Climate Change Baseline Assessment

Majuro Atoll
Republic of the Marshall Islands

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ACRONYMS

ANOVA	Analysis of Variance
AusAID	Australian Agency for International Development
CMI	College of Marshall Islands
COTS	Crown-of-thorns starfish
CPC	Coral Point Count
D-UVC	Distance-sampling underwater visual census
EEZ	Exclusive Economic Zone
GDP	Gross Domestic Product
GPS	Global Positioning System
GR	Government Revenue
ha	hectare
ICCAI	International Climate Change Adaptation Initiative (Australia)
IPCC	Intergovernmental Panel on Climate Change
IRD	Institut de Recherche pour le Développement
MCRMP	Millennium Coral Reef Mapping Project
MICS	Marshall Islands Conservation Society
MIMRA	Marshall Islands Marine Resource Authority
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
RMI	Republic of the Marshall Islands
RMIEPA	Republic of the Marshall Islands Environmental Protection Authority
SCUBA	self-contained underwater breathing apparatus
SEAFRAME	Sea Level Fine Resolution Acoustic Measuring Equipment
SOPAC	Applied Geoscience and Technology Division of SPC
SPC	Secretariat of the Pacific Community
SE	standard error
SST	Sea-surface temperature
TL	Total length
USD	United States dollar(s)

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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 Majuro Atoll, Republic of the Marshall Islands (RMI), in April and May 2011.

Survey Design

Survey work at Majuro Atoll covered four disciplines (water temperature monitoring, benthic habitat assessments and assessments of finfish and invertebrate resources), and was conducted by staff from SPC's Coastal Fisheries Science and Management Section, in collaboration with staff from Marshall Islands Marine Resource Authority (MIMRA), the Marshall Islands Conservation Society (MICS), the College of Marshall Islands (CMI), and Republic of the Marshall Islands Environmental Protection Authority (RMIEPA). The fieldwork included capacity development of local counterparts by providing training in survey design and methodologies, data collection and entry, and data analysis.

Two survey regions were defined on Majuro Atoll: the Laura site in the west of the atoll and Majuro site in the east. The Majuro site was considered an 'impact' site since it has a relatively high population and high fishing pressure, while the Laura site was considered a 'control' since it is less populated and subject to relatively low fishing pressure. This design allows for potential de-coupling of the effects of overfishing and pollution from other causes (e.g. climate-related effects). The data presented here provides a quantitative baseline that will be analysed after future monitoring events to examine changes in coastal habitat and fishery resources over time.

Benthic Habitat Assessments

Benthic habitats of Laura and Majuro were assessed via photoquadrat analysis. Thirty-three 50 m benthic habitat assessment transects were established across the back-, lagoon- and outer-reef habitats of Majuro Atoll, with 17 transects completed on the Laura site and 16 transects completed on the Majuro 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, back-reef habitats of both Laura and Majuro were characterised by high cover of sand and macroalgae, and low cover of hard corals. In contrast, outer-reef habitats were characterised by high cover of hard corals (predominantly *Acropora*, *Pocillopora* and *Porites* species), crustose coralline algae, macroalgae (predominantly *Halimeda* and *Lobophora*) and low cover of sand. Lagoon-reef habitats of Laura and Majuro varied considerably. The lagoon reefs at Laura were characterised by high cover of sand, and moderate cover of hard corals (*Porites*) and macroalgae (*Halimeda*). In contrast, the lagoon reefs of Majuro were characterised by high (> 50%) cover of hard corals (predominantly *Porites*-rus), moderate cover of sand and low macroalgae cover.

Finfish Surveys

Finfish resources and their supporting habitats of Laura and Majuro were surveyed using distance-sampling underwater visual census (D-UVC) methodology. Thirty-three 50 m D-UVC monitoring transects were established across the back-, lagoon- and outer-reef habitats of Majuro Atoll, with 15 transects completed at the Laura site and 18 at the Majuro site. Habitats supporting finfish at both Laura and Majuro were largely similar to those recorded during the benthic habitat assessments, with back-reef habitats consisting of high cover of sand and macroalgae, lagoon-reefs consisting of high coral cover and moderate cover of sand, and outer-reef habitats consisting of high cover of corals and macroalgae, and low cover of sand.

A total of 22 families, 70 genera, 189 species and 27,294 individual fish were recorded from the 33 D-UVC transects, with 20 families, 56 genera, 154 species and 13,181 individual fish recorded from the Laura monitoring stations, and 17 families, 55 genera, 141 species and 14,113 individual fish recorded from the Majuro monitoring stations. At Laura, outer-reef habitats supported a greater density and biomass of finfish than back- or lagoon-reef habitats, while the lagoon-reef habitats supported a greater density and biomass of finfish than back-reef habitats. At Majuro, density and biomass of finfish resources was lower in the outer-reef transects compared to those conducted in the back- and lagoon-reef habitats. The common families observed on the back- and lagoon-reef habitats of both Laura and Majuro included Acanthuridae, Labridae, Scaridae, and Pomacentridae. Common families observed on the outer-reefs of Laura and Majuro included Acanthuridae, Holocentridae, Labridae, Serranidae and Pomacentridae. Both the density and abundance of finfish resources of the back- and lagoon-reefs at the Laura site appeared lower than that recorded during PROCFish surveys conducted by SPC in 2007, however these surveys were generally conducted at different locations, thus these results may be at least partially influenced by spatial differences in habitat cover or depth among surveys. Futher monitoring is warranted to assess changes in fish populations over time.

Invertebrate Surveys

Invertebrate resources and their supporting habitats of Majuro Atoll were surveyed using two complementary approaches: a broad-scale method, using manta tows, and a fine-scale method, using reef-benthos transects (RBT). Nine manta tow monitoring stations (6 x 300 m replicates) were established at Laura, while six manta tow stations were established at Majuro. Individual species observed in the highest mean densities during the manta tow surveys at Laura included the sea cucumbers *Holothuria atra* (235.42±105.22 individuals/ha) and *H. edulis* (7.64±7.64 individuals/ha) and the gastropod *Tectus niloticus* (3.82±0.90 individuals/ha), while at Majuro the sea cucumber *Thelenota anax* (122.22±32.79 individuals/ha) was observed in the highest density. The mean density of *Holothuria atra* and *Tectus niloticus* was significantly higher at Laura than Majuro, while the mean density of *Thelenota anax* was significantly higher at Majuro. A single individual of the coral-eating crown-of-thorns starfish, *Acanthaster planci*, was observed during the manta tow surveys at the Laura site, with no individuals observed at Majuro.

To assess invertebrate resources associated at finer-spatial scales, reef-benthos transects (RBT) were used. Six RBT monitoring stations (6 x 40 m replicates) were established at Laura, while five RBT monitoring stations were established at Majuro. Individual species observed in the highest mean densities during the RBT surveys at Laura included the sea cucumber *Holothuria atra* (608.33±424.84 individuals/ha) and the gastropod *Conomurex luhuanus* (225.00±184.75 individuals/ha), while at Majuro *C. luhuanus* (2800.00±1830.46 individuals/ha) and the sea cucumber *Bohadschia argus* (58.33±58.33 individuals/ha) were observed in the highest density. The mean density of *Holothuria atra* was significantly higher at Laura than Majuro, while the mean density of *C. luhuanus* was significantly higher at Majuro than Laura. No crown-of-thorns starfish were observed during the RBT surveys at either site. No differences in mean size of invertebrate species common to both survey sites were apparent.

Both the diversity and density of invertebrate resources of the Laura site generally appeared lower than that recorded during PROCFish surveys conducted in 2007, however as with the finfish surveys these surveys were conducted at different locations, thus these results may be at least partially influenced by spatial differences in habitat cover or depth among surveys. Futher monitoring is warranted to assess changes in invertebrate populations over time.

Recommendations for Future Monitoring

The following recommendations are proposed for future monitoring events:

- During this baseline survey, separate monitoring stations were established for some of the benthic habitat and finfish assessments. For future monitoring events it is recommended that the same stations be used for both the benthic habitat and finfish monitoring. This approach will greatly increase survey efficiency (thus reducing field costs), and provide a secondary indicator of habitat health from which to explore relationships between environmental variables and the status of finfish resources.

- Due to strong currents and poor weather, two back-reef and one lagoon-reef benthic habitat and finfish transect at the Laura site could not be completed. To balance the survey design, these transects should be established during the re-survey event.

- During the baseline survey, depth varied markedly among finfish transects within a habitat (e.g. 2–15 m for lagoon-reef habitats at Majuro). Given that depth has been routinely demonstrated to be a significant factor influencing the distribution and abundance of fish and corals, it is recommended that depth be standardised among transects within a habitat during future monitoring events.

- The substantial differences observed in densities and biomass of finfish families common to the current study and the PROCFish survey is of considerable concern, as it indicates a significant reduction in finfish populations over a short-term period. It is strongly recommended that survey stations be established at the same positions as those examined during the PROCFish study, to rule out any possible spatial differences. Furthermore, to ensure that these contrasting results, and results of future surveys, were not a result of differences in observer skill or experience, the use of non-observer based monitoring techniques, such as videography, in conjunction with the D-UVC surveys are recommended.

- For this baseline study, manta tow surveys were conducted on back-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 Laura and Majuro 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, finfish and invertebrate resources using SPC resource assessment protocols, and photo quadrats for assessing 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 Majuro Atoll, Republic of the Marshall Islands (RMI), in April and May 2011, by a team from SPC's Coastal Fisheries Science and Management Section, staff from Marshall Islands Marine Resource Authority (MIMRA), Marshall Islands Conservation Society (MICS), College of Marshall Islands (CMI), and Republic of the Marshall Islands Environmental Protection Authority (RMIEPA). Recommendations for future monitoring events are also provided.

Republic of the Marshall Islands

Background

The Republic of the Marshall Islands is located in the western North Pacific Ocean between 4°N and 12°N, stretching from 160°E to 173°E (Figure 1). The country consists of 29 atolls and five low-lying, solitary coral islands. It is bounded on the west by the Federated States of Micronesia, on the south by Nauru and Kiribati, and on the north by the United States territory of Wake Island (Figure 1). The total land area of RMI is approximately 181 km^2, while the Exclusive Economic Zone (EEZ) totals approximately 2.13 million km^2 (Gillet 2009). In 2011, the estimated population RMI was 68,000, with approximately two-thirds of the population living on the capital, Majuro Atoll (Marshall Islands 2011). During the 1999 census over half the population was under the age of 15 years, the highest ratio in the Pacific (Canadian High Commission 2001). The climate is warm and humid, with mean air temperatures ranging from 24.7 to 29.9°C, humidity ranging from 78–83% and an annual rainfall of approximately 4,034 mm. The wet season is from May to November (Sisifa 2002, Turner 2008).

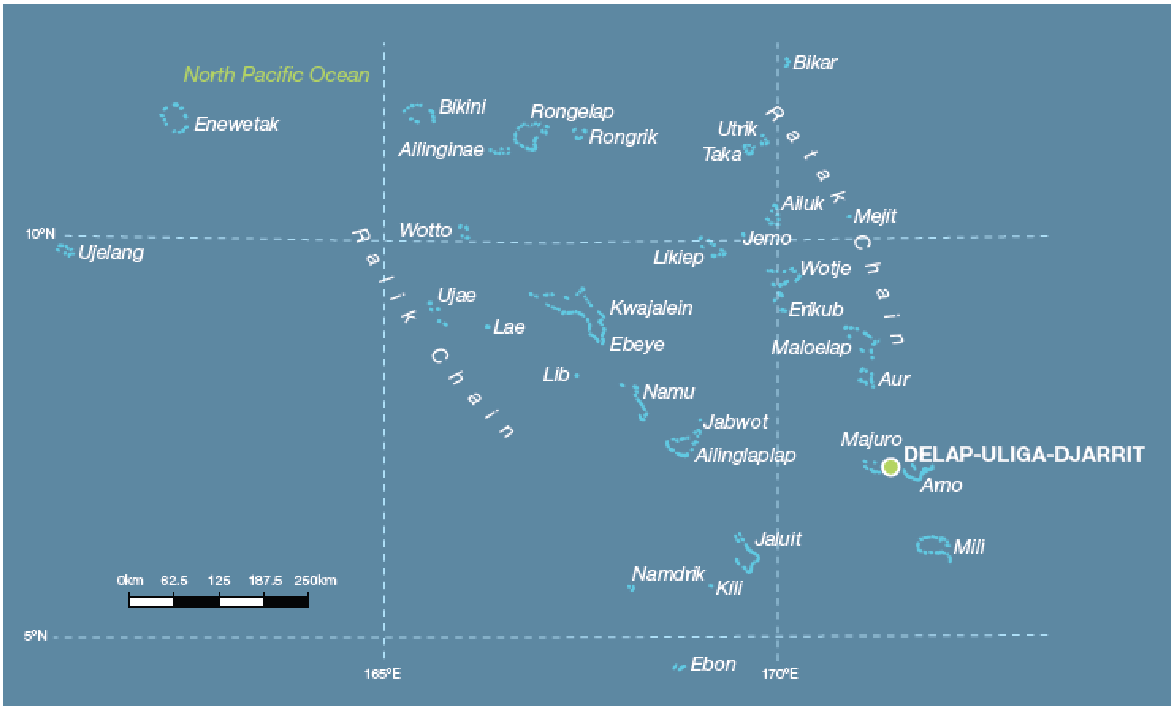

Figure 1 **Republic of the Marshall Islands (from PCCSP 2011).**

Fisheries

Oceanic fisheries

RMI has an industrial purse-seine tuna fishery that operates within its EEZ. Recent average catches (2004–2008) by this fishery have exceeded 47,000 tonnes, worth USD 56.7 million per year (Bell et al. 2011). In 2007, this fishery contributed approximately 20% to the gross domestic product (GDP) of RMI. RMI also licenses foreign fishing vessels to fish for tuna and associated species within its EEZ. Between 1999 and 2008, foreign purse-seine vessels made an average annual catch of approximately 22,500 tonnes, worth USD 20 million per year (Bell et al. 2011). Licence fees for access to the fishery make up a significant portion of government revenue (GR). In 2007, licence fees from foreign and national vessels contributed 2% of GR, while fees from longline vessels contributed a further 1.2% of GR (Gillet 2009).

Coastal fisheries

The coastal fisheries of RMI are comprised of four broad-scale categories: demersal fish (bottom-dwelling fish associated with mangrove, seagrass and coral reef habitats), nearshore pelagic fish (including tuna, wahoo, mackerel, rainbow runner and mahi-mahi), 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 3,750 tonnes, worth > USD 7.2 million (Gillet 2009) (Table 1). The commercial component of this catch was an estimated 950 tonnes, while the subsistence catch was

2,800 tonnes (Gillet 2009) (Table 1). Approximately 64% of the total catch is estimated to be made up of demersal fish (Bell et al. 2011) (Table 2).

Table 1 Annual fisheries and aquaculture harvest in the Republic of the Marshall Islands, 2007 (Gillet 2009)

Harvest sector	Quantity (tonnes)	Value (USD million)
Offshore locally-based	63,569	81,210,390
Offshore foreign-based	12,727	19,572,712
Coastal commercial	950	2,900,000
Coastal subsistence	2,800	4,312,000
Freshwater	0	0
Aquaculture	25,000 pieces	130,000
Total	**80,046 t plus 25,000 pieces**	**108,125,102**

Marshallese harvest, market and consume a wide range of coastal finfish and invertebrates. Fresh fish consumption averages 35kg per person per year, while invertebrate consumption is approximately 6kg per person per year (Pinca et al. 2009). Coastal fish species are harvested with a variety of methods, including gill nets, cast nets, pole and line, trolling and spears. Between 1991 and 2002, seven rural fish bases, equipped with cold-storage and ice-making facilities, were established on outer atolls so that fresh fish from rural areas could be transported to Majuro for marketing (Chapman 2004a). All of these bases focus mainly on harvesting lagoon species, with some catches of pelagics from trolling activities. MIMRA continues to provide the transport vessels to collect the fish from the rural fish base, sometimes every 3–4 months, with the fish either landed in Majuro or Ebeye for marketing (Chapman 2004b).

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	2,417	64
Nearshore pelagic finfish	1,080	29
Targeted invertebrates	3	< 1
Inter/subtidal invertebrates	250	7
Total	**3,750**	**100**

Climate Change Projections for RMI

Air temperature

Historical air temperature data records for RMI are available for Majuro and Kwajalein Atolls. For Majuro Atoll, these records show an increase in average daily temperatures of approximately 0.15°C per decade since recording began in 1956 (Figure 2) (PCCSP 2011).

Mean air temperatures are projected to continue to rise, with increases of +0.6, +0.8 and +0.7°C (relative to 1990 values) projected for 2030, under the IPCC B1 (low), A1B (medium) and A2 (high) emissions scenarios, respectively, for the northern Marshall Islands and +0.7, +0.8 and +0.7°C (relative to 1990 values) projected for 2030, under the IPCC B1, A1B and A2 emissions scenarios, respectively, for the southern Marshall Islands (PCCSP 2011) (Table 3).

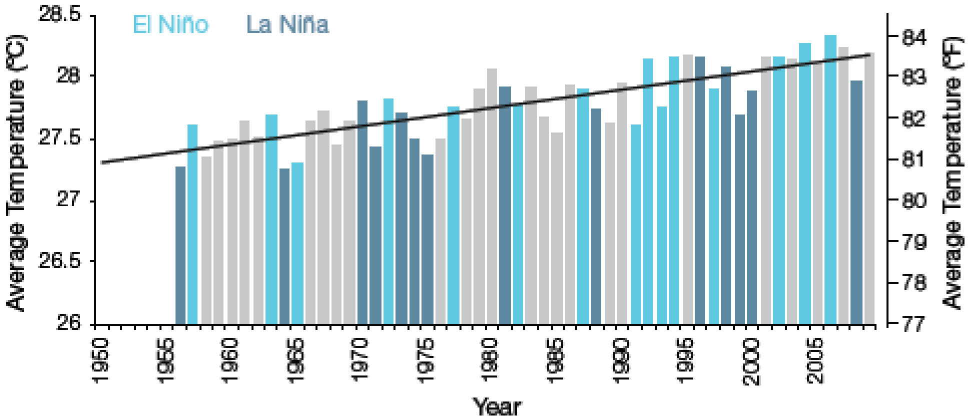

Figure 2 **Mean annual air temperature at Majuro (1956–2009) (from PCCSP 2011).**

Table 3 **Projected air temperature increases (in °C) for a) northern and b) southern Republic of the Marshall Islands under various IPCC emission scenarios (from PCCSP 2011)**

Region	Emission scenario	2030	2055	2090
a) northern RMI	B1	+0.6 ± 0.4	+1.0 ± 0.5	+1.5 ± 0.7
	A1B	+0.8 ± 0.4	+1.5 ± 0.6	+2.3 ± 0.9
	A2	+0.7 ± 0.3	+1.4 ± 0.4	+2.8 ± 0.7
b) southern RMI	B1	+0.7 ± 0.4	+1.1 ± 0.6	+1.6 ± 0.8
	A1B	+0.8 ± 0.5	+1.5 ± 0.7	+2.4 ± 0.9
	A2	+0.7 ± 0.3	+1.4 ± 0.4	+2.8 ± 0.7

Sea-surface temperature

In accordance with mean air surface temperatures, sea-surface temperatures are projected to further increase, with increases of +0.7, +0.8 and +0.7°C (relative to 1990 values) projected for 2030, under the IPCC B1 (low), A1B (medium) and A2 (high) emissions scenarios, respectively, for the northern Marshall Islands and +0.3, +0.4 and +0.4°C (relative to 1990 values) projected for 2030, under the IPCC B1, A1B and A2 emissions scenarios, respectively, for the southern Marshall Islands (PCCSP 2011) (Table 4).

