.016	0.009	4.387	2.543
Lagoon	Scaridae	*Scarus niger*	0.005	0.005	0.618	0.618
Lagoon	Scaridae	*Scarus rivulatus*	0.005	0.005	0.630	0.630
Lagoon	Scaridae	*Scarus schlegeli*	0.001	0.001	0.069	0.069
Lagoon	Scaridae	*Scarus xanthopleura*	0.002	0.002	0.740	0.740
Lagoon	Serranidae	*Cephalopholis argus*	0.001	0.000	0.386	0.322
Lagoon	Serranidae	*Cephalopholis urodeta*	0.001	0.001	0.091	0.080
Lagoon	Serranidae	*Epinephelus merra*	0.008	0.005	0.189	0.118
Lagoon	Tetraodontidae	*Canthigaster solandri*	0.001	0.001	0.001	0.001
Lagoon	Zanclidae	*Zanclus cornutus*	0.001	0.001	0.168	0.168
Outer	Acanthuridae	*Acanthurus blochii*	0.003	0.003	0.036	0.036
Outer	Acanthuridae	*Acanthurus nigricans*	0.012	0.005	2.752	1.053
Outer	Acanthuridae	*Acanthurus nigrofuscus*	0.002	0.002	0.081	0.081

Habitat	Family	Species	Density (fish/m^2)	SE Density	Biomass (g/m^2)	SE density
Outer	Acanthuridae	*Acanthurus triostegus*	0.001	0.001	0.152	0.152
Outer	Acanthuridae	*Ctenochaetus striatus*	0.065	0.019	8.742	5.005
Outer	Acanthuridae	*Zebrasoma scopas*	0.009	0.005	1.231	0.737
Outer	Balistidae	*Balistapus undulatus*	0.006	0.004	1.399	0.853
Outer	Balistidae	*Balistoides viridescens*	0.001	0.001	6.036	6.036
Outer	Balistidae	*Melichthys niger*	0.002	0.002	0.976	0.976
Outer	Balistidae	*Melichthys vidua*	0.003	0.001	0.793	0.397
Outer	Balistidae	*Odonus niger*	0.001	0.001	0.138	0.087
Outer	Balistidae	*Pseudobalistes flavimarginatus*	0.002	0.001	0.079	0.056
Outer	Balistidae	*Pseudobalistes fuscus*	0.000	0.000	0.175	0.175
Outer	Balistidae	*Rhinecanthus aculeatus*	0.001	0.001	0.197	0.197
Outer	Balistidae	*Sufflamen bursa*	0.004	0.002	0.542	0.342
Outer	Balistidae	*Sufflamen chrysopterus*	0.001	0.001	0.079	0.053
Outer	Belonidae	*Tylosurus crocodilus crocodilus*	0.028	0.028	0.174	0.174
Outer	Caesionidae	*Pterocaesio tile*	0.460	0.337	81.801	78.900
Outer	Carangidae	*Caranx melampygus*	0.028	0.028	39.258	38.637
Outer	Chaetodontidae	*Chaetodon auriga*	0.002	0.001	0.154	0.125
Outer	Chaetodontidae	*Chaetodon bennetti*	0.001	0.001	0.042	0.031
Outer	Chaetodontidae	*Chaetodon ephippium*	0.000	0.000	0.044	0.044
Outer	Chaetodontidae	*Chaetodon lineolatus*	0.000	0.000	0.144	0.144
Outer	Chaetodontidae	*Chaetodon lunula*	0.001	0.001	0.014	0.009
Outer	Chaetodontidae	*Chaetodon lunulatus*	0.001	0.001	0.041	0.041
Outer	Chaetodontidae	*Chaetodon meyeri*	0.007	0.002	0.399	0.173
Outer	Chaetodontidae	*Chaetodon ornatissimus*	0.001	0.001	0.040	0.032
Outer	Chaetodontidae	*Chaetodon ulietensis*	0.002	0.001	0.149	0.067
Outer	Chaetodontidae	*Chaetodon vagabundus*	0.001	0.001	0.058	0.058
Outer	Chaetodontidae	*Forcipiger longirostris*	0.001	0.001	0.125	0.103
Outer	Chaetodontidae	*Heniochus acuminatus*	0.001	0.001	0.060	0.060
Outer	Cirrhitidae	*Paracirrhites arcatus*	0.001	0.001	0.008	0.006
Outer	Cirrhitidae	*Paracirrhites forsteri*	0.005	0.002	0.275	0.178
Outer	Gobiidae	*Amblygobius phalaena*	0.001	0.001	0.012	0.012
Outer	Labridae	*Anampses melanurus*	0.001	0.001	0.003	0.003
Outer	Labridae	*Anampses meleagrides*	0.002	0.001	0.092	0.062
Outer	Labridae	*Cheilinus undulatus*	0.000	0.000	17.863	17.863
Outer	Labridae	*Coris gaimard*	0.001	0.001	0.001	0.001
Outer	Labridae	*Gomphosus varius*	0.007	0.003	0.227	0.082
Outer	Labridae	*Halichoeres hortulanus*	0.002	0.001	0.124	0.085
Outer	Labridae	*Halichoeres leucurus*	0.002	0.002	0.087	0.087
Outer	Labridae	*Halichoeres trimaculatus*	0.002	0.002	0.002	0.002
Outer	Labridae	*Hemigymnus melapterus*	0.000	0.000	0.051	0.051
Outer	Labridae	*Labroides dimidiatus*	0.006	0.002	0.037	0.030
Outer	Labridae	*Labroides pectoralis*	0.003	0.003	0.003	0.003