Table 4 Projected sea-surface temperature increases (in °C) for a) northern and b) southern Republic of the Marshall Islands under various IPCC emission scenarios (from PCCSP 2011)

Region	Emission scenario	2030	2055	2090
a) northern RMI	B1	+0.7 ± 0.5	+1.1 ± 0.7	+1.5 ± 0.9
	A1B	+0.8 + 0.6	+1.4 ± 0.7	+2.3 ± 1.0
	A2	+0.7 ± 0.4	+1.4 ± 0.6	+2.7 ± 0.7
b) southern RMI	B1	+0.3 ± 0.3	+0.6 ± 0.3	+0.8 ± 0.4
	A1B	+0.4 ± 0.3	+0.8 ± 0.3	+1.2 ± 0.5
	A2	+0.4 ± 0.2	+0.7 ± 0.3	+1.4 ± 0.4

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 at Majuro Atoll in May 1993. According to the 2010 Pacific country report on sea level and climate for the Republic of the Marshall Islands (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 at Majuro Atoll (accounting for barometric pressure and tidal gauge movement) was calculated at +3.8 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 the RMI region, 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 (PCCSP 2011). Climate models suggest that by 2035 the annual maximum aragonite saturation state for RMI will reach values below 3.5 (the lowest saturation level considered adequate for coral growth (Guinotte et al. 2003)) and continue to decline thereafter (PCCSP 2011). These projections suggest that coral reefs of RMI 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. 2009a, Munday et al. 2009b). The impact of acidification change on the health of reef ecosystems is likely to be compounded by other stressors including coral bleaching, storm damage and fishing pressure (PCCSP 2011).

Projected Effects of Climate Change of Coastal Fisheries of RMI

Climate change is expected to add to the existing local threats to the coral reef, mangrove and seagrass habitats of the Marshall Islands, resulting in declines in the quality and area of all habitats (Table 5). Accordingly, all coastal fisheries categories in RMI are projected to show progressive declines in productivity due to both the direct (e.g. increased SST) and indirect effects (e.g. changes to fish habitats) of climate change (Table 6) (Bell et al. 2011).

Table 5 Projected changes in coastal fish habitat in RMI 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 to -10	-5 to -25	-10 to -30

* 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]	0	-10	-15 to -20
Targeted invertebrates	-2 to -5	-10	-20
Inter/subtidal invertebrates	0	-5	-10

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

2. Site and Habitat Selection

Site Selection

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

- Marshall Islands mentions *Strengthen the relevant institutions and improve procedural mechanisms so as to be able to secure the optimal support from both international and regional efforts, in minimising the adverse impact of climate change* as one of its goals in the RMI/SPC Joint Country Strategy 2008–2010;

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

- A wave buoy has been deployed in May 2010 to monitor wave height, time between waves and sea surface temperature near Majuro (College of Marshall Islands);

- Fish, invertebrate and socio-economic data were collected by SPC during the PROCFish/C project at Laura, on the western side of Majuro Atoll, in 2007 (Pinca et al. 2009); and

- Non-governmental organization (NGOs) and MIMRA offices are located on Majuro, which simplifies logistics.

Majuro Atoll is located at approximately 7° N latitude and 171° E longitude, and is comprised of 64 islands. Majuro Atoll consists of approximately 9.7 km^2 of land area and encloses a lagoon of 295 km^2 of lagoon. Being an urbanized atoll, Majuro's reefs are impacted by various anthropogenic stressors including poor waste management systems and increased coastal development causing increased sedimentation and coastal erosion (Pinca et al. 2002).

Two survey regions were defined on Majuro Atoll by dividing the land area into two: the Laura site in the west of the atoll and Majuro site in the east (Figure 3). The Majuro was considered an 'impact' site since it has a relatively high population and high fishing pressure, while the Laura site was considered a 'control' since it is less populated and subject to relatively low fishing pressure. This design allowed for potential de-coupling of the effects of overfishing and pollution from other causes (e.g. climate-related effects). 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.

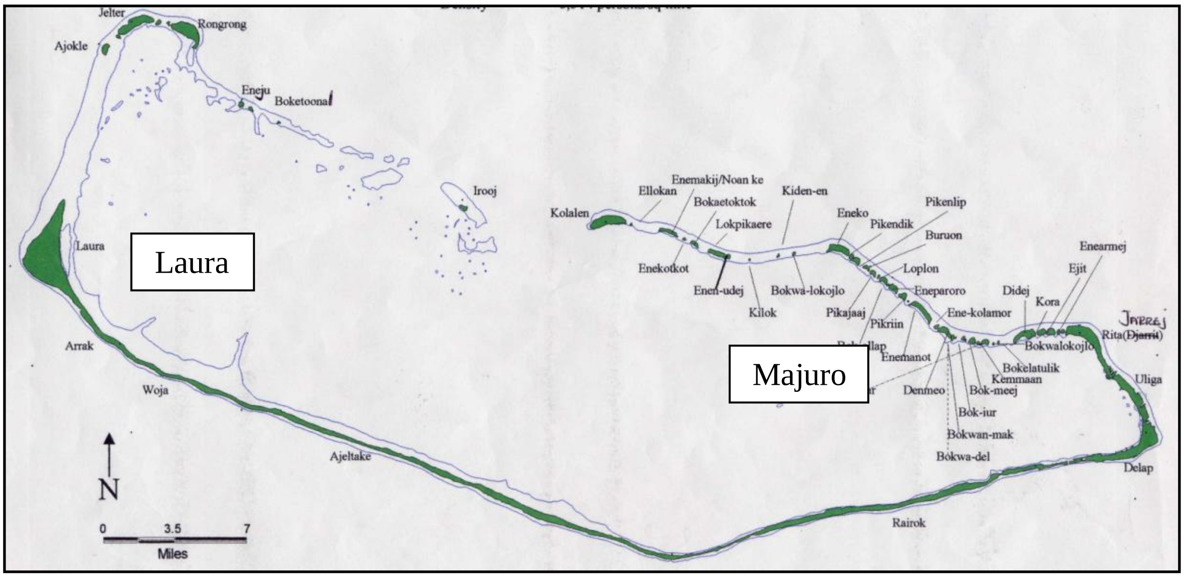

Figure 3 Majuro Atoll indicating the Laura and Majuro study regions.

Fisheries of Majuro Atoll

Fishing is an important activity for the people of Majuro Atoll. Socio-economic survey work conducted at Laura as part of the PROCFish surveys by SPC in 2007 revealed that 96% of households surveyed engage in some form of fishing activity (Pinca et al. 2009). Per capita consumption of fresh fish was found to be almost 90 kg/person/year, more than double the regional average of approximately 35 kg/person/year (Pinca et al. 2009). By comparison, consumption of invertebrates (edible meat weight only) was found to be considerably lower at approximately 5 kg/person/year (Pinca et al. 2009). Fishers typically use a variety of fishing methods, and target a number of habitats, per fishing trip (Pinca et al 2009). Most frequently, a combination of gillnets, cast nets, handlines and spears are used. Fishing is mainly a male domain, as males are either exclusive finfish fishers or combine both finfish fishing and invertebrate collection (Pinca et al 2009).

Habitat Definition and Selection

Coral reefs are highly complex and diverse ecosystems. The NASA Millennium Coral Reef Mapping Project (MCRMP) has identified and classified coral reefs of the world in about 1000 categories. These very detailed categories can be used directly to try to explain the status of living resources or be lumped into more general categories to fit a study's particular needs. For the purposes of the baseline field surveys in Majuro 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 May 2011, two temperature loggers were deployed at the Laura site: one on the outer reef and one in the lagoon. The loggers were calibrated to an accuracy of ±0.002ºC and programmed to record temperature every five minutes. For security reasons both loggers were housed in a PVC tube with holes to allow flow of water and encased in a concrete block (Figure 4). These blocks were then secured to the sea floor using rebars. Loggers were planned to be deployed at a depth of approximately 10 m, however, due to unforeseen circumstances one logger was deployed at approximately 20 m (Table 7). The collected data will be stored on SPC servers and made available to networks of researchers, governmental services and conservation non-government organizations (NGOs).

Figure 4 Concrete housings for the temperature logger being readied for deployment at Majuro Atoll, 2011.

Table 7 Details of temperature loggers deployed at Majuro Atoll.

Details	Majuro 1	Majuro 2
Deployment date	17/05/2011	17/05/2011
Location	Laura, Majuro Atoll	Laura, Majuro Atoll
Habitat	Outer reef	Lagoon
Longitude	171.045127	171.054299
Latitude	7.198610	7.192523
Depth	19 m	10 m

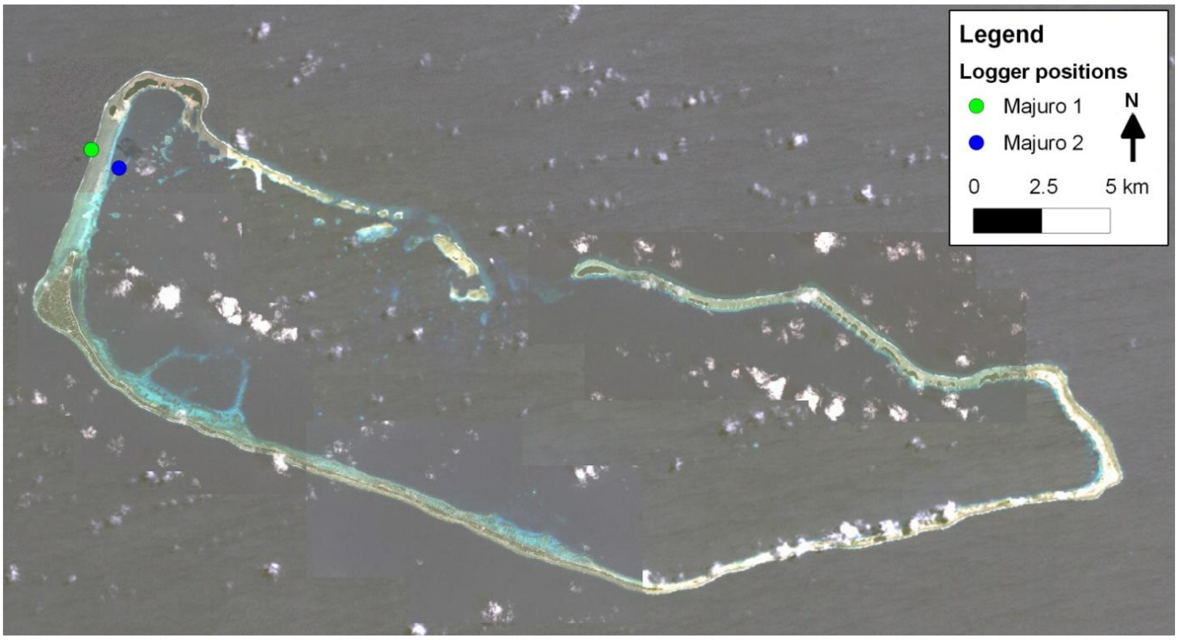

Figure 5 **Location of water temperature loggers deployed in Majuro Atoll, 2011.**

Results

The logger on the outer reef of Majuro Atoll (Majuro 1) was retrieved on the 26th July 2012, after it had been deployed for approximately 13 months. The logger recorded water temperature continuously until its retrieval. Water temperature on the outer-reef was constant between July and early November 2011, and then generally declined from late November 2011 to a low of 23.35°C shortly before the logger was retrieved (Figure 6). At the time of writing, it was unknown whether the decrease in water temperature observed from late November 2011 onwards was due to a fault in the logger, the logger shifting from its original location, or a result of cold-upwelling in the area. Due to security issues, this logger was not re-deployed following retrieval. The logger in the lagoon of Majuro Atoll (Majuro 2) was also planned to be retrieved in July 2012, however, after multiple search events this logger could not be located. This logger has subsequently been replaced with a newer model (Seabird SBE 56).

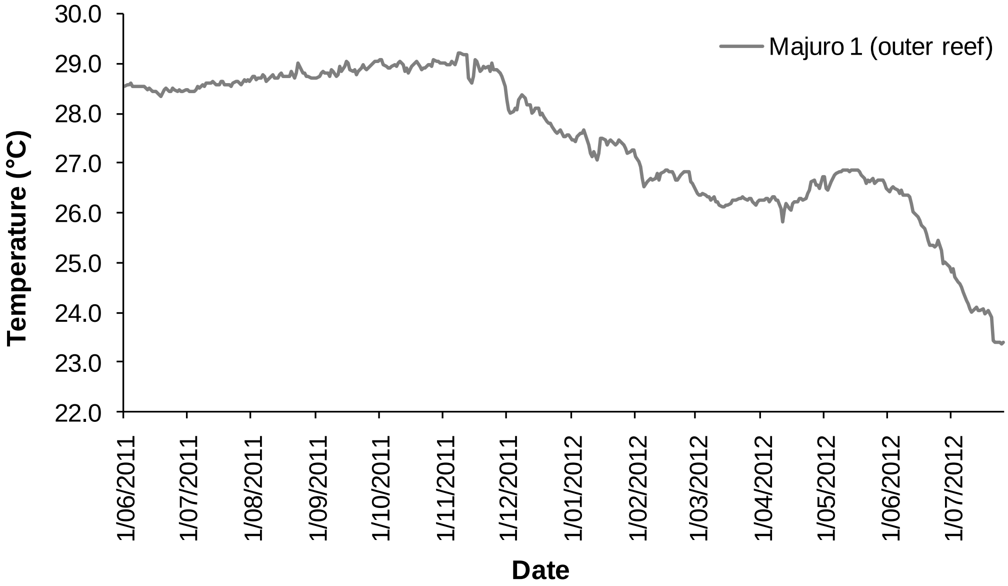

Figure 6 **Mean daily temperatures recorded on the outer-reef at Majuro, 1st June 2011 to 26th July 2012.**

4. Benthic Habitat Assessment

Methodologies

Data collection

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

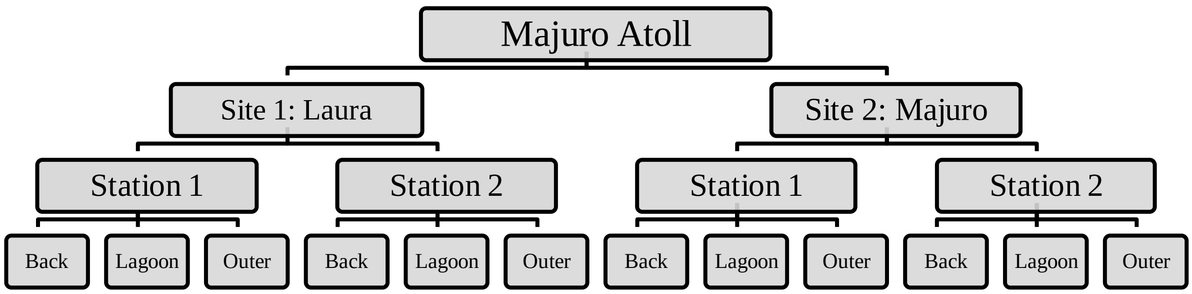

Figure 7 **Survey design of the benthic habitat and finfish assessments in Majuro, RMI. Three replicate 50m transects were planned in each back-, lagoon- or outer-reef habitat.**

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);
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*,

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

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 newly exposed white skeletons with visible corallites and no polyps present, while bleached coral was defined as white coral with polyps still present. All data processing and identifications were checked by an experienced surveyor. Resulting data were then summarized as percentages and extracted to MS Excel. To assess broad-scale patterns in benthic habitat among sites and habitats, principle component analysis (PCA) was conducted on log(x+1) transformed mean percent cover values of each major substrate category, using Primer 6. To explore differences among sites and habitats, coverage data of each major benthic category in each individual transect were square-root transformed to reduce heterogeneity of variances and analysed by two-way analysis of variance (ANOVA) using Statistica 7.1, with site (Laura and Majuro) and habitat (back-reef, lagoon-reef, and outer-reef) as fixed factors in the analysis. Tukey-Kramer post-hoc pairwise tests were used to identify specific differences between factors at $P = 0.05$. Where transformed data failed Cochran's test for homogeneity of variances ($P < 0.05$), an increased level of significance of $P = 0.01$ was used. 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 33 benthic habitat assessment transects were completed across the back-, lagoon- and outer reef habitats of Majuro Atoll, with 17 transects completed in the Laura site and 16 transects completed in the Majuro site (Figure 8; Table 8). Due to strong currents and poor weather one transect in the back reef of both Laura 1 and Majuro 3, and one transect of the outer-reef of Majuro 4, could not be completed. A list of GPS positions for each benthic habitat assessment transect is presented as Appendix 1.

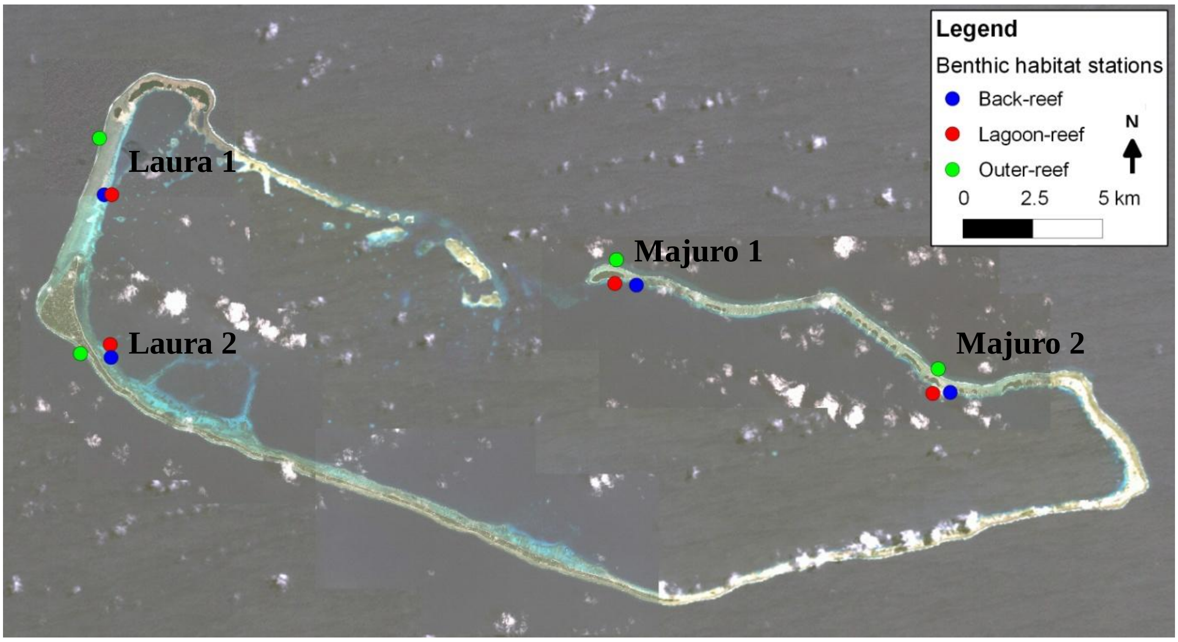

Figure 8 **Location of benthic habitat assessment stations established in Majuro Atoll, 2011.**

Table 8 **Summary of benthic habitat assessment transects at Laura and Majuro, 2011.**

Site	Station	Habitat	No. of transects
Laura	Laura 1	Back-reef	2
		Lagoon-reef	3
		Outer-reef	3
	Laura 2	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3
Majuro	Majuro 1	Back-reef	2
		Lagoon-reef	3
		Outer-reef	3
	Majuro 2	Back-reef	3
		Lagoon-reef	3
		Outer-reef	2

Back-reef habitats

In general, back-reef habitats of both the Laura and Majuro stations differed from back- and outer-reef habitats by the presence of relatively high cover of sand and macroalgae, and low cover of hard corals (Figure 9; Figure 10). The dominant benthic category in terms of overall mean cover for both the Laura and Majuro sites was sand, which constituting 46.2±10.1% and 52.4±3.7% of overall cover, respectively. Back-reefs at Laura had a greater mean percent cover of macroalgae than those at Majuro (P = 0.003), with *Halimeda* the most commonly observed genus (Figure 10).

Hard coral cover was low for the back-reef habitats of both the Laura and Majuro sites, with hard corals constituting 13.2±2.9% and 9.1±3.2% of overall cover, respectively. At Laura, a total of nine types of hard coral were recorded from the back-reef habitats, while six types of hard coral were recorded from the back-reef habitats at Majuro (Figure 10). In terms of cover, *Acropora* and *Porites*-massive were the most common hard coral types of the Laura sites, representing 5.4±1.6% and 3.4±1.2% of overall cover, respectively. *Porites*-massive *Acropora* and *Porites*-rus were the most common hard coral types of the Majuro stations, representing 3.8±2.5%, 1.9±1.0% and 1.6±0.8% of overall cover, respectively (Figure 10). Hard coral cover at the back-reef habitats of Majuro was significantly lower than that observed for the lagoon- and outer-reefs of this site ($P \leq 0.022$), while no significant difference were observed in hard coral cover among back-, lagoon- and outer-reef habitats of Laura. No bleached or recently dead corals were observed in the back-reef habitats of Laura. At Majuro, the percentage cover of bleached and recently dead corals was low, constituting 0.1±0.1% and 0.2±0.1% of overall mean cover of hard corals.

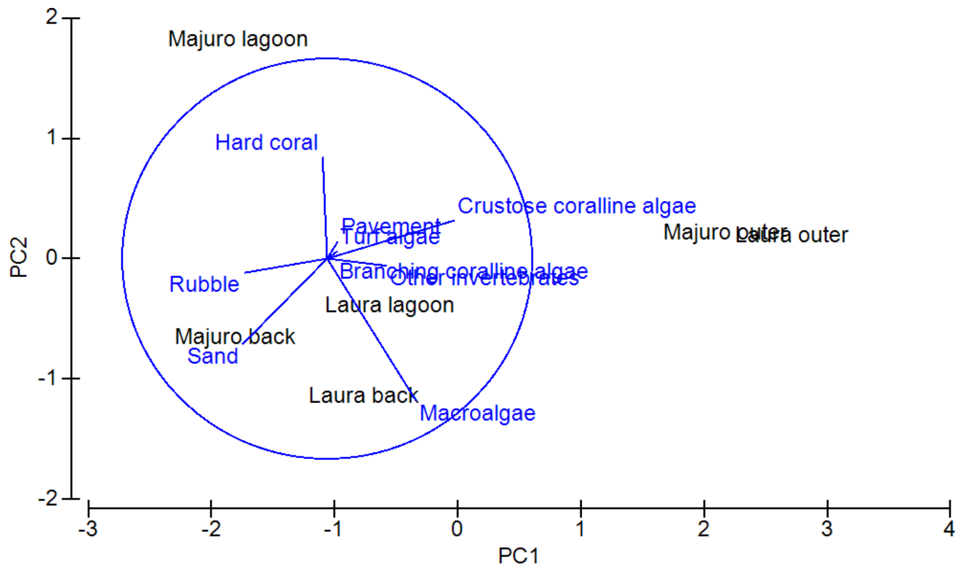

Figure 9 **Principle Component Analysis (PCA) of each major benthic substrate category for each site. Sites separate along a gradient of sand and rubble versus crustose coralline algae (PC1) and hard coral versus macroalgae (PC2).**

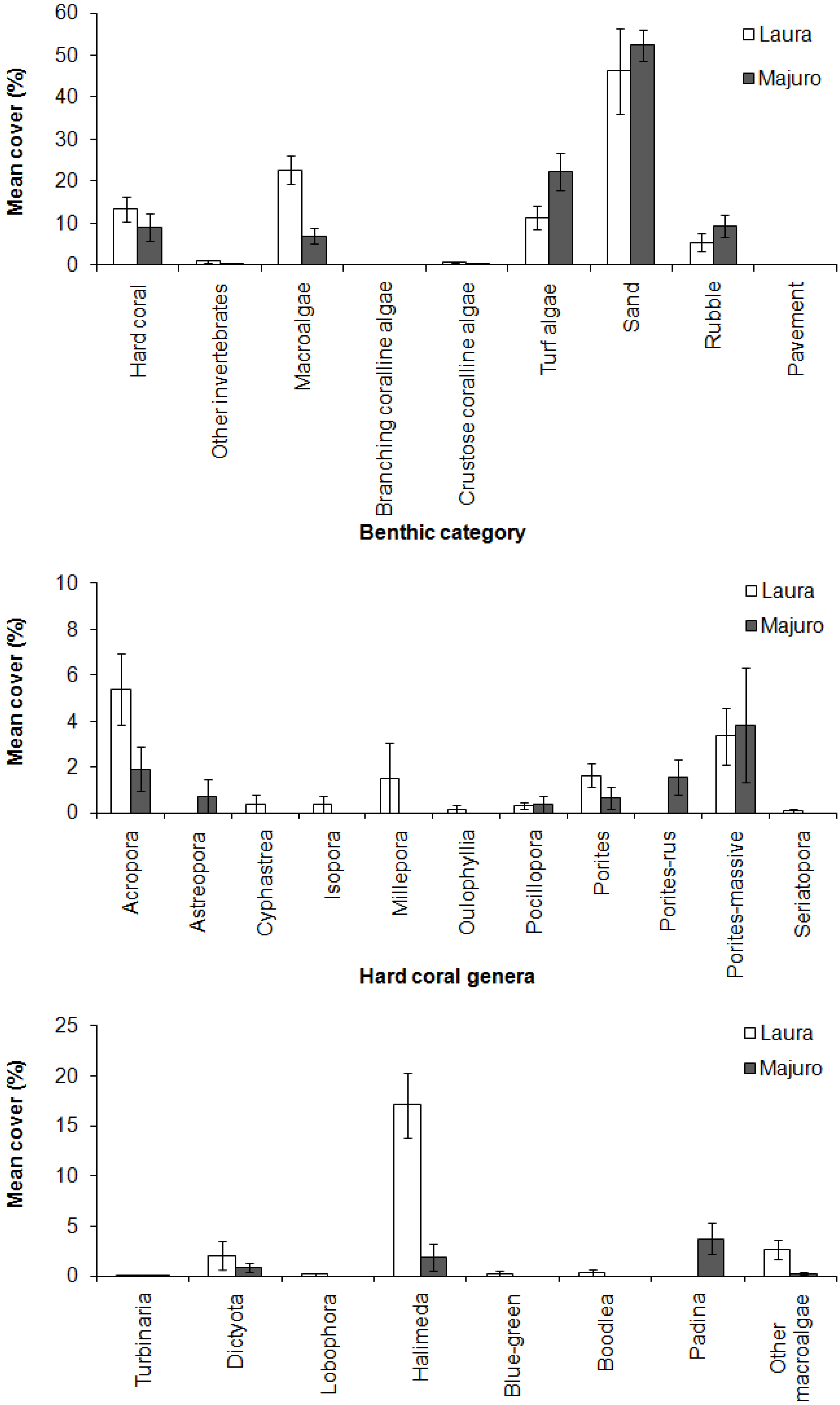

Figure 10 **Mean cover (± SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at back-reef habitats during benthic habitat assessments at Laura and Majuro, 2011.**

Lagoon-reef habitats

Considerable variation in benthic cover was observed among the lagoon-reef habitats of the Laura and Majuro monitoring stations (Figure 9; Figure 11). The dominant benthic categories in terms of overall mean cover for the Laura stations were sand (which constituted 32.3±8.2% of overall cover), hard corals (25.4±5.1% of overall cover) and turf algae (20.7±3.3% of overall cover). Lagoon-reef habitats of Majuro had the highest percent cover of hard coral of any habitat and site, with hard corals constituting 56.7±6.5% of overall cover. The cover of hard corals on the lagoon-reefs of Majuro was significantly higher than those at Laura ($P = 0.004$) (Figure 11). Lagoon-reefs at Laura had a significantly higher cover of macroalge than those at Majuro ($P < 0.001$), with *Halimeda* the most commonly observed genus (Figure 11).

At Laura, a total of 13 types of hard coral were recorded from the lagoon-reef habitats, while nine types of hard coral were recorded from the lagoon-reef habitats of Majuro (Figure 11). In terms of cover, *Porites*, *Porites*-rus and *Porites*-massive were the most common hard coral types of the lagoon-reef habitats of both the Laura and Majuro sites, representing 9.7±3.5%, 4.9±2.7% and 3.7±1.2% of overall cover at Laura, and 10.0±3.6%, 36.8±7.1% and 6.3±2.9% of overall cover at Majuro, respectively (Figure 11). Overall cover of both bleached and recently dead corals was low at both sites, with bleached and recently dead corals constituting 0.2±0.2% and 0.4±0.1% of overall mean hard coral cover at Laura, and 0.2±0.1% and 0.4±0.1% of overall mean hard coral cover at Majuro, respectively.

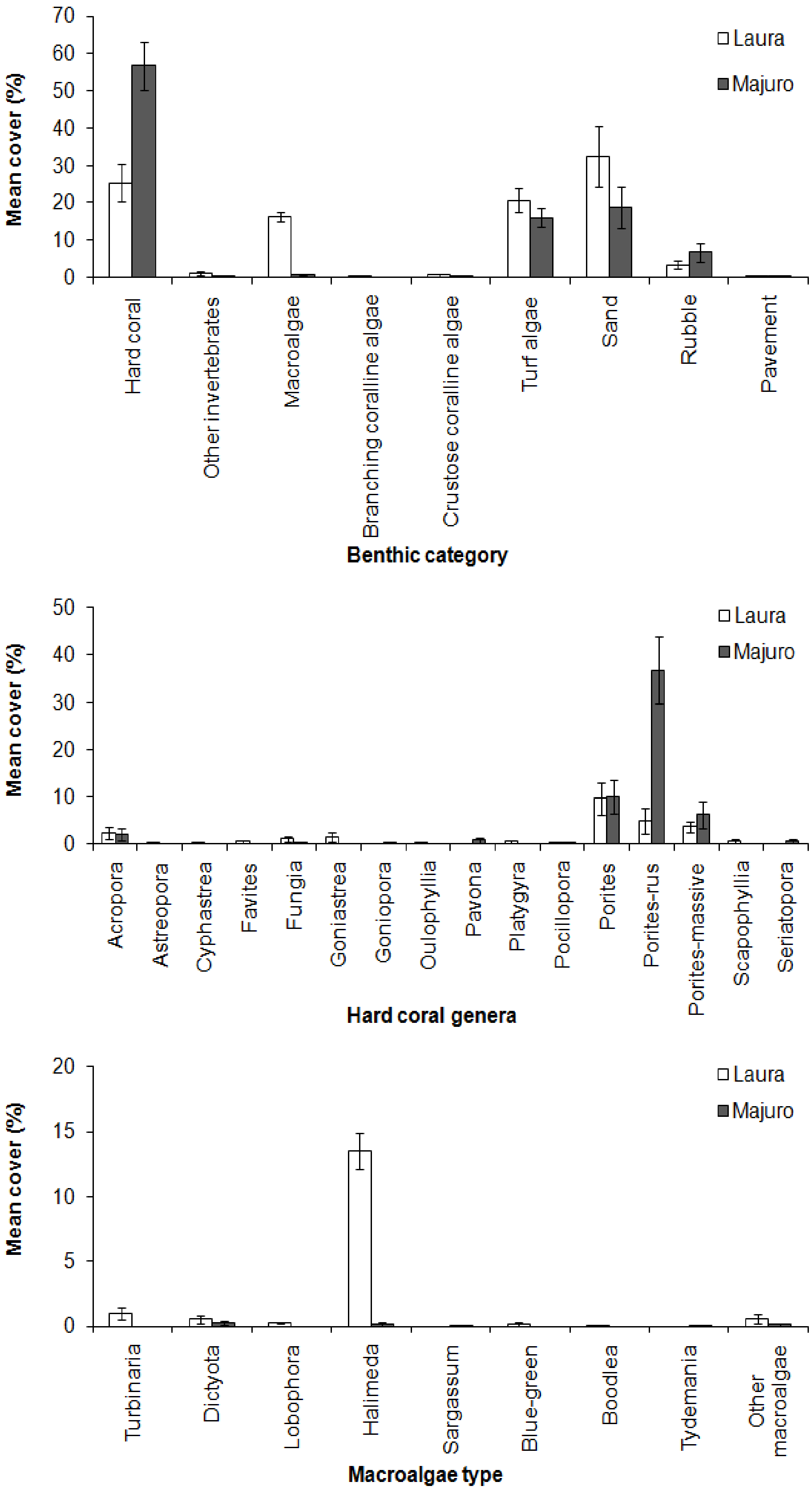

Figure 11 **Mean cover (± SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at lagoon-reef habitats during benthic habitat assessments at Laura and Majuro, 2011.**

Outer-reef habitats

Outer-reef habitats of both the Laura and Majuro monitoring stations differed from back- and lagoon-reef habitats by the presence of a relatively high percent cover of crustose coralline algae and macroalgae, and low cover of sand (Figure 9; Figure 12). Outer-reef transects within the Majuro monitoring stations had a greater mean cover of hard corals, and a lower mean cover of rubble and pavement, than those within the Laura monitoring stations (Figure 12), however these differences were not significant at $P = 0.05$. Outer-reefs at Laura had significantly higher cover of branching and crustose coralline algae than those at Majuro ($P = 0.001$, and $P = 0.013$, respectively).

A total of eight types of hard coral were recorded from the outer-reef habitats at Laura, while 12 types of hard coral were recorded from the outer-reef habitats of Majuro (Figure 12). In terms of cover, *Acropora*, *Isopora*, *Porites*-massive, *Pocillopora* and *Porites* were the most common hard coral types at Laura, representing 4.1±1.9%, 2.8±2.5%, 2.6±2.0%, 2.1±0.9 and 1.8±1.1% of overall cover respectively. *Acropora*, *Pocillopora*, *Astreopora*, *Montipora* and *Porites* were the most common hard coral types at Majuro, representing 11.2±1.2%, 4.9±0.8%, 4.6±1.4%, 2.0±0.5% and 1.7±0.5% of overall cover, respectively. No bleached or recently dead corals were observed in the outer-reef habitats of Laura. For the outer-reef habitats at Majuro, the percentage cover of bleached coral was low, constituting 0.1±0.1% of the overall mean cover of hard corals, while no recently dead coral was observed. *Halimeda* and *Lobophora* were the dominant macroalgae genera observed at both the Laura and Majuro sites (Figure 12).

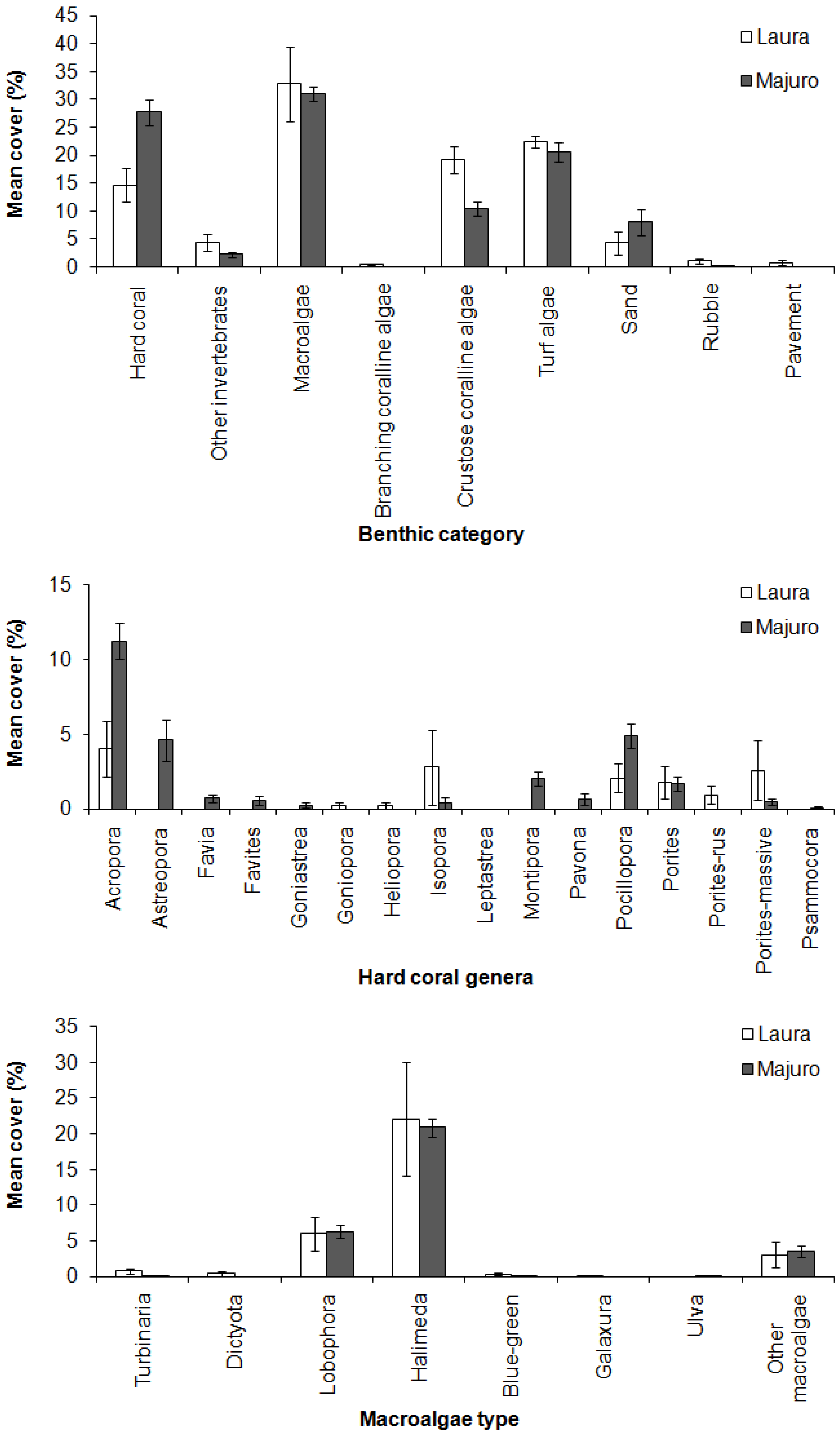

Figure 12 **Mean cover (± SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at outer-reef habitats during benthic habitat assessments at Laura and Majuro, 2011.**

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 Laura and Majuro sites (Figure 7). Each transect census was completed by two SCUBA divers who recorded the species name, abundance and total length (TL) of all fish observed (Appendix 2). The distance of the fish from the transect line was also recorded (Figure 13). Two distance measurements were recorded for a school of fish belonging to the same species and size (D1 and D2; Figure 13), while for individual fish only one distance was recorded (D1). Regular review of identification books and cross-checks between divers after the dive ensured that accurate and consistent data were collected.

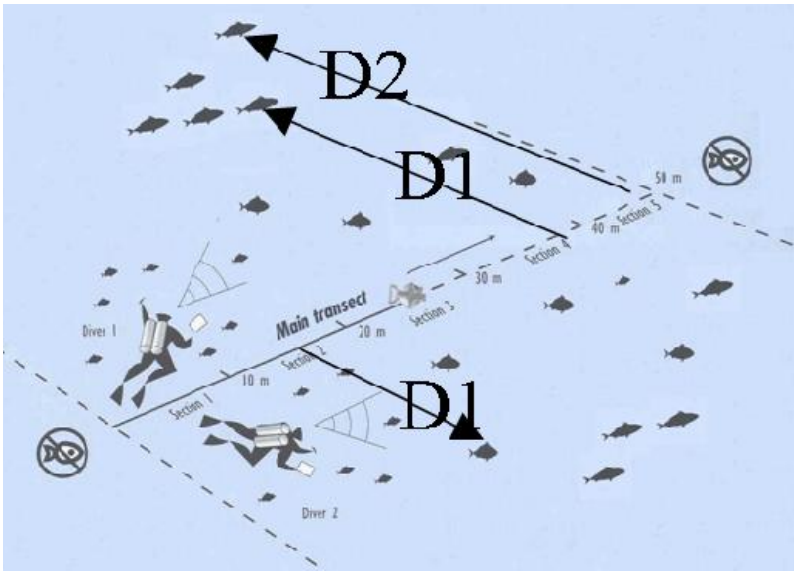

Figure 13 Diagram portraying the D-UVC method.

Habitats supporting finfish

Habitats supporting finfish were documented after the finfish survey using a modified version of the medium scale approach of Clua et al (2006). This component uses a separate form (Appendix 3) from that of the finfish assessment, 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 meter 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 Laura and Majuro 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 (Laura and Majuro) and habitat (back-reef, lagoon-reef, and outer-reef) 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 mean density and biomass data from the Laura stations were compared against those collected during the PROCFish surveys in this region in 2007 (Pinca et al. 2009) by habitat using one-way ANOVA. While the PROCFish project collected data relating to species of interest to fisheries only, precluding comparisons of overall density and biomass and comparisons among trophic groups against the current study, data of commonly recorded families (Acanthuridae, Balistidae, Chaetodontidae, Holocentridae, Kyphosidae, Lethrinidae, Lutjanidae, Mullidae, Nemipteridae, Scaridae, Siganidae and Zanclidae) can nevertheless be compared, providing an important starting point from which to explore changes over time.

Results

Coverage

A total of 33 D-UVC transects were completed across the back-, lagoon- and outer-reef habitats of Majuro Atoll, with 15 transects completed in the Laura site and 18 transects completed in the Majuro site (Figure 14; Table 9). Due to strong currents and poor weather at the time of survey, two back-reef transects and one lagoon-reef transect at the Laura 2 station could not be completed. A list of GPS coordinates for each D-UVC transect is presented as Appendix 4.