Habitat	Family	Species	Density (fish/m²)	SE Density	Biomass (g/m²)	SE density
Outer	Labridae	*Thalassoma amblycephalum*	0.035	0.033	0.083	0.082
Outer	Labridae	*Thalassoma hardwicke*	0.002	0.001	0.158	0.101
Outer	Labridae	*Thalassoma lunare*	0.002	0.001	0.016	0.012
Outer	Labridae	*Thalassoma purpureum*	0.001	0.001	0.088	0.088
Outer	Labridae	*Thalassoma quinquevittatum*	0.001	0.001	0.053	0.053
Outer	Lethrinidae	*Gnathodentex aureolineatus*	0.032	0.019	3.376	2.913
Outer	Lethrinidae	*Monotaxis grandoculis*	0.002	0.002	0.111	0.111
Outer	Lutjanidae	*Aprion virescens*	0.000	0.000	0.322	0.322
Outer	Lutjanidae	*Lutjanus bohar*	0.001	0.001	0.198	0.146
Outer	Lutjanidae	*Lutjanus gibbus*	0.002	0.002	0.106	0.106
Outer	Lutjanidae	*Lutjanus kasmira*	0.001	0.001	0.005	0.005
Outer	Mullidae	*Parupeneus barberinus*	0.001	0.001	0.075	0.075
Outer	Mullidae	*Parupeneus bifasciatus*	0.002	0.002	0.273	0.200
Outer	Mullidae	*Parupeneus cyclostomus*	0.001	0.001	0.014	0.014
Outer	Mullidae	*Parupeneus indicus*	0.001	0.001	0.042	0.042
Outer	Mullidae	*Parupeneus multifasciatus*	0.025	0.009	2.760	1.919
Outer	Mullidae	*Parupeneus pleurostigma*	0.002	0.002	0.074	0.074
Outer	Pomacanthidae	*Centropyge bicolor*	0.003	0.002	0.063	0.056
Outer	Pomacanthidae	*Centropyge flavissimus*	0.021	0.013	0.164	0.059
Outer	Pomacanthidae	*Centropyge loriculus*	0.038	0.018	0.220	0.100
Outer	Pomacanthidae	*Pomacanthus semicirculatus*	0.001	0.001	0.031	0.031
Outer	Pomacanthidae	*Pygoplites diacanthus*	0.001	0.001	0.011	0.011
Outer	Pomacentridae	*Abudefduf sexfasciatus*	0.001	0.001	0.013	0.013
Outer	Pomacentridae	*Amphiprion chrysopterus*	0.002	0.002	0.005	0.005
Outer	Pomacentridae	*Amphiprion clarkii*	0.002	0.002	0.005	0.005
Outer	Pomacentridae	*Chromis acares*	0.037	0.025	0.055	0.046
Outer	Pomacentridae	*Chromis amboinensis*	0.010	0.010	0.068	0.068
Outer	Pomacentridae	*Chromis margaritifer*	0.456	0.120	0.816	0.255
Outer	Pomacentridae	*Chromis ternatensis*	0.175	0.086	1.292	0.716
Outer	Pomacentridae	*Chromis vanderbilti*	0.243	0.152	0.191	0.147
Outer	Pomacentridae	*Chromis viridis*	0.018	0.018	0.036	0.036
Outer	Pomacentridae	*Chromis weberi*	0.026	0.013	0.292	0.204
Outer	Pomacentridae	*Chromis xanthura*	0.166	0.074	1.490	0.561
Outer	Pomacentridae	*Chrysiptera biocellata*	0.000	0.000	0.002	0.002
Outer	Pomacentridae	*Dascyllus aruanus*	0.012	0.012	0.013	0.013
Outer	Pomacentridae	*Plectroglyphidodon dickii*	0.028	0.012	0.157	0.077
Outer	Pomacentridae	*Plectroglyphidodon lacrymatus*	0.050	0.020	0.214	0.068
Outer	Pomacentridae	*Pomacentrus coelestis*	0.451	0.245	1.778	1.200
Outer	Pomacentridae	*Pomacentrus vaiuli*	0.027	0.027	0.107	0.107
Outer	Scaridae	*Chlorurus sordidus*	0.012	0.005	2.336	1.454
Outer	Scaridae	*Scarus ghobban*	0.001	0.001	0.061	0.061
Outer	Scaridae	*Scarus xanthopleura*	0.004	0.004	0.364	0.364

Habitat	Family	Species	Density (fish/m²)	SE Density	Biomass (g/m²)	SE density
Outer	Serranidae	*Aethaloperca rogaa*	0.001	0.000	0.150	0.101
Outer	Serranidae	*Anyperodon leucogrammicus*	0.001	0.001	0.022	0.022
Outer	Serranidae	*Cephalopholis argus*	0.012	0.007	3.014	1.432
Outer	Serranidae	*Cephalopholis boenak*	0.002	0.002	0.410	0.363
Outer	Serranidae	*Cephalopholis urodeta*	0.032	0.011	2.551	0.824
Outer	Serranidae	*Epinephelus merra*	0.001	0.000	0.148	0.094
Outer	Serranidae	*Plectropomus areolatus*	0.018	0.018	0.418	0.418
Outer	Serranidae	*Pseudanthias dispar*	0.383	0.292	0.494	0.266
Outer	Siganidae	*Siganus argenteus*	0.014	0.014	0.989	0.989
Outer	Tetraodontidae	*Canthigaster solandri*	0.001	0.001	0.002	0.002
Outer	Zanclidae	*Zanclus cornutus*	0.002	0.001	0.179	0.071

Appendix 8: Mean density and biomass (± SE) of all fish recorded at Bike by habitat