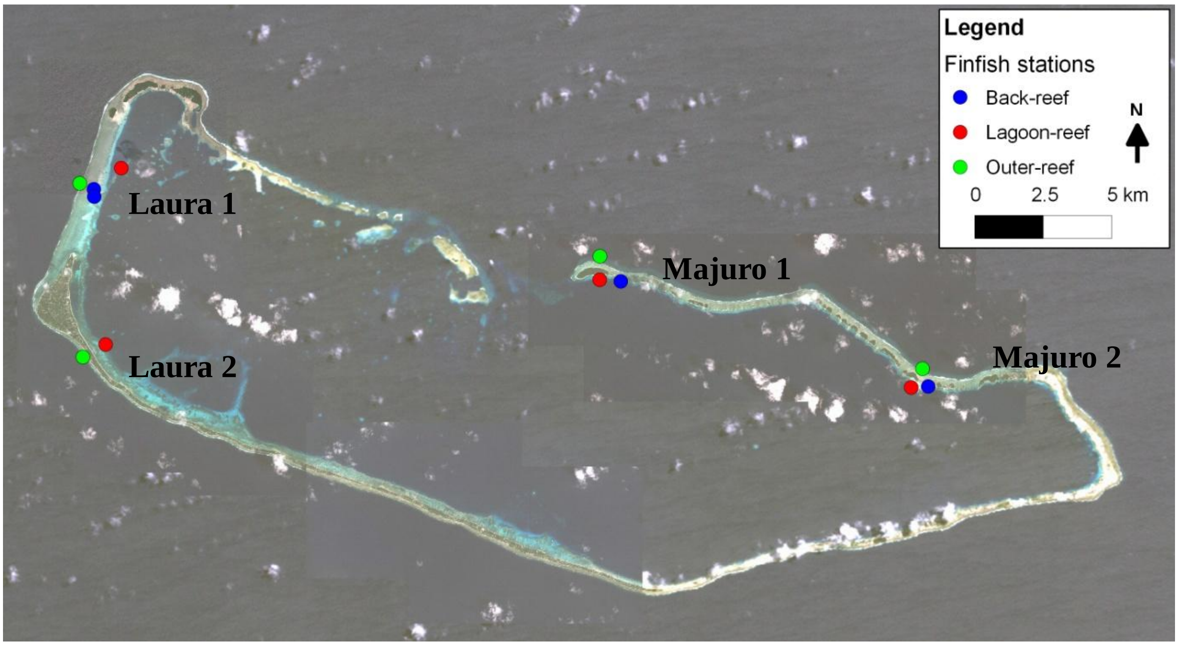

Figure 14 Location of finfish assessment stations established in Majuro Atoll, 2011.

Table 9 Summary of distance underwater visual census (D-UVC) transects among habitats for Laura and Majuro monitoring sites.

Site	Station	Habitat	No. of transects
Laura	Laura 1	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3
	Laura 2	Back-reef	1
		Lagoon-reef	2
		Outer-reef	3
Majuro	Majuro 1	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3
	Majuro 2	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3

Finfish surveys

Overall

A total of 22 families, 70 genera, 189 species and 27,294 individual fish were recorded from the 33 D-UVC transects. Of these, 20 families, 56 genera, 154 species and 13,181 individual fish were recorded from the Laura monitoring stations, while 17 families, 55 genera, 141 species and 14,113 individual fish were recorded from the Majuro monitoring stations (see Appendices 5–8 for a full list of families and species recorded at both the Laura and Majuro sites). At both sites, diversity was typically lowest within back-reef habitats, and highest within lagoon- and outer-reef habitats (Table 10). Within the Laura site, overall mean density appeared higher within the outer-reef compared to the lagoon- or back-reef habitats (Figure 15). Within the Majuro site, overall mean density appeared higher within the back- and lagoon-reef habitats compared to the outer reef. Overall mean density appeared higher at Majuro than Laura for back- and lagoon-reef habitats, while overall mean density appeared higher at Laura than Majuro for the outer-reef habitats (Figure 15). In terms of overall mean biomass, back-reef habitats at Majuro supported a greater mean biomass than those at Laura, while outer reef habitats at Laura supported a greater mean biomass than those at Majuro. No difference was apparent in overall mean biomass between Laura and Majuro for the lagoon-reef habitats. At Laura, outer-reef habitats supported a higher biomass than back- or lagoon-reefs, while lagoon-reefs supported a higher biomass than back-reefs (Figure 16). At Majuro, lagoon-reefs supported a higher biomass than back-reefs, while no difference was apparent in terms of mean biomass between outer-reefs and either lagoon or back-reefs (Figure 16).

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

Parameter	Back-reef		Lagoon-reef		Outer-reef	
	Laura	Majuro	Laura	Majuro	Laura	Majuro
No. of families	12	13	12	16	19	12
No. of genera	29	36	34	48	51	39
No. of species	55	82	83	106	117	79
Diversity	13.8	13.7	16.6	17.7	19.5	13.2

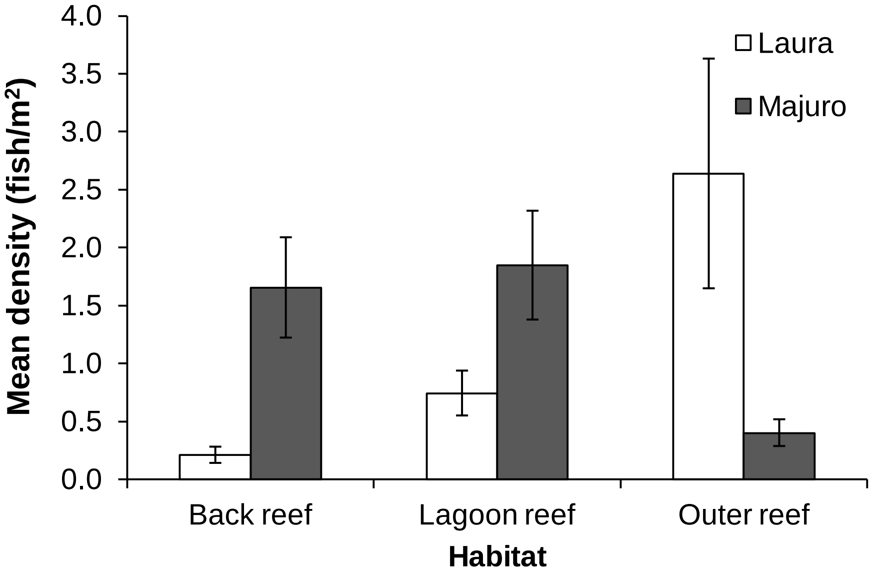

Figure 15 **Overall mean density of finfish (± SE) within back-, lagoon and outer-reef habitats within the Laura and Majuro monitoring sites, 2011.**

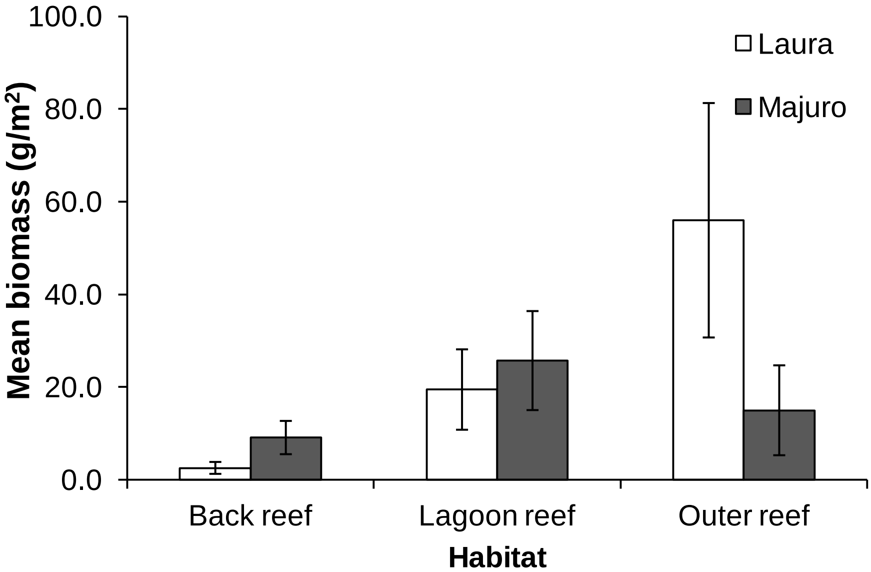

Figure 16 **Overall mean biomass of finfish (± SE) within back-, lagoon and outer-reef habitats within the Laura and Majuro monitoring sites, 2011.**

Back-reef habitats

Habitats supporting finfish

Of the three habitat types, back-reef habitats had the greatest mean percent cover of abiotic material, macroalgae, turf algae and silt covering coral, and the lowest cover of hard coral (Figure 17). Sand was the dominant substrate type for the back-reefs of both Laura and Majuro. Live hard coral cover was low at sites, representing 27.3±12.9% and 14.0±2.9% of overall cover at Laura and Majuro, respectively. Of the corals present, massive, branching, sub-massive and digitate were the dominant coral growth forms present at both sites (Figure 17). No significant differences were observed in the depth, topography, or complexity of the D-UVC transects among on the back-reefs of Laura and Majuro (P = 0.05). Of the major substrate categories, only the cover of turf algae differed among sites (P = 0.016), with back-reefs at Laura having a greater percent cover of turf compared to those at Majuro (Figure 17).

Finfish surveys

A total of 12 families, 29 genera, 55 species and 563 individual fish were recorded from back-reef habitats of the Laura monitoring stations, while 13 families, 36 genera, 82 species and 5,582 individuals were recorded from back-reef habitats of the Majuro monitoring stations (Table 10). Of the 18 selected ‘indicator’ families, the families Pomacentridae (0.091±0.025 fish/m^2), Labridae (0.055±0.014 fish/m^2) and Acanthuridae (0.041±0.019 fish/m^2) occurred in the greatest densities (Figure 18). For the back-reefs of Laura, these families comprised 43.4%, 26.1% and 19.5% of the total observed density, respectively. Similarly, mean density within the back-reef transects of Majuro was dominated the families Pomacentridae (1.295±0.294 fish/m^2, constituting 78.3% of the total observed density at this site), followed to a lesser extent by members of the families Acanthuridae (0.159±0.083 fish/m^2, 9.6% of total observed density), Labridae (0.114±0.025 fish/m^2, 6.9% of the total observed density), and Mullidae (0.038±0.012 fish/m^2, 2.3% of the total observed density). Mean densities of Mullidae and Pomacentridae were significantly greater within the Majuro stations than the Laura stations ($P \leq 0.039$) (Figure 18). The species observed in the highest mean densities within the back-reef habitats of Laura were the pomacentrids *Chrysiptera biocellata* and *Pomacentrus coelestis*, the acanthurids *Zebrasoma scopas* and *Acanthurus triostegus*, and the labrid *Halichoeres trimaculatus* (Table 11). The individual species observed in the highest densities within the back-reef habitats of Majuro were the pomacentrids *Pomacentrus coelestis* and *Chromis viridis*, the acanthurids *Ctenochaetus strigosus* and *C. striatus*, and the labrid *Halichoeres trimaculatus* (Table 11).

For back-reef habitats of Laura, members of the Acanthuridae had the greatest biomass (1.34±0.54 g/m^2), representing 52.6% of the total biomass observed at this site, followed by members of the families Balistidae (0.26±0.16 g/m^2, 10.4% of total observed biomass), Lutjanidae (0.26±0.26 g/m^2, 10.3% of total observed biomass), Serranidae (0.18±0.11 g/m^2, 7.2% of total observed biomass), and Pomacentridae (0.18±0.09 g/m^2, 7.0% of total observed biomass). At the back-reef habitats of Majuro, members of the Pomacentridae had the greatest biomass (3.11±1.38 g/m^2, representing 34.2% of the total biomass observed at this site), followed by members of the families Acanthuridae (2.83±0.85 g/m^2, 31.12% of total observed biomass), Labridae (1.43±0.74 g/m^2, 15.8% of total observed biomass) and Mullidae (0.49±0.11 g/m^2, 5.4% of total observed biomass) (Figure 18). No significant differences were apparent in mean biomass of any of the 18 indicator families among back-reefs of Laura and Majuro at P = 0.05. The species that had the greatest biomass within the back-reef habitats of Laura were the acanthurids *Acanthurus triostegus* and *Zebrasoma scopas*, the balistid *Rhinecanthus aculeatus*, the lutjanid *Lutjanus monostigma*, and the serranid *Epinephalus melanostigma* (Table 12). The species with the greatest biomass within the back-reef habitats of Majuro were the pomacentrid *Pomacentrus coelestis*, the acanthurids *Zebrasoma scopas*, *Ctenochaetus striatus* and *Acanthurus triostegus*, and the serranid *Epinephalus merra* (Table 12).

No significant differences were apparent in mean size or mean size ratio of any of the 18 indicator families among sites. At Laura, the mean size and mean ratio of Mullidae was significantly smaller at back-reef habitats compared to outer-reef habitats (P = 0.044 and P = 0.022, respectively) (Figure 18; Figure 26).

In terms of trophic structure, herbivores (0.129±0.024 fish/m^2) and carnivores (0.067±0.016 fish/m^2) occurred in the greatest mean density within the back-reef habitats of Laura, while herbivores (1.260±0.420 fish/m^2), planktivores (0.213±0.150 fish/m^2) and carnivores (0.164±0.033 fish/m^2) occurred in the greatest density within the back-reef habitats of Majuro (Figure 19). Mean density of herbivores was significantly higher within back-reef habitats of Majuro than those at Laura (P = 0.020) (Figure 19). The dominant trophic groups in terms of biomass in the back-reef habitats of both Laura and Majuro were herbivores, with mean biomasses of 1.524±0.516 g/m^2 and 5.948±1.854 g/m^2 at Laura and Majuro, respectively. No significant differences were observed in mean biomass, mean size or mean size ratio of any trophic group among the back-reef habitats of Laura and Majuro (P > 0.05). Overall, the size ratio of all trophic groups was low (typically below 50% of average maximum values) for both Laura and Majuro (Figure 19).

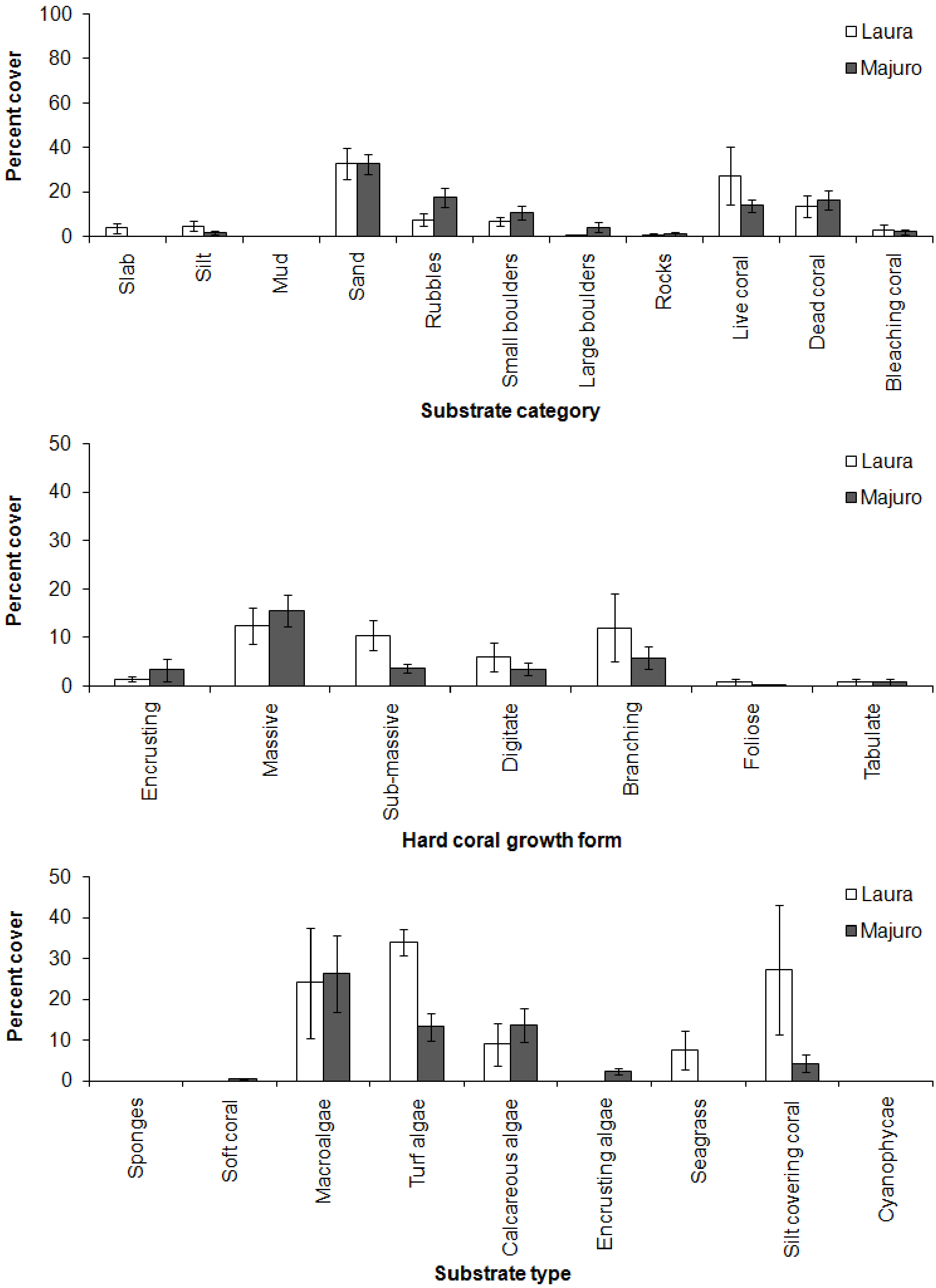

Figure 17 **Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate type (bottom) present at back-reef habitats during finfish surveys at Laura and Majuro, 2011.**

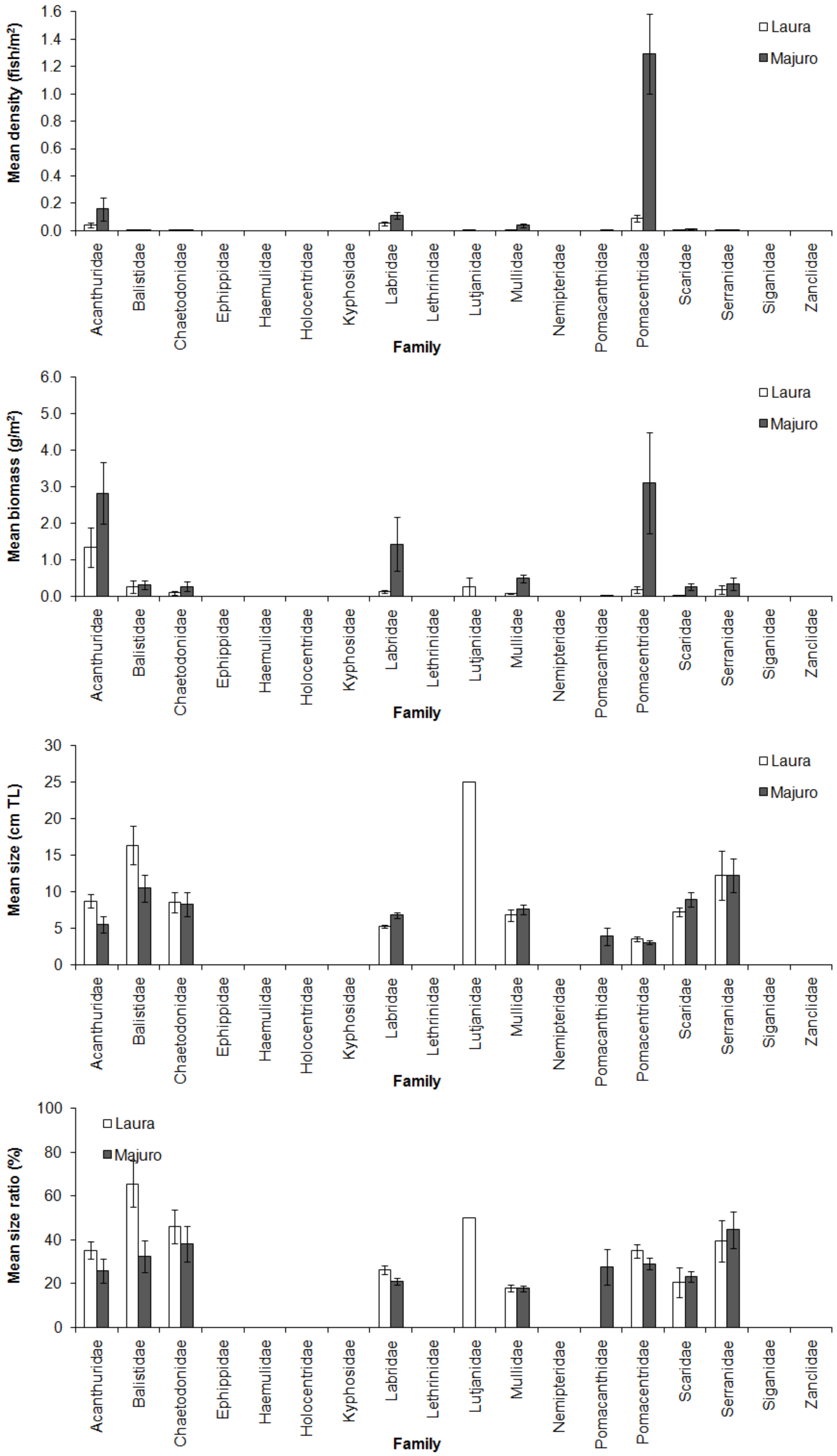

Figure 18 **Profile of finfish indicator families in back-reef habitats of Laura and Majuro monitoring stations, 2011.**