Habitat	Family	Species	Density (fish/m²)	SE Density	Biomass (g/m²)	SE density
Back	Acanthuridae	*Acanthurus achilles*	0.005	0.005	1.472	1.472
Back	Acanthuridae	*Acanthurus nigricans*	0.000	0.000	0.052	0.052
Back	Acanthuridae	*Acanthurus triostegus*	0.012	0.004	0.215	0.142
Back	Acanthuridae	*Ctenochaetus striatus*	0.002	0.002	0.570	0.570
Back	Balistidae	*Rhinecanthus aculeatus*	0.008	0.002	1.355	0.473
Back	Balistidae	*Sufflamen bursa*	0.002	0.002	0.218	0.218
Back	Carangidae	*Caranx melampygus*	0.000	0.000	0.443	0.443
Back	Chaetodontidae	*Chaetodon auriga*	0.004	0.001	0.151	0.056
Back	Chaetodontidae	*Chaetodon ephippium*	0.001	0.001	0.160	0.160
Back	Chaetodontidae	*Chaetodon lunulatus*	0.002	0.002	0.097	0.097
Back	Chaetodontidae	*Chaetodon rafflesii*	0.000	0.000	0.001	0.001
Back	Chaetodontidae	*Chaetodon ulietensis*	0.001	0.001	0.040	0.040
Back	Chaetodontidae	*Chaetodon vagabundus*	0.002	0.001	0.049	0.030
Back	Chaetodontidae	*Heniochus acuminatus*	0.001	0.001	0.089	0.089
Back	Cirrhitidae	*Paracirrhites arcatus*	0.002	0.002	0.004	0.004
Back	Labridae	*Cheilinus fasciatus*	0.000	0.000	0.001	0.001
Back	Labridae	*Halichoeres chrysus*	0.004	0.004	0.005	0.005
Back	Labridae	*Halichoeres hortulanus*	0.036	0.035	10.183	10.175
Back	Labridae	*Halichoeres margaritaceus*	0.002	0.002	0.003	0.003
Back	Labridae	*Halichoeres trimaculatus*	0.049	0.022	1.113	0.847
Back	Labridae	*Labroides dimidiatus*	0.004	0.003	0.002	0.002
Back	Labridae	*Thalassoma hardwicke*	0.003	0.003	0.100	0.061
Back	Labridae	*Thalassoma lunare*	0.002	0.001	0.050	0.036
Back	Labridae	*Thalassoma lutescens*	0.000	0.000	0.001	0.001
Back	Labridae	*Thalassoma purpureum*	0.000	0.000	0.053	0.053
Back	Lethrinidae	*Lethrinus harak*	0.001	0.001	0.520	0.373
Back	Lethrinidae	*Lethrinus obsoletus*	0.001	0.001	0.300	0.205
Back	Lutjanidae	*Lutjanus fulvus*	0.020	0.017	9.105	8.692
Back	Lutjanidae	*Lutjanus gibbus*	0.101	0.077	32.998	27.800
Back	Mullidae	*Parupeneus barberinus*	0.006	0.003	0.627	0.495
Back	Mullidae	*Parupeneus bifasciatus*	0.000	0.000	0.004	0.004
Back	Mullidae	*Parupeneus multifasciatus*	0.020	0.013	1.117	0.767
Back	Pomacanthidae	*Centropyge flavissimus*	0.002	0.002	0.025	0.025
Back	Pomacentridae	*Chrysiptera biocellata*	0.008	0.004	0.042	0.028
Back	Pomacentridae	*Dascyllus aruanus*	0.010	0.010	0.055	0.055
Back	Pomacentridae	*Plectroglyphidodon dickii*	0.001	0.001	0.002	0.002
Back	Pomacentridae	*Pomacentrus coelestis*	0.225	0.192	0.734	0.660
Back	Pomacentridae	*Stegastes nigricans*	0.000	0.000	0.043	0.043
Back	Scaridae	*Chlorurus sordidus*	0.003	0.003	0.172	0.172
Back	Scaridae	*Scarus ghobban*	0.001	0.001	0.555	0.555
Back	Scaridae	*Scarus oviceps*	0.002	0.002	0.056	0.056

Habitat	Family	Species	Density (fish/m^2)	SE Density	Biomass (g/m^2)	SE density
Back	Serranidae	*Epinephelus merra*	0.002	0.001	0.035	0.021
Back	Tetraodontidae	*Arothron reticularis*	0.000	0.000	0.036	0.036
Back	Zanclidae	*Zanclus cornutus*	0.000	0.000	0.054	0.054
Lagoon	Acanthuridae	*Acanthurus achilles*	0.002	0.002	0.426	0.426
Lagoon	Acanthuridae	*Acanthurus auranticavus*	0.009	0.009	7.503	7.503
Lagoon	Acanthuridae	*Acanthurus blochii*	0.025	0.014	40.969	32.243
Lagoon	Acanthuridae	*Acanthurus mata*	0.005	0.005	2.779	2.779
Lagoon	Acanthuridae	*Acanthurus nigricans*	0.017	0.017	3.551	3.551
Lagoon	Acanthuridae	*Acanthurus nigricauda*	0.007	0.007	5.345	5.345
Lagoon	Acanthuridae	*Acanthurus pyroferus*	0.001	0.001	0.012	0.012
Lagoon	Acanthuridae	*Ctenochaetus striatus*	0.056	0.009	5.768	0.755
Lagoon	Acanthuridae	*Naso lituratus*	0.001	0.001	0.448	0.448
Lagoon	Acanthuridae	*Naso unicornis*	0.003	0.002	2.037	1.427
Lagoon	Acanthuridae	*Naso vlamingii*	0.005	0.005	0.002	0.002
Lagoon	Apogonidae	*Cheilodipterus isostigmus*	0.007	0.007	0.054	0.054
Lagoon	Balistidae	*Balistapus undulatus*	0.012	0.000	5.765	1.003
Lagoon	Balistidae	*Melichthys niger*	0.008	0.008	1.341	1.341
Lagoon	Balistidae	*Pseudobalistes flavimarginatus*	0.008	0.008	20.250	20.250
Lagoon	Balistidae	*Sufflamen bursa*	0.006	0.006	1.459	1.459
Lagoon	Caesionidae	*Caesio caerulaurea*	0.133	0.133	11.141	11.141
Lagoon	Caesionidae	*Caesio teres*	0.033	0.033	1.655	1.655
Lagoon	Caesionidae	*Pterocaesio trilineata*	0.201	0.200	6.375	6.317
Lagoon	Carangidae	*Carangoides ferdau*	0.001	0.001	0.907	0.907
Lagoon	Chaetodontidae	*Chaetodon auriga*	0.012	0.008	1.452	0.739
Lagoon	Chaetodontidae	*Chaetodon bennetti*	0.004	0.002	0.442	0.222
Lagoon	Chaetodontidae	*Chaetodon ephippium*	0.016	0.001	4.484	0.754
Lagoon	Chaetodontidae	*Chaetodon kleinii*	0.009	0.007	0.160	0.081
Lagoon	Chaetodontidae	*Chaetodon lunula*	0.020	0.016	2.313	1.647
Lagoon	Chaetodontidae	*Chaetodon lunulatus*	0.003	0.003	0.306	0.306
Lagoon	Chaetodontidae	*Chaetodon mertensii*	0.001	0.001	0.015	0.015
Lagoon	Chaetodontidae	*Chaetodon trifascialis*	0.001	0.001	0.183	0.183
Lagoon	Chaetodontidae	*Chaetodon vagabundus*	0.007	0.002	2.138	0.611
Lagoon	Chaetodontidae	*Forcipiger longirostris*	0.003	0.003	0.098	0.098
Lagoon	Chaetodontidae	*Heniochus acuminatus*	0.001	0.001	0.543	0.313
Lagoon	Cirrhitidae	*Paracirrhites arcatus*	0.001	0.001	0.006	0.006
Lagoon	Holocentridae	*Sargocentron spiniferum*	0.010	0.010	5.606	5.606
Lagoon	Labridae	*Gomphosus varius*	0.040	0.040	0.203	0.203
Lagoon	Labridae	*Halichoeres hortulanus*	0.001	0.001	0.105	0.105
Lagoon	Labridae	*Halichoeres trimaculatus*	0.031	0.007	0.812	0.341
Lagoon	Labridae	*Labroides dimidiatus*	0.008	0.004	0.025	0.013
Lagoon	Labridae	*Labropsis micronesica*	0.031	0.031	0.011	0.011
Lagoon	Labridae	*Thalassoma hardwicke*	0.003	0.001	0.016	0.008

Habitat	**Family**	**Species**	**Density (fish/m²)**	**SE Density**	**Biomass (g/m²)**	**SE density**
Lagoon	Labridae	*Thalassoma lunare*	0.015	0.003	1.164	0.246
Lagoon	Lethrinidae	*Gnathodentex aureolineatus*	0.202	0.192	13.908	13.674
Lagoon	Lethrinidae	*Monotaxis grandoculis*	0.017	0.005	3.142	2.624
Lagoon	Lutjanidae	*Aprion virescens*	0.005	0.005	7.240	7.240
Lagoon	Lutjanidae	*Lutjanus bohar*	0.001	0.001	1.638	1.638
Lagoon	Mullidae	*Parupeneus barberinus*	0.022	0.010	6.183	4.626
Lagoon	Mullidae	*Parupeneus bifasciatus*	0.007	0.007	0.666	0.666
Lagoon	Mullidae	*Parupeneus cyclostomus*	0.001	0.001	0.023	0.023
Lagoon	Mullidae	*Parupeneus multifasciatus*	0.039	0.013	2.352	0.407
Lagoon	Mullidae	*Parupeneus pleurostigma*	0.023	0.023	1.617	1.617
Lagoon	Pomacanthidae	*Centropyge bicolor*	0.031	0.008	0.998	0.236
Lagoon	Pomacanthidae	*Centropyge flavissimus*	0.008	0.003	0.218	0.119
Lagoon	Pomacanthidae	*Pygoplites diacanthus*	0.001	0.001	0.246	0.246
Lagoon	Pomacentridae	*Chromis acares*	0.050	0.050	0.093	0.093
Lagoon	Pomacentridae	*Chromis margaritifer*	0.400	0.064	2.938	2.100
Lagoon	Pomacentridae	*Chromis ternatensis*	0.015	0.007	0.056	0.028
Lagoon	Pomacentridae	*Chromis viridis*	0.170	0.160	0.214	0.155
Lagoon	Pomacentridae	*Chromis weberi*	0.513	0.391	14.142	13.292
Lagoon	Pomacentridae	*Chromis xanthura*	0.003	0.003	0.013	0.013
Lagoon	Pomacentridae	*Chrysiptera brownriggii*	0.002	0.002	0.023	0.023
Lagoon	Pomacentridae	*Dascyllus aruanus*	0.163	0.046	0.731	0.488
Lagoon	Pomacentridae	*Plectroglyphidodon dickii*	0.002	0.002	0.007	0.007
Lagoon	Pomacentridae	*Plectroglyphidodon johnstonianus*	0.005	0.005	0.009	0.009
Lagoon	Pomacentridae	*Pomacentrus coelestis*	0.247	0.076	2.570	1.335
Lagoon	Scaridae	*Chlorurus sordidus*	0.079	0.040	6.944	4.265
Lagoon	Scaridae	*Scarus ghobban*	0.054	0.037	8.784	6.439
Lagoon	Scaridae	*Scarus oviceps*	0.019	0.019	1.854	1.854
Lagoon	Serranidae	*Anyperodon leucogrammicus*	0.003	0.003	1.609	1.609
Lagoon	Serranidae	*Cephalopholis argus*	0.026	0.020	5.391	2.698
Lagoon	Serranidae	*Cephalopholis boenak*	0.001	0.001	0.286	0.286
Lagoon	Serranidae	*Cephalopholis urodeta*	0.012	0.004	1.724	0.637
Lagoon	Serranidae	*Epinephelus fuscoguttatus*	0.001	0.001	0.292	0.292
Lagoon	Serranidae	*Epinephelus merra*	0.022	0.018	5.793	5.647
Lagoon	Serranidae	*Epinephelus polyphekadion*	0.001	0.001	1.903	1.903
Lagoon	Serranidae	*Pseudanthias dispar*	0.167	0.167	0.182	0.182
Lagoon	Tetraodontidae	*Arothron nigropunctatus*	0.001	0.001	0.061	0.061
Lagoon	Zanclidae	*Zanclus cornutus*	0.002	0.000	0.197	0.070
Outer	Acanthuridae	*Acanthurus blochii*	0.035	0.031	10.459	10.131
Outer	Acanthuridae	*Acanthurus nigricans*	0.023	0.010	2.776	0.903
Outer	Acanthuridae	*Acanthurus nigricauda*	0.001	0.001	0.106	0.106
Outer	Acanthuridae	*Acanthurus nigrofuscus*	0.018	0.012	2.915	2.432
Outer	Acanthuridae	*Acanthurus olivaceus*	0.003	0.003	0.518	0.518