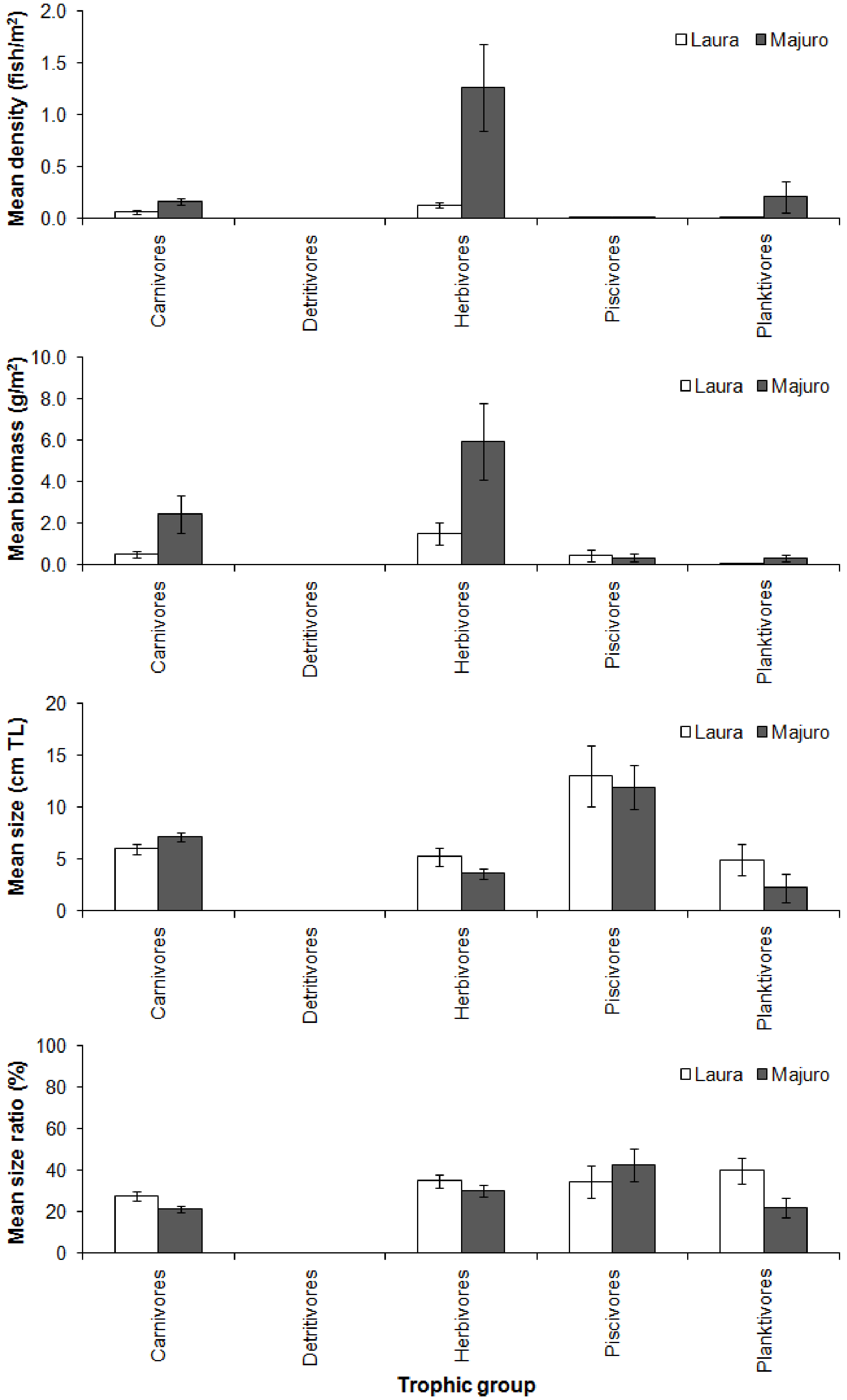

Figure 19 Profile of finfish by trophic level in back-reef habitats of Laura and Majuro monitoring stations, 2011.

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

Site	Species	Family	Density (fish/m^2±SE)
Laura	*Chrysiptera biocellata*	Pomacentridae	0.051±0.032
	Pomacentrus coelestis	Pomacentridae	0.029±0.015
	Zebrasoma scopas	Acanthuridae	0.018±0.015
	Acanthurus triostegus	Acanthuridae	0.013±0.005
	Halichoeres trimaculatus	Labridae	0.013±0.008
Majuro	*Pomacentrus coelestis*	Pomacentridae	1.019±0.345
	Chromis viridis	Pomacentridae	0.165±0.149
	Ctenochaetus strigosus	Acanthuridae	0.076±0.051
	Ctenochaetus striatus	Acanthuridae	0.038±0.019
	Halichoeres trimaculatus	Labridae	0.033±0.013

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

Site	Species	Family	Biomass (g/m^2±SE)
Laura	*Acanthurus triostegus*	Acanthuridae	0.530±0.273
	Zebrasoma scopas	Acanthuridae	0.512±0.296
	Rhinecanthus aculeatus	Balistidae	0.264±0.164
	Lutjanus monostigma	Lutjanidae	0.262±0.262
	Epinephelus melanostigma	Serranidae	0.173±0.111
Majuro	*Pomacentrus coelestis*	Pomacentridae	2.655±1.313
	Zebrasoma scopas	Acanthuridae	1.687±0.955
	Ctenochaetus striatus	Acanthuridae	0.561±0.266
	Epinephelus merra	Serranidae	0.332±0.172
	Acanthurus triostegus	Acanthuridae	0.286±0.264

Comparisons with PROCFish (2007) surveys

Both the density and biomass of finfish resources observed on back-reef habitats of Laura during the current (2011) survey appeared lower than those observed during the PROCFish surveys of 2007 (Figure 20). Observed mean densities of Acanthuridae and Balistidae, and observed mean biomass of Acanthuridae, Balistidae and Scaridae, were significantly lower at back-reef habitats during the current (2011) survey than during the PROCFish survey ($P < 0.05$) (Figure 20). 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 surveys (Table 13). Further monitoring is required to determine whether these differences are consistent over time.

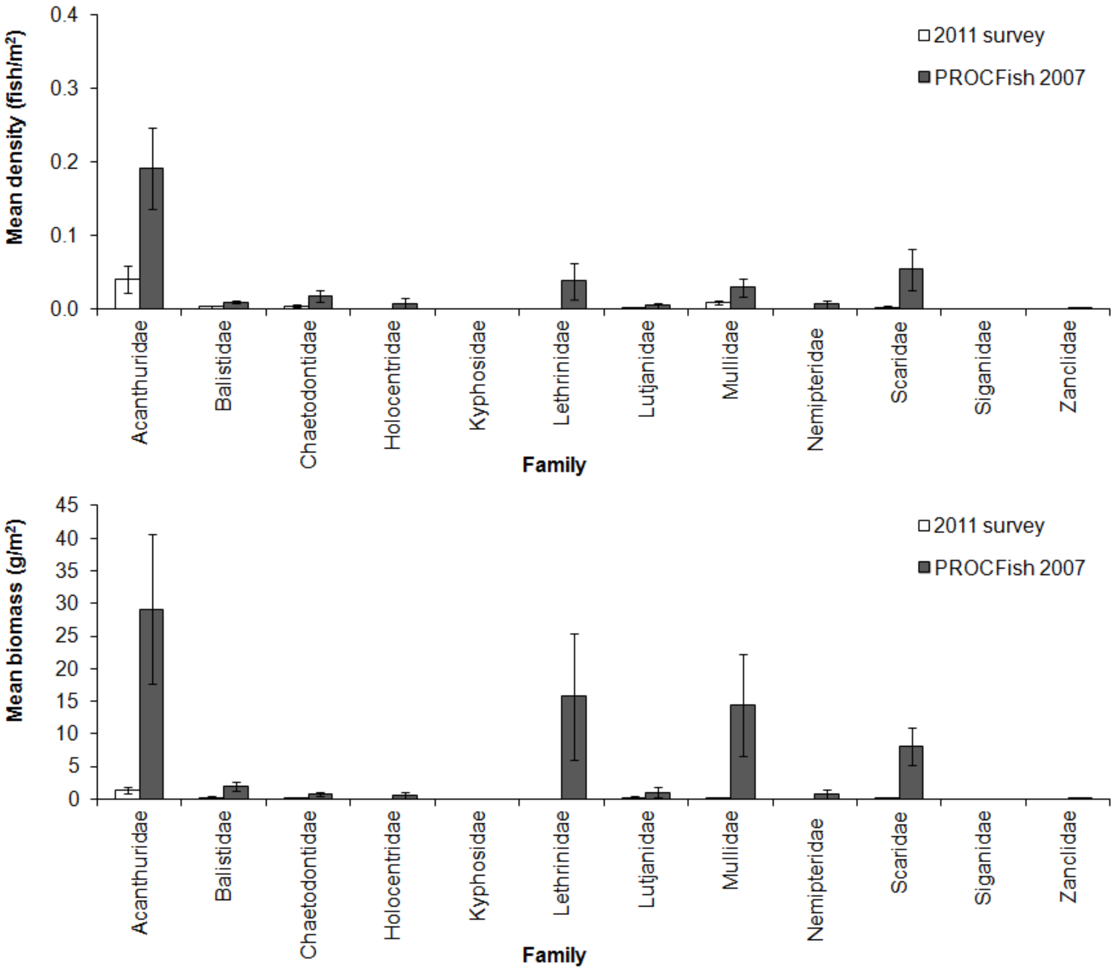

Figure 20 **Comparison of mean density (top) and biomass (bottom) of families recorded from back-reef habitats of Laura in the current study and during PROCFish surveys in 2007 (± SE).**

Table 13 Mean scores (± SE) of major substrate categories in back-reef habitats of the current survey and the PROCFish 2007 surveys.

Habitat category	2011 survey	PROCFish 2007
Depth (m)	1.7±0.2	8.2±3.4
Depth range (m)	1.25–2.0	1.0–19.0
Topography	1.3±0.3	1.2±0.2
Complexity	2.0±0.0	1.5±0.2
Hard substrate	34.1±6.7	63.0±7.0
Soft substrate	65.9±6.7	37.0±7.0
Abiotic	56.4±11.4	49.0±13.4
Hard corals	43.6±11.4	51.0±13.4
Slab	3.7±2.5	9.2±3.6
Silt	4.6±2.3	1.5±1.4
Mud	0.0±0.0	4.2±4.2
Sand	32.9±7.2	25.8±10.7
Rubbles	7.5±2.9	7.4±2.9
Small boulders	6.9±2.1	0.9±0.6
Large boulders	0.0±0.0	0.0±0.0
Rocks	0.7±0.6	0.0±0.0
Live corals	27.3±12.9	20.6±7.8
Dead corals	13.6±4.8	30.5±8.8
Bleaching corals	2.7±2.6	0.0±0.0

Lagoon-reef habitats

Habitats supporting finfish

Lagoon-reef habitats where finfish D-UVC transects were conducted at both Laura and Majuro were dominated by hard corals (both live and dead) and sand (Figure 21). Live hard coral cover was relatively high at both sites, constituting 37.3±7.8% and 52.3±6.79% of overall cover of the lagoon-reef habitats at Laura and Majuro, respectively. Of the corals present, massives were the most prevalent growth form at Laura, while sub-massives were the most prevalent growth form at Majuro (Figure 21). No significant differences were observed in the depth, topography, or complexity of the D-UVC transects among on the lagoon-reefs of Laura and Majuro (P = 0.05). Of the major substrate categories, only the cover of silt (P = 0.037) and turf algae (P = 0.002) differed significantly among sites, with lagoon-reefs at Laura having a greater percent cover of each of these variables compared to Majuro (Figure 21).

Finfish surveys

A total of 12 families, 34 genera, 83 species and 2,262 individual fish were recorded from lagoon-reef habitats of the Laura monitoring stations, while 16 families, 48 genera, 106 species and 6,834 individual fish were recorded from lagoon-reef habitats of the Majuro monitoring stations (Table 10). For the 18 selected 'indicator' families, mean density within the lagoon-reef environments of both Laura and Majuro was dominated by the families Pomacentridae, with 0.484±0.121 fish/m^2 and 1.504±0.353 fish/m^2, constituting 65.2% and 81.5% of the observed overall density at Laura and Majuro, respectively (Figure 22). Mean densities of Chaetodontidae and Pomacentridae were significantly higher at Majuro than Laura ($P \leq 0.038$) (Figure 22). Individual species observed in the highest mean densities within the back-reef habitats of Laura were the pomacentrids *Pomacentrus coelestis*, *Chrysiptera biocellata*, *Chromis viridis* and *Pomacentrus simsiang*, and the acanthurid *Ctenochaetus striatus* (Table 14). At Majuro, the individual species observed in the highest mean densities were the pomacentrids *Pomacentrus coelestis*, *Chromis viridis*, *Chromis ternatensis*, *Chrysiptera traceyi* and *Dascyllus aruanus* (Table 14).

For lagoon-reef habitats of Laura, members of the Acanthuridae had the greatest biomass (11.307±5.378 g/m^2), comprising 58.14% of the total observed biomass, followed by members of the families Scaridae (3.550±1.349 g/m^2, 18.3% of overall biomass), Pomacentridae (1.826±0.486 g/m^2. 9.4% of overall biomass), Mullidae (0.991±0.432 g/m^2, 5.1% of overall biomass) and Labridae (0.679±0.203 g/m^2, 3.5% of total observed biomass) (Figure 22). In accordance with their high density, members of the Pomacentridae had the greatest biomass in lagoon-reef habitats of Majuro at 7.858±2.993 g/m^2, comprising 30.6% of total observed biomass, followed by Acanthuridae (7.782±1.572 g/m^2, 30.3% of overall biomass), Lutjanidae (2.951±2.591 g/m^2, 11.5% of overall biomass), Scaridae (2.618±1.265 g/m^2, 10.2% of overall biomass) and Chaetodontidae (2.005±0.679 g/m^2, 7.8% of overall biomass) (Figure 22). No significant differences were apparent among lagoon-reef habitats of Laura and Majuro in mean biomass of any of the 18 indicator families. Individual species that had the greatest mean biomass within the lagoon-reef habitats of Laura were the acanthurids *Ctenochaetus striatus*, *Zebrasoma scopas* and *Acanthurus nigricauda*, the scarid *Chlorurus sordidus*, and the mullid *Parupeneus barberinus* (Table 15). Individual species that had the greatest mean biomass within the lagoon-reef habitats of Majuro were the acanthurids *Ctenochaetus striatus* and *Zebrasoma scopas*, the pomacentrids *Pomacentrus coelestis* and *Chromis viridis*, and the lutjanid *Lutjanus gibbus* (Table 15).

No significant differences were apparent in mean size or mean size ratio of any of the 18 indicator families among sites. At Majuro, the mean size ratio of Scaridae at lagoon-reef habitats was significantly smaller than outer-reef habitats (P = 0.030) (Figure 22; Figure 26).

In terms of trophic structure, herbivores (0.523±0.746 fish/m^2) occurred in the greatest mean density within the lagoon-reef habitats of Laura, followed by carnivores (0.120±0.024 fish/m^2), while planktivores (0.969±0.169 fish/m^2) and herbivores (0.746±0.129 fish/m^2) occurred in the greatest densities at Majuro, reflective of the high densities of pomacentrids observed at this site (Figure 23). The mean density of planktivores within lagoon-reefs was significantly greater at Majuro than Laura (P = 0.024), consistent with the greater densities of pomacentrids at this site (Figure 23). In terms of mean biomass, herbivores (16.364±6.558 g/m^2) and carnivores (2.665±1.195 g/m^2) were the dominant trophic groups within the Laura stations, while herbivores had the greatest biomass at Majuro (13.877±0.2.552 g/m^2). No significant differences were observed in mean biomass, mean size or mean size ratio of any trophic group among the lagoon-reef habitats of Laura and Majuro (P > 0.05). As with back-reef habitats, the size ratio of all trophic groups was low (typically below 50% of average maximum values) for lagoon-reef habitats of both Laura and Majuro (Figure 23).

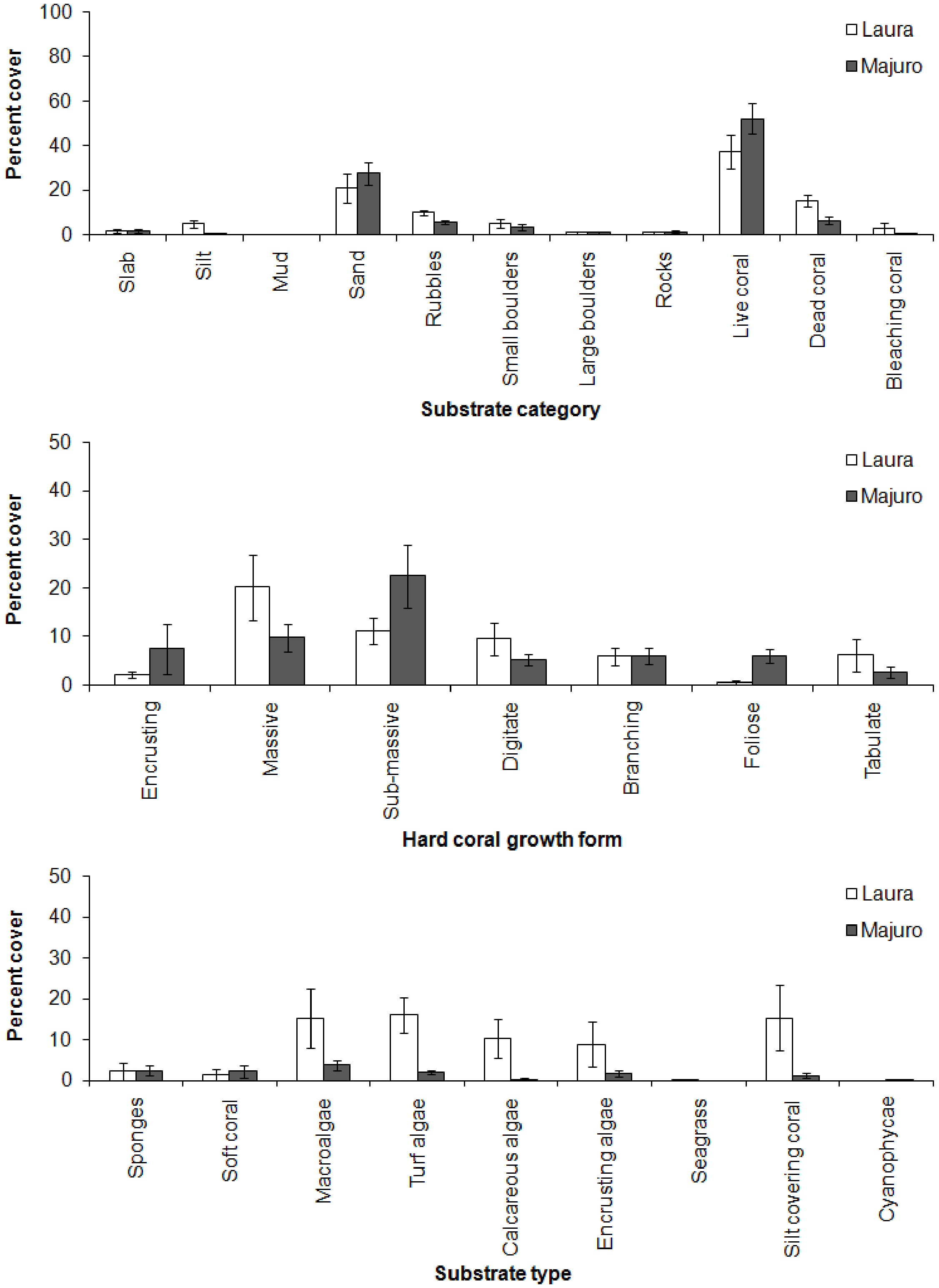

Figure 21 **Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate type (bottom) present at lagoon-reef habitats during finfish surveys at Laura and Majuro, 2011.**