Habitat	Family	Species	Density (fish/m^2)	SE Density	Biomass (g/m^2)	SE density
Outer	Acanthuridae	*Acanthurus pyroferus*	0.001	0.001	0.027	0.027
Outer	Acanthuridae	*Acanthurus xanthopterus*	0.002	0.002	0.175	0.175
Outer	Acanthuridae	*Ctenochaetus marginatus*	0.002	0.002	0.935	0.935
Outer	Acanthuridae	*Ctenochaetus striatus*	0.088	0.029	16.111	9.477
Outer	Acanthuridae	*Naso caesius*	0.001	0.001	0.536	0.536
Outer	Acanthuridae	*Naso lituratus*	0.002	0.002	0.712	0.637
Outer	Acanthuridae	*Naso unicornis*	0.004	0.002	2.009	1.706
Outer	Acanthuridae	*Paracanthurus hepatus*	0.007	0.007	0.005	0.005
Outer	Acanthuridae	*Zebrasoma scopas*	0.009	0.002	0.836	0.391
Outer	Apogonidae	*Nectamia bandanensis*	0.000	0.000	0.004	0.004
Outer	Balistidae	*Balistapus undulatus*	0.008	0.003	0.719	0.245
Outer	Balistidae	*Balistoides conspicillum*	0.000	0.000	0.099	0.099
Outer	Balistidae	*Melichthys niger*	0.015	0.009	1.837	1.157
Outer	Balistidae	*Melichthys vidua*	0.004	0.002	1.410	0.954
Outer	Balistidae	*Pseudobalistes fuscus*	0.001	0.001	0.007	0.007
Outer	Balistidae	*Rhinecanthus aculeatus*	0.001	0.001	0.204	0.204
Outer	Balistidae	*Sufflamen bursa*	0.004	0.004	0.238	0.238
Outer	Caesionidae	*Caesio teres*	0.040	0.040	0.044	0.044
Outer	Carangidae	*Caranx melampygus*	0.002	0.002	10.954	10.129
Outer	Chaetodontidae	*Chaetodon auriga*	0.002	0.001	0.171	0.106
Outer	Chaetodontidae	*Chaetodon bennetti*	0.002	0.001	0.159	0.151
Outer	Chaetodontidae	*Chaetodon ephippium*	0.002	0.001	0.414	0.141
Outer	Chaetodontidae	*Chaetodon kleinii*	0.001	0.001	0.041	0.041
Outer	Chaetodontidae	*Chaetodon lineolatus*	0.001	0.001	0.056	0.056
Outer	Chaetodontidae	*Chaetodon lunula*	0.003	0.001	0.211	0.143
Outer	Chaetodontidae	*Chaetodon lunulatus*	0.003	0.002	0.183	0.120
Outer	Chaetodontidae	*Chaetodon meyeri*	0.008	0.003	0.581	0.240
Outer	Chaetodontidae	*Chaetodon trifascialis*	0.002	0.002	0.211	0.180
Outer	Chaetodontidae	*Chaetodon ulietensis*	0.003	0.001	0.174	0.085
Outer	Chaetodontidae	*Forcipiger flavissimus*	0.001	0.001	0.077	0.061
Outer	Chaetodontidae	*Forcipiger longirostris*	0.001	0.001	0.007	0.005
Outer	Chaetodontidae	*Heniochus acuminatus*	0.001	0.001	0.421	0.421
Outer	Chaetodontidae	*Heniochus monoceros*	0.000	0.000	0.001	0.001
Outer	Cirrhitidae	*Paracirrhites arcatus*	0.002	0.001	0.004	0.003
Outer	Cirrhitidae	*Paracirrhites forsteri*	0.001	0.001	0.072	0.047
Outer	Cirrhitidae	*Paracirrhites hemistictus*	0.001	0.001	0.118	0.118
Outer	Hemiramphidae	*Hyporhamphus dussumieri*	0.030	0.030	3.312	3.312
Outer	Holocentridae	*Myripristis murdjan*	0.000	0.000	0.200	0.200
Outer	Labridae	*Anampses melanurus*	0.002	0.002	0.031	0.031
Outer	Labridae	*Anampses meleagrides*	0.001	0.001	0.029	0.017
Outer	Labridae	*Cheilinus fasciatus*	0.000	0.000	0.066	0.066
Outer	Labridae	*Cheilinus trilobatus*	0.000	0.000	0.031	0.031

Habitat	**Family**	**Species**	**Density (fish/m²)**	**SE Density**	**Biomass (g/m²)**	**SE density**
Outer	Labridae	*Cheilinus undulatus*	0.000	0.000	0.577	0.577
Outer	Labridae	*Cheilio inermis*	0.001	0.001	0.000	0.000
Outer	Labridae	*Coris aygula*	0.001	0.001	0.020	0.020
Outer	Labridae	*Coris gaimard*	0.001	0.001	0.014	0.014
Outer	Labridae	*Gomphosus varius*	0.013	0.005	0.379	0.190
Outer	Labridae	*Halichoeres chrysus*	0.003	0.002	0.005	0.003
Outer	Labridae	*Halichoeres hortulanus*	0.015	0.003	0.714	0.312
Outer	Labridae	*Halichoeres marginatus*	0.001	0.001	0.005	0.005
Outer	Labridae	*Halichoeres trimaculatus*	0.001	0.000	0.026	0.025
Outer	Labridae	*Hemigymnus fasciatus*	0.001	0.001	0.007	0.007
Outer	Labridae	*Labroides bicolor*	0.002	0.001	0.007	0.007
Outer	Labridae	*Labroides dimidiatus*	0.015	0.007	0.046	0.026
Outer	Labridae	*Labropsis micronesica*	0.097	0.068	0.165	0.141
Outer	Labridae	*Macropharyngodon meleagris*	0.002	0.002	0.003	0.003
Outer	Labridae	*Stethojulis bandanensis*	0.000	0.000	0.004	0.004
Outer	Labridae	*Thalassoma hardwicke*	0.001	0.001	0.066	0.066
Outer	Labridae	*Thalassoma lunare*	0.003	0.002	0.029	0.018
Outer	Labridae	*Thalassoma lutescens*	0.002	0.001	0.054	0.030
Outer	Labridae	*Thalassoma purpureum*	0.002	0.002	0.122	0.078
Outer	Lethrinidae	*Gnathodentex aureolineatus*	0.003	0.003	0.023	0.023
Outer	Lethrinidae	*Monotaxis grandoculis*	0.000	0.000	0.065	0.065
Outer	Lutjanidae	*Aphareus rutilans*	0.005	0.005	1.096	1.040
Outer	Lutjanidae	*Aprion virescens*	0.000	0.000	0.027	0.027
Outer	Lutjanidae	*Lutjanus bohar*	0.001	0.001	0.295	0.295
Outer	Lutjanidae	*Lutjanus kasmira*	0.007	0.007	0.283	0.283
Outer	Lutjanidae	*Lutjanus monostigma*	0.000	0.000	0.077	0.077
Outer	Lutjanidae	*Lutjanus semicinctus*	0.001	0.001	0.053	0.053
Outer	Microdesmidae	*Ptereleotris evides*	0.002	0.001	0.000	0.000
Outer	Mullidae	*Parupeneus barberinus*	0.000	0.000	0.178	0.178
Outer	Mullidae	*Parupeneus bifasciatus*	0.001	0.001	0.123	0.123
Outer	Mullidae	*Parupeneus cyclostomus*	0.004	0.001	0.575	0.353
Outer	Mullidae	*Parupeneus multifasciatus*	0.012	0.001	1.017	0.278
Outer	Pomacanthidae	*Apolemichthys trimaculatus*	0.000	0.000	0.110	0.110
Outer	Pomacanthidae	*Apolemichthys xanthopunctatus*	0.001	0.001	0.134	0.134
Outer	Pomacanthidae	*Centropyge bicolor*	0.004	0.003	0.103	0.079
Outer	Pomacanthidae	*Centropyge colini*	0.001	0.001	0.014	0.014
Outer	Pomacanthidae	*Centropyge flavissimus*	0.018	0.003	0.364	0.135
Outer	Pomacanthidae	*Centropyge loriculus*	0.010	0.006	0.109	0.072
Outer	Pomacanthidae	*Pygoplites diacanthus*	0.003	0.001	0.516	0.329
Outer	Pomacentridae	*Abudefduf septemfasciatus*	0.000	0.000	0.044	0.044
Outer	Pomacentridae	*Chromis acares*	0.021	0.021	0.026	0.026
Outer	Pomacentridae	*Chromis margaritifer*	0.623	0.150	1.842	0.527

Habitat	Family	Species	Density (fish/m²)	SE Density	Biomass (g/m²)	SE density
Outer	Pomacentridae	*Chromis ternatensis*	0.272	0.178	0.533	0.268
Outer	Pomacentridae	*Chromis vanderbilti*	0.423	0.177	0.834	0.395
Outer	Pomacentridae	*Chromis viridis*	0.001	0.001	0.006	0.006
Outer	Pomacentridae	*Chromis weberi*	0.193	0.105	2.259	1.538
Outer	Pomacentridae	*Chromis xanthura*	0.099	0.061	0.667	0.267
Outer	Pomacentridae	*Dascyllus reticulatus*	0.012	0.012	0.126	0.126
Outer	Pomacentridae	*Plectroglyphidodon dickii*	0.069	0.016	0.329	0.134
Outer	Pomacentridae	*Plectroglyphidodon lacrymatus*	0.006	0.004	0.057	0.049
Outer	Pomacentridae	*Pomacentrus coelestis*	0.176	0.100	0.344	0.120
Outer	Pomacentridae	*Pomacentrus moluccensis*	0.000	0.000	0.001	0.001
Outer	Pomacentridae	*Pomacentrus vaiuli*	0.006	0.006	0.055	0.055
Outer	Scaridae	*Chlorurus sordidus*	0.020	0.009	4.900	2.813
Outer	Scaridae	*Hipposcarus longiceps*	0.000	0.000	0.040	0.040
Outer	Scaridae	*Scarus ghobban*	0.004	0.003	0.690	0.535
Outer	Scaridae	*Scarus globiceps*	0.001	0.001	0.212	0.212
Outer	Scaridae	*Scarus oviceps*	0.003	0.002	1.739	1.101
Outer	Scaridae	*Scarus rubroviolaceus*	0.001	0.001	0.481	0.481
Outer	Scaridae	*Scarus spinus*	0.002	0.002	0.324	0.241
Outer	Scaridae	*Scarus tricolor*	0.000	0.000	0.491	0.491
Outer	Serranidae	*Aethaloperca rogaa*	0.001	0.001	0.197	0.129
Outer	Serranidae	*Anyperodon leucogrammicus*	0.000	0.000	0.004	0.004
Outer	Serranidae	*Cephalopholis argus*	0.012	0.004	3.910	1.833
Outer	Serranidae	*Cephalopholis boenak*	0.003	0.002	0.542	0.396
Outer	Serranidae	*Cephalopholis urodeta*	0.021	0.004	1.990	0.562
Outer	Serranidae	*Epinephelus merra*	0.001	0.001	0.017	0.017
Outer	Serranidae	*Epinephelus polyphekadion*	0.000	0.000	0.256	0.256
Outer	Serranidae	*Epinephelus socialis*	0.000	0.000	0.038	0.038
Outer	Serranidae	*Pseudanthias dispar*	0.318	0.240	0.435	0.210
Outer	Zanclidae	*Zanclus cornutus*	0.006	0.003	0.746	0.381

Appendix 9 Invertebrate survey form

DATE		RECORDER		Pg No	

STATION NAME																		
WPT - WIDTH																		
RELIEF / COMPLEXITY **1–5**																		
OCEAN INFLUENCE **1–5**																		
DEPTH (M)																		
% SOFT SED (M – S – CS)																		
% RUBBLE / BOULDERS																		
% CONSOL RUBBLE / PAVE																		
% CORAL *LIVE*																		
% CORAL *DEAD*																		
SOFT / SPONGE / FUNGIDS																		
ALGAE *CCA*																		
CORALLINE																		
OTHER																		
GRASS																		
EPIPHYTES **1–5** / SILT **1–5**																		
bleaching: % of																		
entered /																		

Appendix 10: GPS positions of manta tow surveys conducted at Abatiku and Bike, 2011