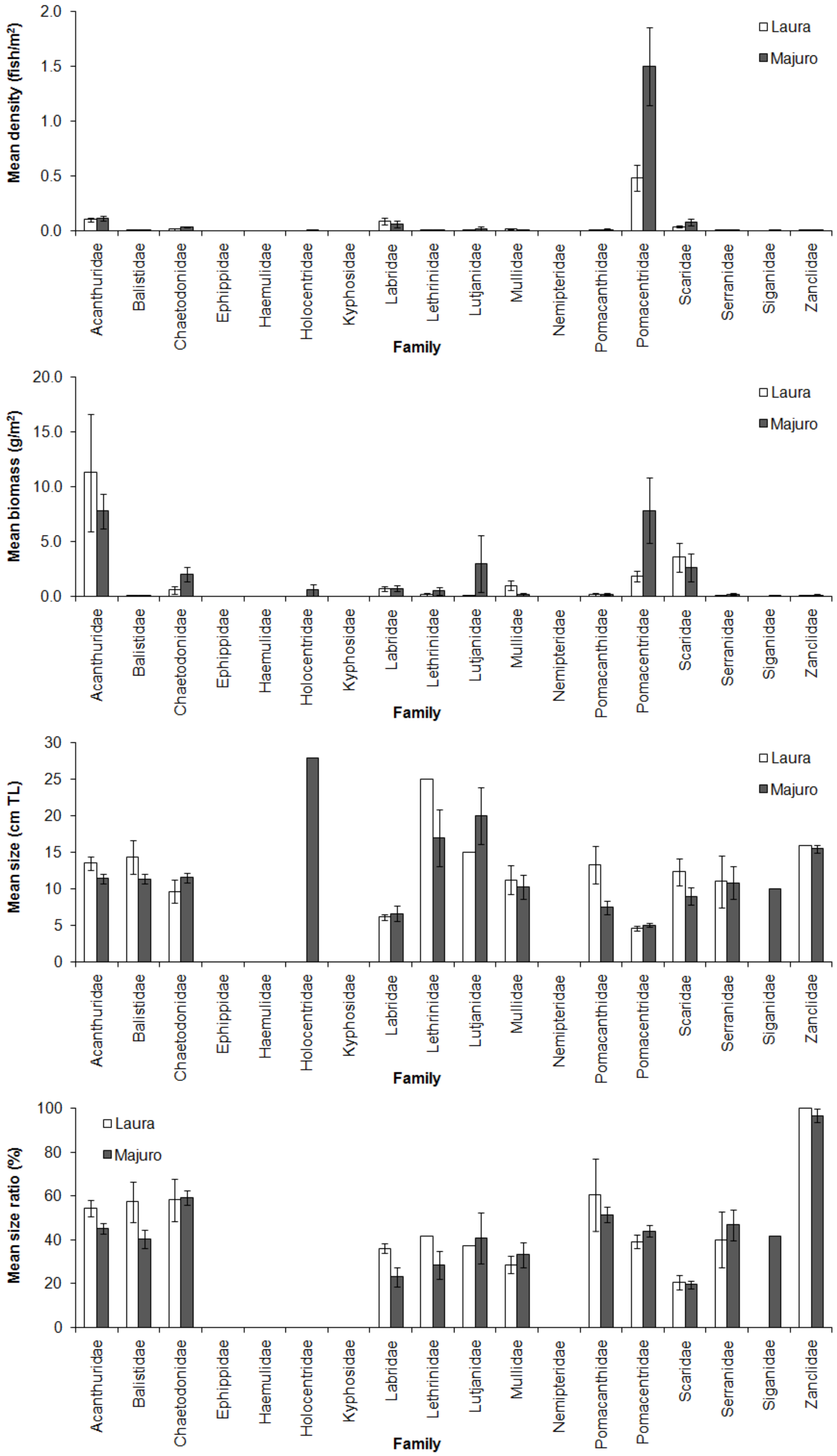

Figure 22 Profile of finfish indicator families in lagoon-reef habitats of Laura and Majuro monitoring stations, 2011.

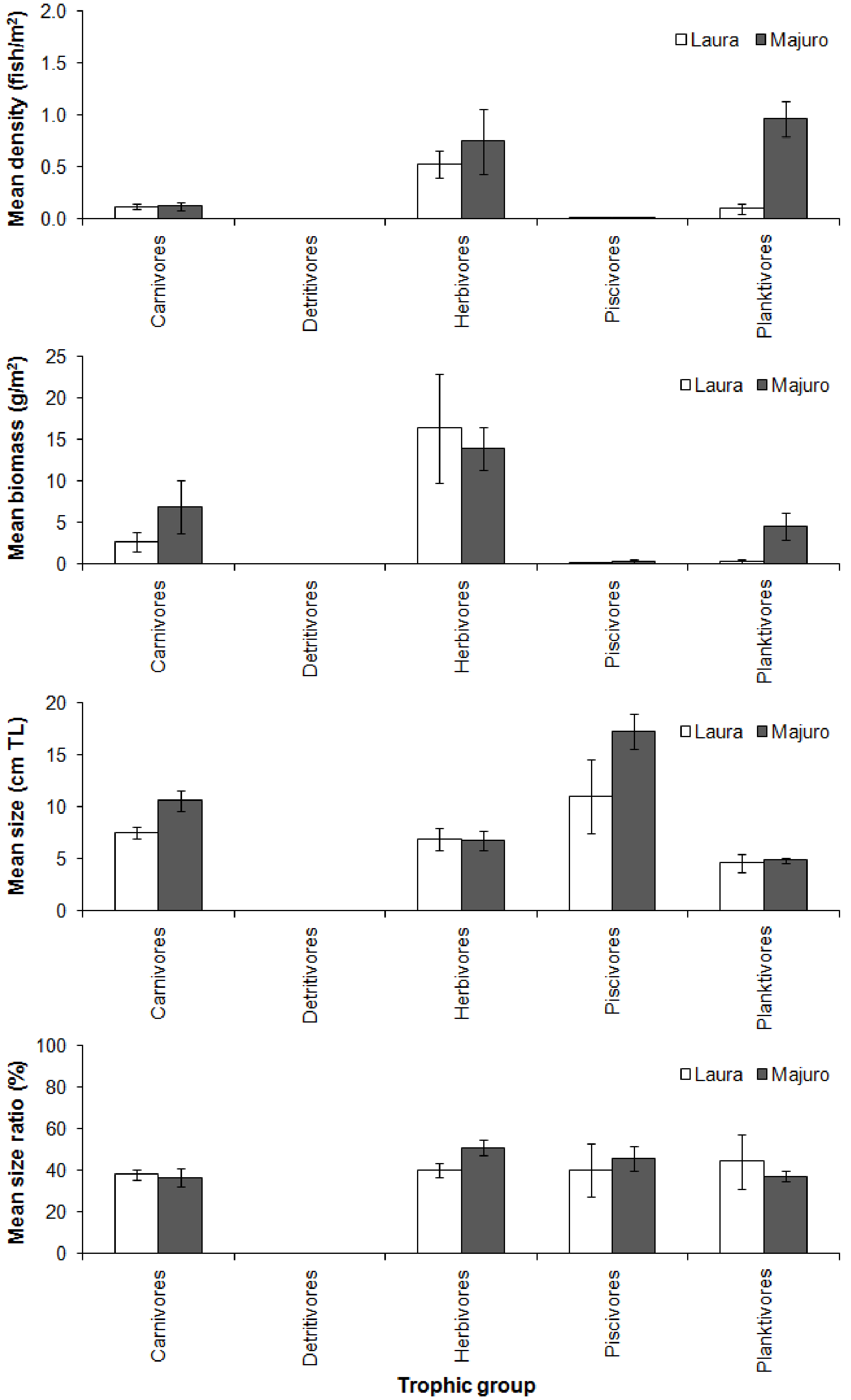

Figure 23 Profile of finfish by trophic level in lagoon-reef habitats of Laura and Majuro monitoring stations, 2011.

Table 14 Finfish species observed in highest densities in lagoon-reef habitats of Laura and Majuro, 2011. See Appendix 7 and 8 for a full list of densities of individual fish species observed at Laura and Majuro monitoring sites.

Site	Species	Family	Density (fish/m^2±SE)
Laura	*Pomacentrus coelestis*	Pomacentridae	0.161±0.070
	Chrysiptera biocellata	Pomacentridae	0.087±0.060
	Ctenochaetus striatus	Acanthuridae	0.072±0.011
	Chromis viridis	Pomacentridae	0.059±0.046
	Pomacentrus simsiang	Pomacentridae	0.026±0.013
Majuro	*Pomacentrus coelestis*	Pomacentridae	0.354±0.305
	Chromis viridis	Pomacentridae	0.341±0.192
	Chromis ternatensis	Pomacentridae	0.193±0.124
	Chrysiptera traceyi	Pomacentridae	0.119±0.049
	Dascyllus aruanus	Pomacentridae	0.095±0.034

Table 15 Finfish species with the highest biomass in lagoon-reef habitats of Laura and Majuro, 2011. See Appendix 7 and 8 for a full list of biomass of individual fish species observed at Laura and Majuro monitoring sites.

Site	Species	Family	Biomass (g/m^2±SE)
Laura	*Ctenochaetus striatus*	Acanthuridae	6.632±4.660
	Zebrasoma scopas	Acanthuridae	2.634±1.416
	Chlorurus sordidus	Scaridae	1.015±0.533
	Parupeneus barberinus	Mullidae	0.773±0.499
	Acanthurus nigricauda	Acanthuridae	0.710±0.710
Majuro	*Ctenochaetus striatus*	Acanthuridae	3.269±0.919
	Pomacentrus coelestis	Pomacentridae	2.911±2.838
	Lutjanus gibbus	Lutjanidae	2.636±2.636
	Zebrasoma scopas	Acanthuridae	2.511±1.522
	Chromis viridis	Pomacentridae	1.929±1.291

Comparisons with PROCFish (2007) surveys

As with back-reef habitats, both the density and biomass of finfish resources observed on lagoon-reef habitats of Laura during the current (2011) study generally appeared lower than those observed during the PROCFish surveys of 2007 (Figure 24). The observed mean biomass of Scaridae and Siganidae were significantly greater during the PROCFish (2007) surveys than the current survey ($P < 0.05$), while the observed mean density of Mullidae was significantly greater during the current survey than the PROCFish survey ($P = 0.034$). 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 surveys (Table 16). Further monitoring is required to determine whether these differences are consistent over time.

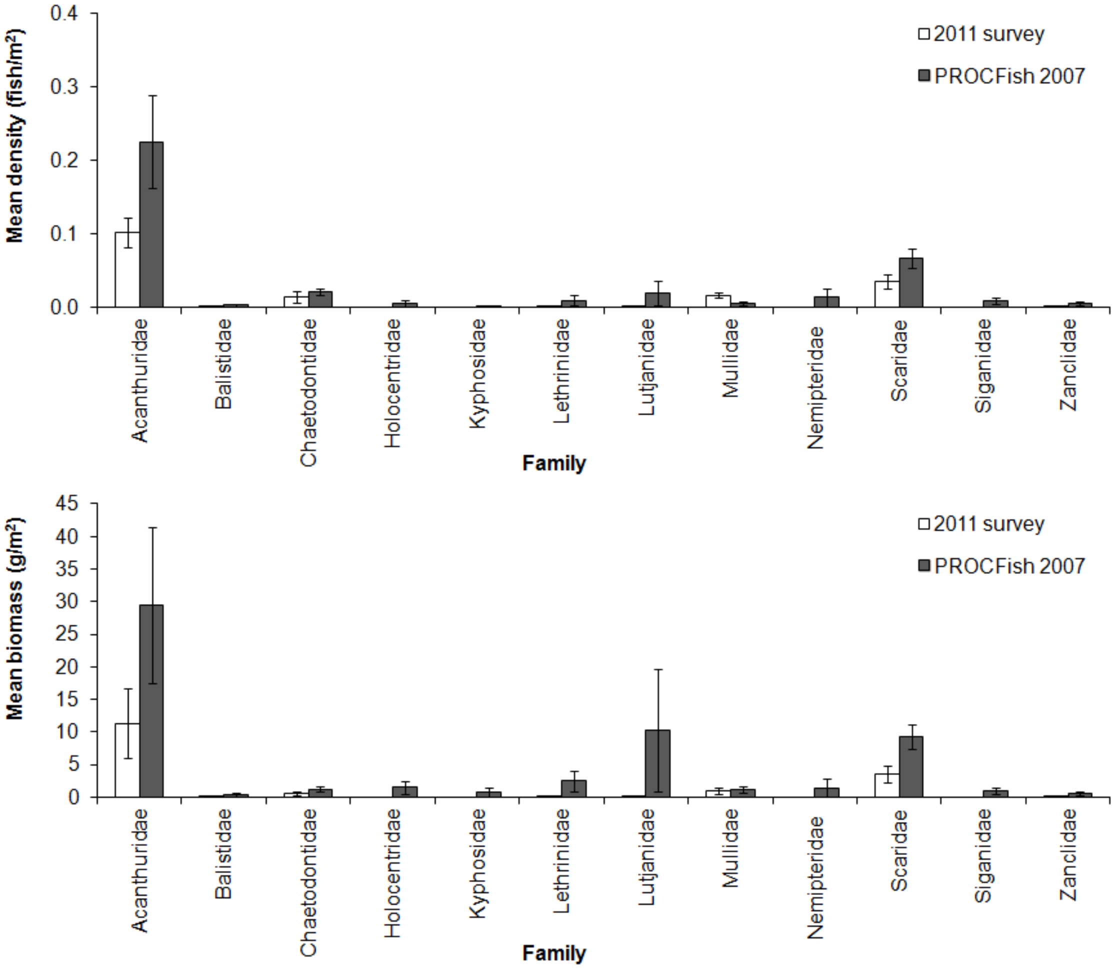

Figure 24 Comparison of mean density (top) and biomass (bottom) of families recorded from lagoon-reef habitats of Laura in the current study and during PROCFish surveys in 2007 (± SE).

Table 16 Mean scores (± SE) of major substrate categories in lagoon-reef habitats of the current survey and the PROCFish 2007 surveys.

Habitat category	2011 survey	PROCFish 2007
Depth (m)	3.1±0.4	9.5±2.6
Depth range (m)	2.0–4.0	1.0–16.6
Topography	1.8±0.4	1.5±0.3
Complexity	2.4±0.2	2.0±0.4
Hard substrate	66.1±5.4	83.2±4.4
Soft substrate	33.9±5.4	16.8±4.4
Abiotic	44.8±6.8	19.3±4.6
Hard corals	55.2±6.8	80.7±4.6
Slab	1.7±1.0	10.8±1.2
Silt	5.0±1.6	0.0±0.0
Mud	0.0±0.0	0.0±0.0
Sand	21.0±6.3	5.6±3.4
Rubbles	10.1±1.1	2.9±0.9
Small boulders	5.3±1.9	0.0±0.0
Large boulders	0.9±0.5	0.0±0.0
Rocks	0.9±0.7	0.0±0.0
Live corals	37.3±7.8	26.6±9.5
Dead corals	15.4±2.5	54.0±9.6
Bleaching corals	2.6±2.6	0.1±0.1

Outer-reef habitats

Habitats supporting finfish

Of the three habitat types, outer-reef habitats had the greatest mean percent cover of hard substrate (comprised of slab and hard corals), and consequently the lowest percent of soft substrate. Live hard coral cover was relatively high at both sites, representing 41.8±7.9% and 53.1.0±5.8% of overall cover at Laura and Majuro, respectively (Figure 25). Of the corals present, sub-massive growth forms were the dominant corals on the outer-reefs of Laura, representing 27.0±3.4% of the coral cover at this site, while encrusting growth forms were the most prevalent type at on the outer-reefs of Majuro, representing 17.6±2.8% of the overall coral cover at this site. Of the habitat categories and substrate types, only complexity (P = 0.009) and the cover of rubbles (P = 0.018) differed significantly among outer-reef habitats at Laura and Majuro, with outer-reefs at Laura being on average slightly more complex and having a slightly higher cover of rubbles than those at Majuro (Figure 21).

Finfish surveys

Outer-reef habitats supported the greatest diversity of finfish, with 19 families, 51 genera, 117 species and 10,356 individual fishes recorded from outer-reef habitats of the Laura monitoring stations, while 12 families, 39 genera, 79 species and 1,697 individual fish were recorded from outer-reef habitats of the Majuro monitoring stations (Table 10). Overall, mean density of outer-reef habitats was considerably higher at Laura than Majuro (Figure 15). At Laura, mean density was dominated by members of the Serranidae (1.357±0.642 fish/m^2, 51.5% of overall mean density), followed by the families Pomacentridae (0.743±0.171 fish/m^2, 28.2% of overall density) and Acanthuridae (0.198±0.032 fish/m^2, 7.5% of overall density). At Majuro, members of the Labridae occurred in the highest densities (0.147±0.041 fish/m^2, 36.7% of overall density), followed by the families Pomacentridae (0.107±0.032 fish/m^2, 26.8% of overall density) and Acanthuridae (0.094±0.022 fish/m^2, 23.4% of overall density) (Figure 26). Mean densities of Chaetodontidae, Holocentridae, Pomacanthidae, Pomacentridae and Serranidae were all significantly higher in outer-reef habitats at Laura than Majuro ($P \leq 0.021$) (Figure 26). The individual species observed in the highest mean densities within the outer-reef habitats of Laura were the serranids *Pseudanthais pascalus* and *Pseudanthais bartlettorum*, the pomacentrids *Chromis margaritifer* and *Chromis acares*, and the acanthurid *Ctenochaetus striatus* (Table 17). Individual species observed in the highest densities within the outer-reef habitats of Majuro was the labrid *Halichoeres marginatus*, the acanthurid *Ctenochaetus striatus*, the pomacentrids *Pomacentrus coelestis* and *Chromis acares*, and the scarid *Chlorurus sordidus* (Table 17).

Considerable variability in mean biomass was observed for most families at outer-reef habitats for both Laura and Majuro monitoring stations, evidenced by the large standard error values in Figure 26. For outer-reef habitats of Laura, members of the Acanthuridae and Holocentridae had the greatest biomass (16.740±4.385 g/m^2 and 16.433±8.435 g/m^2, comprising 29.9% and 29.4% of the total observed biomass, respectively), followed by members of the families Lethrinidae (5.806±5.700 g/m^2, 10.4% of observed biomass) and Balistidae (3.042±1.327 g/m^2, 5.4% of observed biomass). At Majuro, members of the Scaridae had the greatest biomass (5.274±3.735 g/m^2, 35.2% of observed biomass) followed by Acanthuridae (4.332±1.802 g/m^2, 28.9% of observed biomass), Lutjanidae (2.303±2.303 g/m^2, 15.4% of observed biomass) and Labridae (1.637±1.240 g/m^2, 10.9% of observed biomass). In accordance with the higher overall biomass at outer-reef habitats of Laura (Figure 16), the observed mean biomass of Acanthuridae, Chaetodontidae, Holocentridae and Pomacanthidae was significantly higher at Laura than Majuro ($P <$ 0.05) (Figure 26). The individual species that had the greatest mean biomass within the outer-reef habitats of Laura were the acanthurids *Naso lituratus*, *Ctenochaetus striatus* and *Acanthurus nigricans*, the lethrinid *Monotaxis grandoculis*, and the holocentrid *Myripristis pralinia* (Table 18). Individual species that had the greatest mean biomass within the outer-reef habitats of Majuro were the scarids *Bolbometopon muricatum* and *Chlorurus sordidus*, the lutjanid *Lutjanus gibbus*, and the acanthurids *Ctenochaetus striatus* and *Naso lituratus* (Table 18). A full list of biomass by family and individual species can be found in Appendices 5–8.

No significant differences were apparent in mean size or mean size ratio of any of the 18 indicator families among outer-reef habitats of the Laura and Majuro sites (Figure 26).