Site	Station name	Replicate	Start		End	
			Latitude (N)	Longitude (E)	Latitude (N)	Longitude (E)
Abatiku	Manta 6	1	0.36837	173.83318	0.37132	173.83293
Abatiku	Manta 6	2	0.37132	173.83228	0.37402	173.83087
Abatiku	Manta 6	3	0.37422	173.83097	0.37608	173.82913
Abatiku	Manta 6	4	0.37618	173.82890	0.37837	173.82697
Abatiku	Manta 6	5	0.37852	173.82668	0.38038	173.82453
Abatiku	Manta 6	6	0.38043	173.82427	0.38227	173.82212
Abatiku	Manta 7	1	0.38285	173.82093	0.38512	173.81850
Abatiku	Manta 7	2	0.38515	173.81842	0.38690	173.81615
Abatiku	Manta 7	3	0.38693	173.81607	0.38843	173.81362
Abatiku	Manta 7	4	0.38852	173.81332	0.38985	173.81068
Abatiku	Manta 7	5	0.38985	173.81068	0.39110	173.80815
Abatiku	Manta 7	6	0.39112	173.80800	0.39275	173.80605
Abatiku	Manta 8	1	0.39225	173.80485	0.39247	173.80180
Abatiku	Manta 8	2	0.39388	173.79900	0.39538	173.79647
Abatiku	Manta 8	3	0.39783	173.79530	0.39788	173.79505
Abatiku	Manta 8	4	0.40053	173.79432	0.40057	173.79412
Abatiku	Manta 8	5	0.40308	173.79322	0.40308	173.79317
Abatiku	Manta 8	6	0.40305	173.79315	0.40303	173.79317
Abatiku	Manta 9	1	0.40238	173.91227	0.40515	173.91152
Abatiku	Manta 9	2	0.40538	173.91135	0.40812	173.91057
Abatiku	Manta 9	3	0.40830	173.91030	0.41097	173.90918
Abatiku	Manta 9	4	0.41123	173.90885	0.41358	173.90738
Abatiku	Manta 9	5	0.41383	173.90703	0.41647	173.90620
Abatiku	Manta 9	6	0.41672	173.90593	0.41940	173.90502
Abatiku	Manta 10	1	0.42210	173.90293	0.42468	173.90142
Abatiku	Manta 10	2	0.42498	173.90105	0.42745	173.89933
Abatiku	Manta 10	3	0.42780	173.89892	0.42962	173.89633
Abatiku	Manta 10	4	0.42995	173.89598	0.43157	173.89370
Abatiku	Manta 10	5	0.43180	173.89328	0.43298	173.89088
Abatiku	Manta 10	6	0.43337	173.89057	0.43563	173.88888
Abatiku	Manta 11	1	0.44258	173.88123	0.44498	173.87972
Abatiku	Manta 11	2	0.44525	173.87952	0.44767	173.87778
Abatiku	Manta 11	3	0.44787	173.87748	0.44950	173.87537
Abatiku	Manta 11	4	0.44965	173.87505	0.45162	173.87298
Abatiku	Manta 11	5	0.45175	173.87270	0.45382	173.87083
Abatiku	Manta 11	6	0.45397	173.87058	0.45620	173.86893
Bike	Manta 1	1	0.31237	173.90205	0.31922	173.90525
Bike	Manta 1	2	0.31922	173.90525	0.31697	173.91408
Bike	Manta 1	3	0.31697	173.91408	0.31827	173.91678
Bike	Manta 1	4	0.31697	173.91408	0.31827	173.91678

Site	Station name	Replicate	Start		End	
			Latitude (N)	Longitude (E)	Latitude (N)	Longitude (E)
Bike	Manta 1	5	0.31887	173.91905	0.32073	173.92800
Bike	Manta 1	6	0.32092	173.92808	0.32613	173.93285
Bike	Manta 2	1	0.32702	173.93232	0.34292	173.93202
Bike	Manta 2	2	0.34317	173.93190	0.35017	173.93322
Bike	Manta 2	3	0.35075	173.93303	0.35925	173.93312
Bike	Manta 2	4	0.36142	173.93140	0.36442	173.93057
Bike	Manta 2	5	0.36448	173.93055	0.36733	173.92947
Bike	Manta 2	6	0.36740	173.92940	0.36695	173.92812
Bike	Manta 3	1	0.33410	173.85598	0.33260	173.85843
Bike	Manta 3	2	0.33248	173.85840	0.33017	173.86038
Bike	Manta 3	3	0.32990	173.86030	0.32888	173.86273
Bike	Manta 3	4	0.32885	173.86342	0.32788	173.86602
Bike	Manta 3	5	0.32752	173.86635	0.32667	173.86893
Bike	Manta 3	6	0.32667	173.86917	0.32645	173.87192
Bike	Manta 4	1	0.33827	173.84645	0.33925	173.84393
Bike	Manta 4	2	0.33957	173.84350	0.34210	173.84240
Bike	Manta 4	3	0.34740	173.84360	0.34900	173.84125
Bike	Manta 4	4	0.34920	173.84088	0.34898	173.83902
Bike	Manta 4	5	0.34633	173.83752	0.34583	173.83517
Bike	Manta 5	1	0.35352	173.83592	0.35467	173.83430
Bike	Manta 5	2	0.35455	173.83425	0.35710	173.83415
Bike	Manta 5	3	0.35712	173.83410	0.35992	173.83463
Bike	Manta 5	4	0.35993	173.83478	0.36267	173.83477
Bike	Manta 5	5	0.36263	173.83438	0.36553	173.83463
Bike	Manta 5	6	0.36550	173.83492	0.35110	173.83325
Bike	Manta 12	1	0.37042	173.92803	0.37307	173.92600
Bike	Manta 12	2	0.37312	173.92595	0.37585	173.92420
Bike	Manta 12	3	0.37590	173.92417	0.37850	173.92282
Bike	Manta 12	4	0.37853	173.92278	0.38142	173.92167
Bike	Manta 12	5	0.38155	173.92158	0.38437	173.92045
Bike	Manta 12	6	0.38440	173.92043	0.38712	173.91913

Appendix 11: GPS positions of RBT and SIQ surveys conducted at Abatiku and Bike, 2011

Site	Station ID	Latitude (N)	Longitude (E)
Abatiku	RBT 6	0.36228	173.83385
Abatiku	RBT 7	0.37923	173.81985
Abatiku	RBT 8	0.38922	173.80500
Abatiku	RBT 9	0.38893	173.81020
Abatiku	RBT 10	0.40288	173.79318
Bike	RBT 1	0.31213	173.89947
Bike	RBT 2	0.31213	173.89947
Bike	RBT 3	0.32443	173.87635
Bike	RBT 4	0.33518	173.85163
Bike	RBT 5	0.33805	173.84785
Abatiku	SIQ 7	0.42970	173.90028
Abatiku	SIQ 8	0.42948	173.89903
Abatiku	SIQ 9	0.42990	173.89903
Abatiku	SIQ 10	0.48272	173.84428
Abatiku	SIQ 11	0.48272	173.84428
Abatiku	SIQ 12	0.48313	173.84348
Bike	SIQ 1	0.39510	173.92037
Bike	SIQ 2	0.39410	173.92062
Bike	SIQ 3	0.39782	173.91857
Bike	SIQ 4	0.35355	173.93350
Bike	SIQ 5	0.35210	173.93217
Bike	SIQ 6	0.35408	173.93090

Appendix 12: **Mean percent cover (± SE) of each habitat category at the manta tow survey sites of Abatiku and Bike, 2011.**

Habitat category	Abatiku	Bike
Depth	2.75±1.12	2.47±1.11
Relief	1.89±0.46	1.30±0.30
Complexity	2.08±0.44	1.37±0.29
Ocean influence	2.83±0.31	1.79±0.42
Mud	0.00±0.00	0.00±0.00
Sand	55.97±5.14	64.87±15.82
Coarse sand	2.36±1.37	0.00±0.00
Rubble	9.44±0.85	6.13±2.50
Boulders	1.25±1.09	3.63±2.64
Consolidated rubble	0.28±0.28	0.67±0.67
Pavement	1.11±1.11	1.23±0.81
Live coral	25.00±6.06	18.67±9.44
Dead coral	4.58±1.55	4.80±3.01
Bleached coral	0.00±0.00	0.00±0.00
CCA	2.78±2.46	5.30±2.80
Coralline algae	2.50±1.72	0.00±0.00
Other algae	38.47±18.50	0.00±0.00
Seagrass	0.00±0.00	22.17±12.50
Soft coral	0.00±0.00	0.00±0.00
Sponge	0.00±0.00	15.83±15.83

Appendix 13: Mean density (± SE) of invertebrate species recorded during manta tow surveys within the Abatiku and Bike stations, 2011.