In terms of trophic group, planktivores occurred in the greatest mean density within the outer-reef habitats of Laura, with 1.906±0.732 $fish/m^2$, resulting from the high densities of *Pseudanthias pascalus* and *P. bartlettorum* (Table 17). For the outer-reefs of Majuro, herbivores (0.0186±0.047 $fish/m^2$) and carnivores (0.161±0.039 $fish/m^2$) occurred in the highest densities. Consistent with the greater overall mean density, the mean density of planktivores was significantly higher for outer-reefs at Majuro than those at Laura ($P <$ 0.001) (Figure 27). In terms of mean biomass, herbivores (20.408±4.148 g/m^2) carnivores (18.918±8.291 g/m^2) and planktivores (12.725±5.501 g/m^2) had the greatest biomass at Laura, while herbivores (9.727±5.405 g/m^2 and carnivores (4.451±2.659 g/m^2) had the greatest biomass at Majuro. The mean biomass of planktivores was significantly greater at outer-reef habitats of Laura than those at Majuro ($P = 0.002$) (Figure 27). No significant differences were observed in mean size or mean size ratio of any trophic group among the outer-reef habitats of Laura and Majuro ($P > 0.05$). At Laura, the mean size of carnivores was significantly higher for the outer-reefs than the back-reefs ($P = 0.044$). As with both the lagoon- and back-reef habitats, the size ratio of all trophic groups on outer-reefs was low relative to average maximum sizes for both the Laura and Majuro monitoring stations (Figure 27).

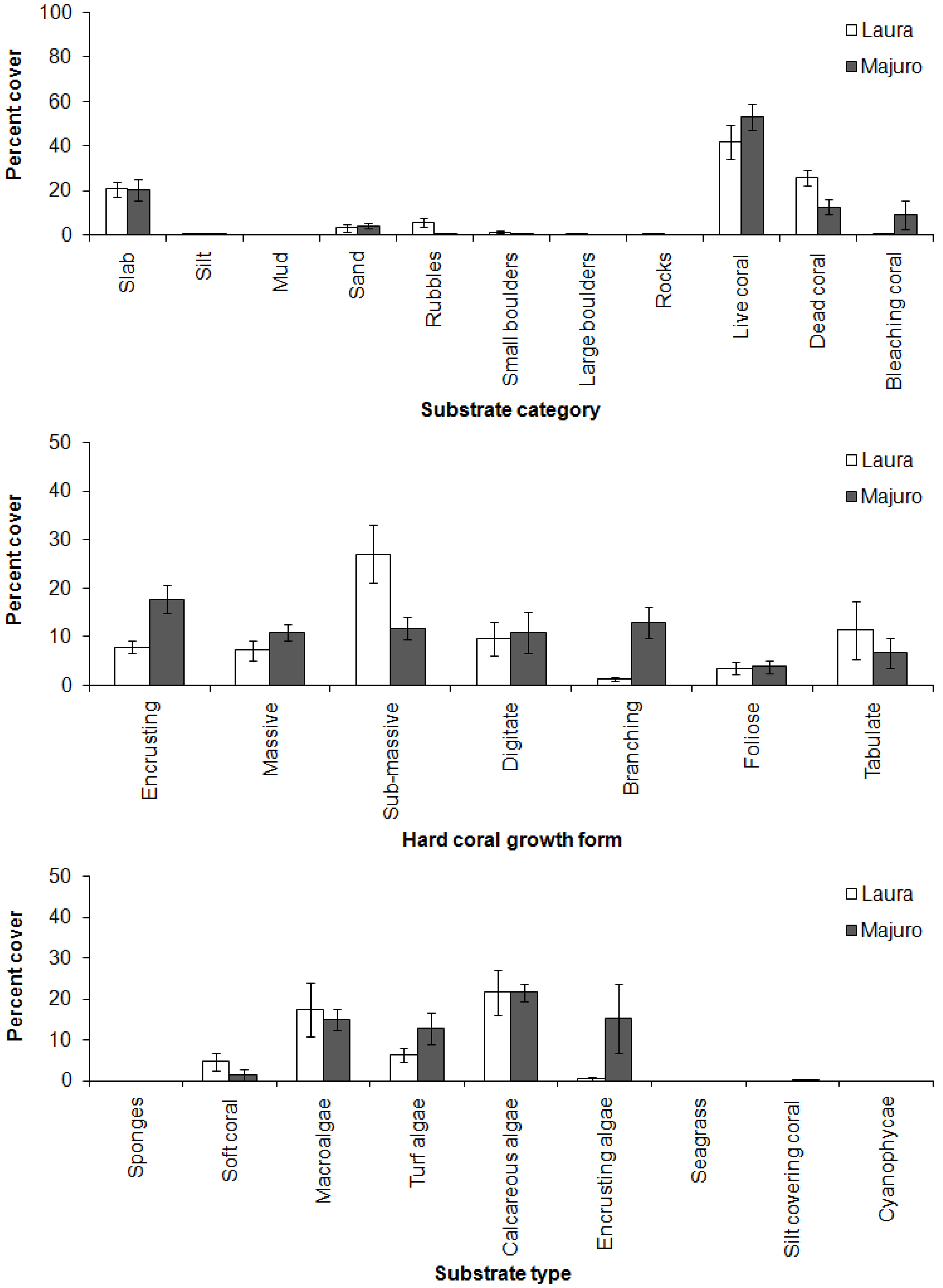

Figure 25 Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate type (bottom) present at outer-reef habitats during finfish surveys at Laura and Majuro, 2011.

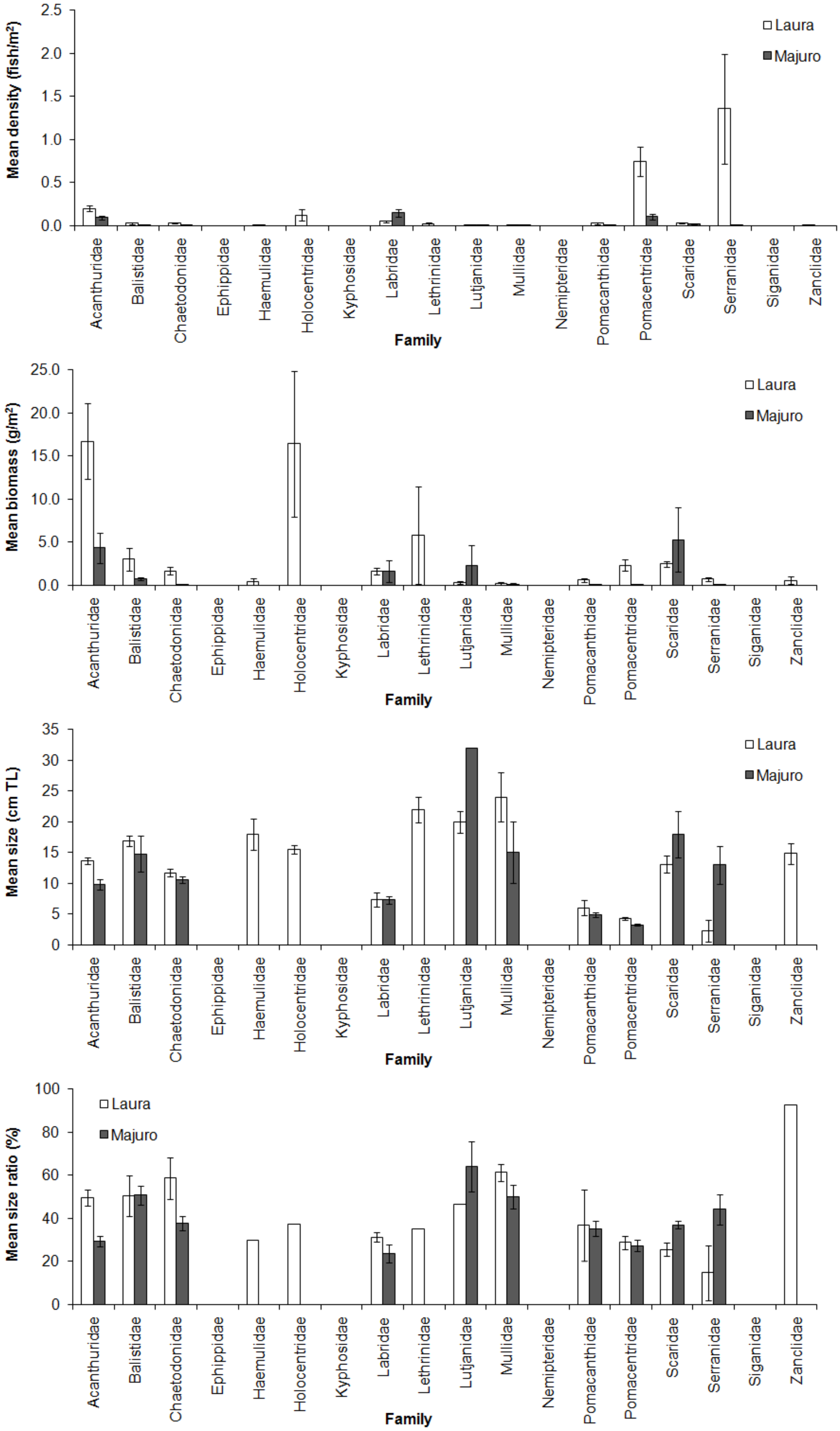

Figure 26 Profile of finfish indicator families in outer-reef habitats of Laura and Majuro monitoring stations, 2011.

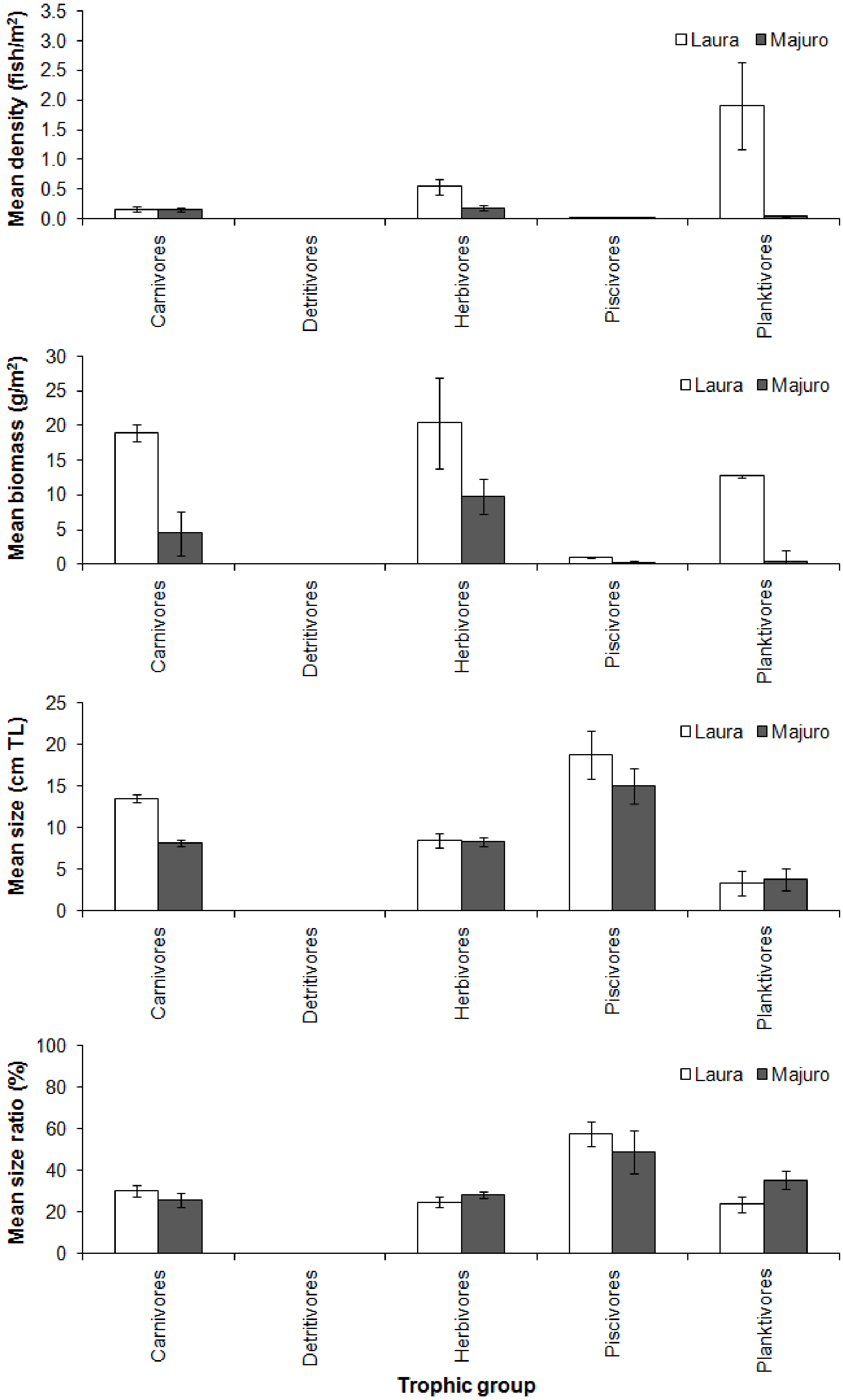

Figure 27 **Profile of finfish by trophic level in outer-reef habitats of Laura and Majuro monitoring stations, 2011.**

Table 17 Finfish species observed in highest densities in outer-reef habitats of Laura and Majuro, 2011. See Appendix 7 and 8 for a full list of densities of individual fish species observed at Laura and Majuro monitoring sites.

Site	Species	Family	Density (fish/m^2±SE)
Laura	*Pseudanthias pascalus*	Serranidae	1.193±0.599
	Chromis margaritifer	Pomacentridae	0.248±0.087
	Pseudanthias bartlettorum	Serranidae	0.113±0.067
	Chromis acares	Pomacentridae	0.086±0.043
	Ctenochaetus striatus	Acanthuridae	0.061±0.018
Majuro	*Halichoeres marginatus*	Labridae	0.060±0.023
	Ctenochaetus striatus	Acanthuridae	0.057±0.017
	Pomacentrus coelestis	Pomacentridae	0.021±0.019
	Chromis acares	Pomacentridae	0.019±0.009
	Chlorurus sordidus	Scaridae	0.016±0.008

Table 18 Finfish species with the highest biomass in outer-reef habitats of Laura and Majuro, 2011. See Appendix 7 and 8 for a full list of biomass of individual fish species observed at Laura and Majuro monitoring sites.

Site	Species	Family	Biomass (g/m^2±SE)
Laura	*Naso lituratus*	Acanthuridae	6.408±3.493
	Monotaxis grandoculis	Lethrinidae	5.717±5.717
	Ctenochaetus striatus	Acanthuridae	5.269±1.784
	Myripristis pralinia	Holocentridae	3.383±3.383
	Acanthurus nigricans	Acanthuridae	3.207±0.957
Majuro	*Bolbometopon muricatum*	Scaridae	3.659±3.659
	Lutjanus gibbus	Lutjanidae	2.303±2.303
	Ctenochaetus striatus	Acanthuridae	1.899±0.987
	Chlorurus sordidus	Scaridae	1.360±0.666
	Naso lituratus	Acanthuridae	0.608±0.589

Comparisons with PROCFish (2007) surveys

In contrast to the differences observed for both back- and lagoon-reef habitats, the density and biomass of most finfish families recorded on outer-reef habitats of Laura during the current (2011) study were largely similar to those observed during the PROCFish surveys of 2007 (Figure 28). Observed mean density and mean biomass of Mullidae was significantly higher during the PROCFish (2007) surveys than the current survey ($P < 0.05$). As with both the back- and lagoon-reef habitats, it should be noted that these surveys were not conducted at exactly the same locations, thus these results may be at least partially influenced by spatial differences in habitat cover or depth among survey locations. Further monitoring is required to determine whether these differences are consistent over time.

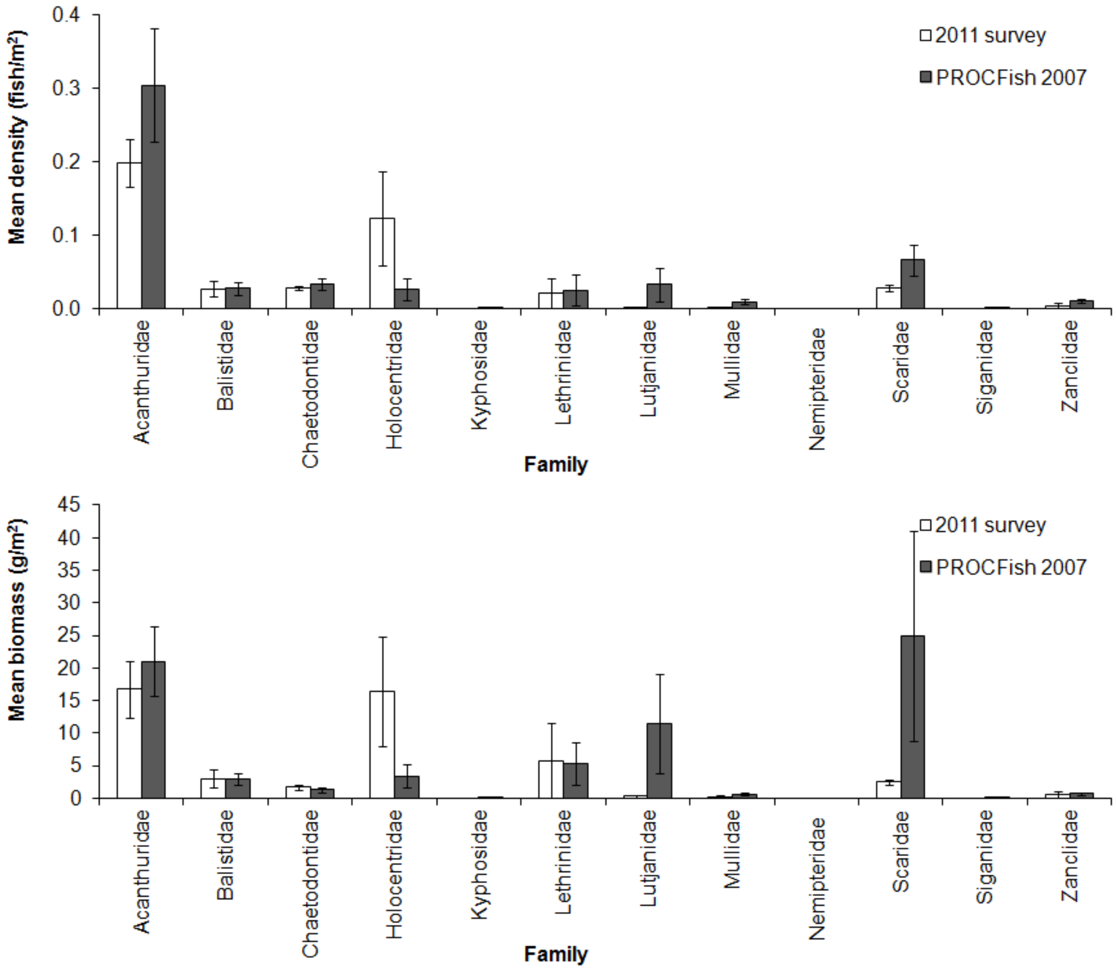

Figure 28 **Comparison of mean density (top) and biomass (bottom) of families recorded from outer-reef habitats of Laura in the current study and during PROCFish surveys in 2007 (± SE).**

Table 19 Mean scores (± SE) of major substrate categories in outer-reef habitats of the current survey and the PROCFish 2007 surveys.

Habitat category	2011 survey	PROCFish 2007
Depth (m)	6.9±1.5	7.8±0.9
Depth range (m)	4.25–11	3.6–10.2
Topography	3.0±0.3	2.0±0.3
Complexity	3.5±0.2	2.8±0.3
Hard substrate	88.8±3.2	96.5±0.8
Soft substrate	11.3±3.2	3.5±0.8
Abiotic	32.3±6.4	16.5±4.5
Hard corals	67.8±6.4	83.5±4.5
Slab	20.7±3.5	14.8±4.0
Silt	0.3±0.3	0.0±0.0
Mud	0.0±0.0	0.0±0.0
Sand	3.2±1.7	1.0±0.5
Rubbles	5.8±2.0	0.7±0.3
Small boulders	1.3±0.5	0.0±0.0
Large boulders	0.6±0.4	0.0±0.0
Rocks	0.5±0.4	0.0±0.0
Live corals	41.8±7.9	46.9±11.5
Dead corals	25.7±3.5	36.7±9.7
Bleaching corals	0.2±0.2	0.0±0.0

6. Invertebrate Surveys

Methods and Materials

Data collection

Invertebrates

Two survey methods were used to assess the abundance, size and condition of invertebrate resources and their habitat across reef zones. Manta tows were used to provide a broad-scale assessment of invertebrate resources associated with reef areas. In this assessment, a snorkeller was towed behind a boat with a manta board for recording the abundance of large sedentary invertebrates (e.g. sea cucumbers) at an average speed of approximately 4km/hour (Figure 29). Hand tally counters were also mounted on the manta board to assist with enumerating the common species on site. The snorkeler's observation belt was two metres wide and tows were conducted in depths typically ranging from one to ten metres. Each tow replicate was 300 m in length and was calibrated using the odometer function within the trip computer option of a Garmin 76Map GPS. Six 300 m manta tow replicates were conducted within each station, with the start and end GPS positions of each tow recorded to an accuracy of within ten meters.