Group	Species	Density (individuals/ha)	
		Abatiku	Bike
Bivalve	*Anadara uropigimelana*	96.03±82.58	111.11±111.11
	Hippopus hippopus	0.40±0.40	-
	Tridacna maxima	483.73±304.77	109.11±91.88
Gastropod	*Conomurex luhuanus*	203.57±101.56	-
Sea cucumber	*Bohadschia vitiensis*	-	3.33±3.33
	Holothuria atra	27.38±17.36	255.56±117.55
Starfish	*Acanthaster planci*	0.40±0.40	-
	Linckia laevigata	-	6.67±6.67
	Linckia sp.	-	0.56±0.56
Urchin	*Echinothrix diadema*	-	4.67±3.27

Appendix 14: Mean percent cover (± SE) of each habitat category at the reef-benthos transects (RBT) survey sites of Abatiku and Bike, 2011

Habitat category	Abatiku	Bike
Depth	1.63±0.73	1.65±0.74
Relief	2.33±0.44	1.80±0.34
Complexity	2.53±0.31	1.93±0.40
Ocean influence	3.57±0.56	4.60±0.24
Mud	0.17±0.17	0.00±0.00
Sand	45.50±7.71	37.00±9.40
Coarse sand	3.17±2.27	3.33±2.19
Rubble	7.17±1.33	12.67±5.51
Boulders	1.17±0.73	12.67±7.87
Consolidated rubble	0.33±0.33	1.83±1.30
Pavement	0.00±0.00	0.00±0.00
Live coral	30.67±7.24	19.67±7.28
Dead coral	11.83±1.85	12.83±3.38
Bleached coral	0.00±0.00	0.00±0.00
CCA	8.67±1.31	17.77±4.42
Coralline algae	5.50±1.95	5.00±3.62
Other algae	3.83±1.31	4.83±2.00
Seagrass	0.00±0.00	0.00±0.00
Soft coral	0.00±0.00	0.00±0.00
Sponge	0.67±0.67	0.83±0.83

Appendix 15: Mean density (± SE) of invertebrate species recorded during reef benthos transect surveys within the Abatiku and Bike stations, 2011.

Group	Species	Mean density (individuals/per ha)	
		Abatiku	Bike
Bivalve	*Anadara uropigimelana*	-	8.33±8.33
	Gafrarium pectinatum	8.33±8.33	-
	Hippopus hippopus	-	8.33±8.33
	Tridacna derasa	-	8.33±8.33
	Tridacna maxima	2441.67±1040.8	791.67±296.68
	Tridacna squamosa	-	41.67±41.67
Gastropod	*Cerithium nodulosum*	41.67±41.67	8.33±8.3
	Conomurex luhuanus	2241.67±2231.26	50±50
	Cypraea tigris	-	8.33±8.33
	Dendropoma maximum	13208.33±6277.88	258.33±153.88
	Monetaria annulus	-	166.67±166.67
	Morula sp.	-	16.67±16.67
	Oxymeris dimidiatus	16.67±16.67	-
Sea cucumber	*Holothuria atra*	-	8.33±8.33
Starfish	*Linckia laevigata*	-	16.67±10.21
Urchin	*Diadema savignyi*	33.33±33.33	116.67±81.65
	Echinothrix calamaris	8.33±8.33	-
	Echinothrix diadema	2083.33±2072.93	66.67±38.64

Appendix 16: **Mean percent cover (± SE) of each habitat category at the soft infaunal quadrat (SIQ) survey sites of Abatiku and Bike, 2011.**

Habitat category	Abatiku	Bike
Depth	0.75±0.31	0.00±0.00
Relief	1.00±0.00	1.00±0.00
Complexity	1.33±0.21	1.00±0.00
Ocean influence	2.83±0.40	2.67±0.33
Mud	0.00±0.00	0.00±0.00
Sand	81.67±3.80	95.00±2.24
Coarse sand	2.50±1.71	0.00±0.00
Rubble	6.67±2.11	3.33±2.11
Boulders	0.00±0.00	0.00±0.00
Consolidated rubble	1.67±1.67	0.00±0.00
Pavement	0.00±0.00	0.00±0.00
Live coral	1.67±1.67	1.67±1.67
Dead coral	5.83±2.71	0.00±0.00
Bleached coral	0.00±0.00	0.00±0.00
CCA	2.50±1.71	0.00±0.00
Coralline algae	1.67±1.67	0.00±0.00
Other algae	19.33±7.77	8.33±3.07
Seagrass	14.17±5.54	23.33±13.76
Soft coral	0.00±0.00	0.00±0.00
Sponge	0.00±0.00	0.00±0.00

Appendix 17: Mean density (± SE) of invertebrate species recorded during soft-infaunal quadrat surveys within the Abatiku and Bike stations, 2011.

Group	Species	Density (individuals/ha)	
		Abatiku	Bike
Bivalve	*Anadara uropigimelana*	60000±6324.55	85833.33±69599.05
	Codakia punctata	-	15000±15000
	Gafrarium pectinatum	57500 ± 39322.38	4166.67±2006.93
	Pinctada margaritifera	-	833.33±833.33
Gastropod	*Conomurex luhuanus*	5833.33±4166.67	15000±10246.95
	Filifusus filamentosus	-	1666.67±1666.67
	Mammilla melanostoma	-	833.33±833.33
	Monetaria annulus	-	6666.67±4216.37
	Monetaria moneta	-	833.33±833.33
	Morula sp.	5833.33±5833.33	8333.33±6540.47
	Ovula ovum	-	833.33±833.33
	Polinices mammilla	3333.33±1666.67	6666.67±4013.86
Sea cucumber	*Holothuria atra*	16666.67±9632.12	247500±156597.95