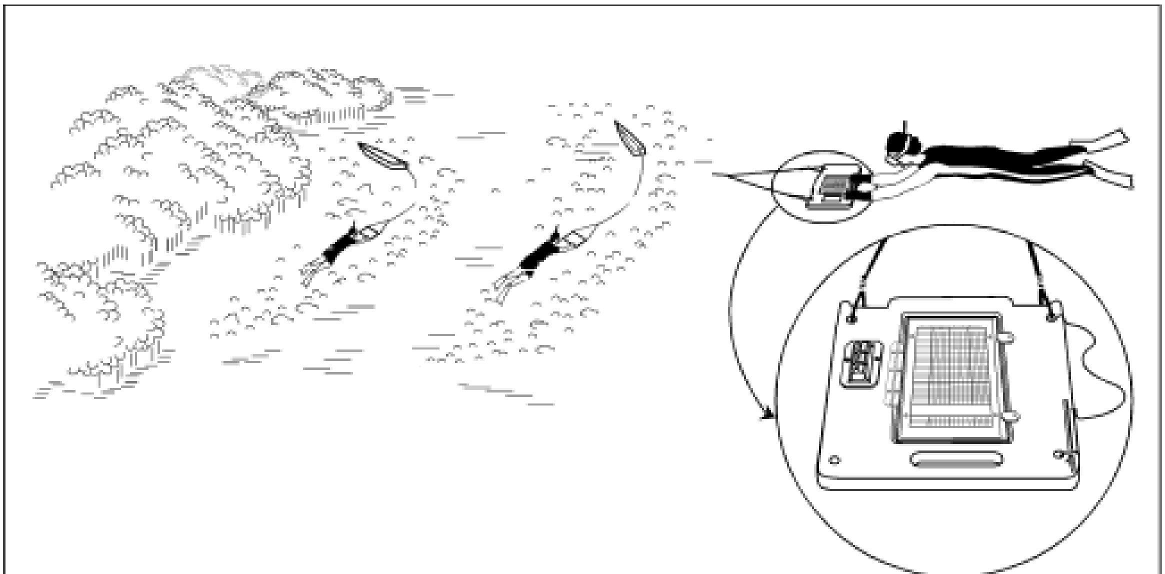

Figure 29 Broad-scale method: manta tow survey

To assess the abundance, size and condition of invertebrate resources and their habitat at finer-spatial scales, reef-benthos transects (RBT) were conducted. Reef-benthos transects were conducted by two snorkellers equipped with measuring instruments attached to their record boards (slates) for recording the abundance and size of invertebrate species. For some species, such as sea urchins (e.g. *Echinometra sp.*), only abundance was recorded due to difficulty in measuring the size of these organisms. Each transect was 40 meters long with a one meter wide observation belt, conducted in depths ranging from one to three meters. The two snorkellers conducted three transects each, totalling six 40 m transects for each RBT station (Figure 30). The GPS position of each station was recorded in the centre of the station.

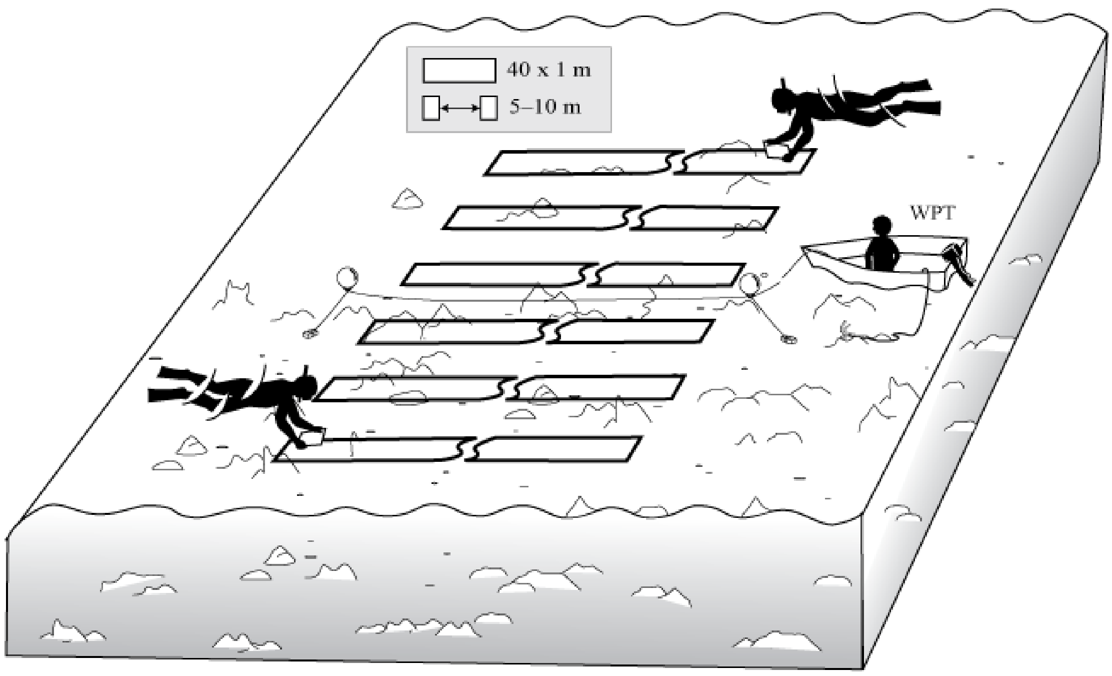

Figure 30 Fine-scale method: reef-benthos transects

Habitats supporting invertebrates

Both manta tows and reef 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 meters);
4. Substrate categories (totalling to 100%):
   - Soft sediments including (1) *mud*, (2) *mud and sand*, (3) *sand* and (4) *coarse sand*;
   - (5) *rubble* - small fragments of coral between 0.5 and 15 cm;
   - (6) *boulders* - detached big pieces of coral stone more than 30 cm;
   - (7) c*onsolidated rubble* - cemented pieces of coral and limestone debris,
   - (8) *pavement* - solid fixed flat limestone;

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

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

Data analysis

In this report, the status of invertebrate resources 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 environment 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, mean density and biomass data from the Laura stations were compared against those collected during the PROCFish surveys in this region in 2007 (Pinca et al. 2009) for both manta tow and RBT methodologies using one-way ANOVA.

Results

Manta tow

Survey coverage

A total of 15 manta tow stations were established, with eight manta tows conducted in Laura and six in Majuro (Figure 31; Table 20). All manta tows were conducted in back-reef habitats. GPS positions of all manta tow replicates are tabulated in Appendix 10.

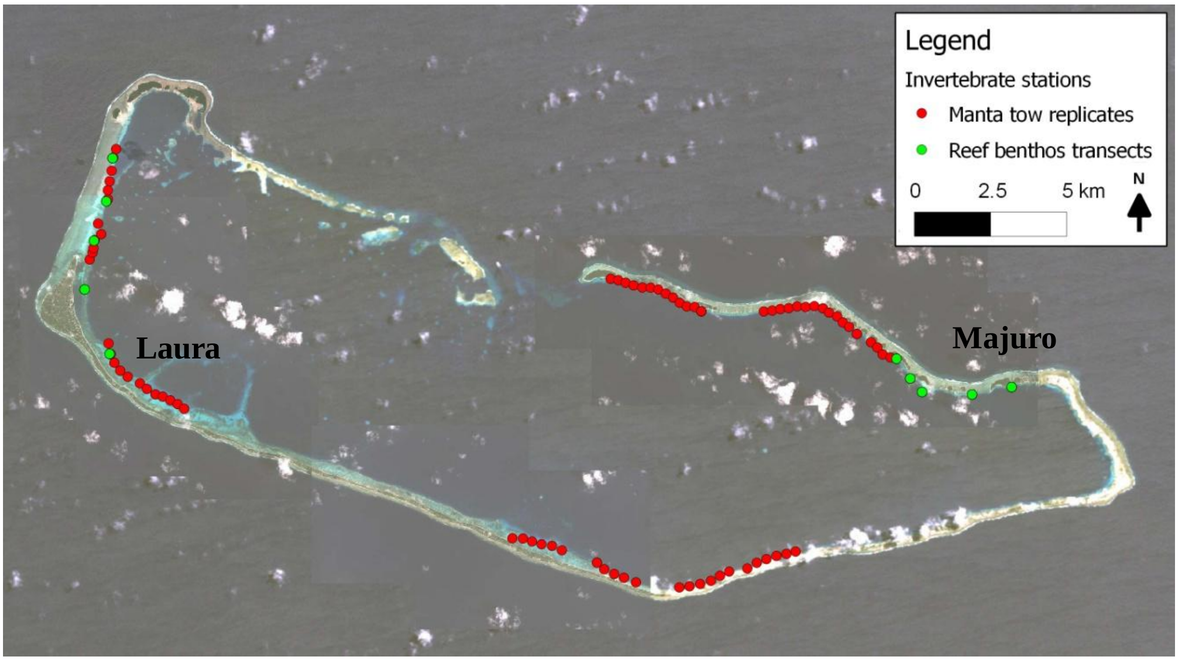

Figure 31 **Locations of invertebrate assessment stations established in Majuro Atoll, 2011. Note six replicate 40 m transects were conducted at each reef benthos station.**

Table 20 **Summary of manta tow stations established at the Laura and Majuro monitoring sites.**

Site	Number of stations	Number of replicates	Area surveyed (m^2)
Laura	8	48	28,800
Majuro	6	36	21,600

Habitats supporting invertebrates

Habitats where the manta tow surveys were conducted varied considerably among the survey sites. The substrate of Majuro stations was dominated by sand, while Laura stations had a much more heterogeneous habitat, dominated by live and dead coral, sand and rubble (Figure 32). Habitats where manta tows were conducted at Majuro had greater complexity ($P < 0.001$) and relief ($P < 0.001$), and a higher percent cover of sand ($P < 0.001$) than those at Laura, while habitats where manta tows were conducted at Laura had a greater percent cover of live coral ($P < 0.001$), dead coral ($P < 0.001$), coralline algae ($P < 0.001$) and 'other' macroalgae ($P < 0.001$) than those at Majuro. A full list of percent cover of each habitat variable recorded during the manta tow surveys is presented as Appendix 12.

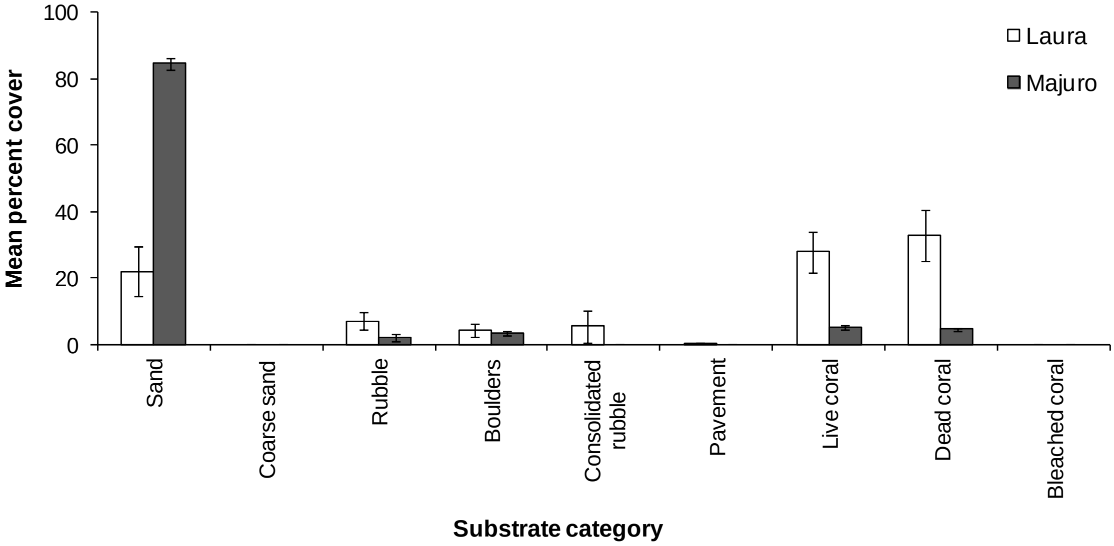

Figure 32 Mean percent cover (± SE) of each major substrate category of manta tow survey stations at Laura and Majuro, 2011.

Invertebrate surveys

A total of 18 species, belonging to 13 families, were recorded during the manta tow surveys at Laura and Majuro. A greater diversity was observed at Laura, where 16 were species recorded compared to three at Majuro (Table 21). Individual species observed in the highest mean densities during the manta tow surveys at Laura included the sea cucumbers *Holothuria atra* (235.42±105.22 individuals/ha) and *H. edulis* (7.64±7.64 individuals/ha) and the gastropod *Tectus niloticus*[2] (3.82±0.90 individuals/ha), while at Majuro *Thelenota anax* (122.22±32.79 individuals/ha) was observed in the highest density. The mean density of *Holothuria atra* and *Tectus niloticus* was significantly higher at Laura than Majuro ($P < 0.001$ and $P = 0.009$, respectively), while the mean density of *Thelenota anax* was significantly higher at Majuro than Laura ($P < 0.001$) (Figure 33). Numbers of trochus (*T. niloticus*) observed in manta tow surveys at both the Laura and Majuro sites were well below the benchmark of 500 individual/ha that indicates a healthy stock (Figure 33; Appendix 13) (Tardy et al. 2009). A single individual of the coral-eating crown-of-thorns starfish, *Acanthaster planci*, was observed at Laura. A full list of densities of individual species observed during the manta tow surveys at each site is presented as Appendix 13.

[2] This species was formerly known as *Trochus niloticus*

Table 21 Total number of genera and species, and diversity of invertebrates observed during manta tow and reef-benthos transects at Laura and Majuro monitoring stations, 2011.

Parameter	Manta tow		Reef-benthos transects	
	Laura	Majuro	Laura	Majuro
No. of genera	14	2	10	9
No. of species	16	3	11	10
Diversity	2.0	0.5	2.2	2.0

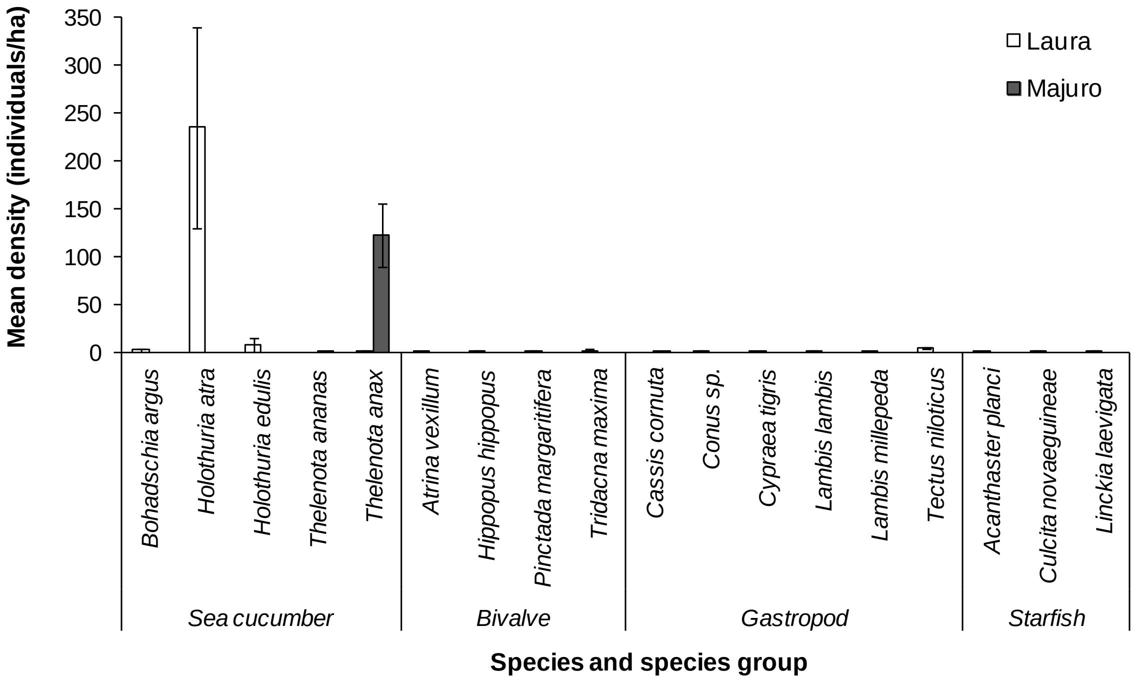

Figure 33 Overall mean density of invertebrate species (± SE) observed within back-reef habitats during manta tow assessments at Laura and Majuro, 2011.

Comparison with PROCFish (2007) surveys

A greater number of individual invertebrate species were observed during the manta tow surveys of the PROCFish (2007) assessment relative to the current study (Table 22), which likely results from greater survey effort in the former study (12 manta tow stations were completed during PROCFish, compared to nine for the current survey). In terms of mean density, greater densities of giants clams (*Hippopus hippopus*, *Tridacna maxima* and *T. squamosa*) were observed during the PROCFish (2007) survey relative to the current study (Table 22). Few differences were observed in mean densities of sea cucumbers, with the mean density of only *Holothuria nobilis* and *Thelenota ananas* appearing higher during the PROCFish surveys (Table 22). As with the finfish surveys, 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 among survey locations.

Table 22 Mean density of invertebrate species recorded during manta tow surveys at Laura during the current (2011) survey and PROCFish (2007) surveys.

Group	Species	Mean density (individual/ha±SE)	
		2011 survey	PROCFish 2007
Sea cucumber	*Actinopyga mauritiana*	-	0.46±0.46
	Bohadschia argus	2.08±1.36	3.23±1.17
	Holothuria atra	235.42±105.22	173.92±75.27
	Holothuria edulis	7.64±7.64	-
	Holothuria nobilis	-	0.93±0.71
	Thelenota ananas	-	3.22±1.17
	Thelenota anax	0.69±0.69	1.39±1.39
Bivalve	*Atrina vexillum*	0.35±0.35	-
	Beguina semiorbiculata	-	0.23±0.23
	Hippopus hippopus	1.04±0.73	4.15±0.99
	Pinctada margaritifera	0.69±0.45	2.76±1.82
	Tridacna maxima	1.74±1.17	29.95±12.72
	Tridacna squamosa	-	2.31±0.89
Crustacean	*Panulirus versicolor*	-	0.23±0.23
Gastropod	*Conomurex luhuanus*[3]	-	5.79±5.54
	Conus bandanus	-	0.46±0.46
	Conus distans	-	1.16±0.72
	Conus leopardus	-	0.23±0.23
	Conus miles	-	0.23±0.23
	Conus sp.	0.69±0.69	-
	Cypraea tigris	0.35±0.35	0.69±0.50
	Harpago chiragra[4]	-	0.93±0.52
	Lambis lambis	0.69±0.45	2.08±0.97
	Lambis millepeda	0.35±0.35	-
	Lambis scorpius	-	0.46±0.31
	Lambis truncata	-	0.46±0.31
	Tectus niloticus[5]	3.82±0.90	2.08±1.19
	Tectus pyramis	-	0.23±0.23
	Vasum turbinellus	-	0.46±0.46
Starfish	*Acanthaster planci*	0.35±0.35	0.23±0.23
	Culcita novaeguineae	1.04±0.73	5.07±1.98
	Linckia laevigata	0.69±0.69	2.77±1.37
Urchin	*Echinothrix diadema*	-	1.39±1.39
	Tripneustes sp.	-	0.23±0.23

[3] This species was formerly known as *Strombus luhuanus*
[4] This species was formerly known as *Lambis chiragra*
[5] This species was formerly known as *Trochus niloticus*

Reef-benthos transects

Coverage

A total of 10 RBT stations were established within Majuro Atoll: five in each of the Laura and Majuro sites (Figure 31; Table 23). GPS positions of all RBT stations are tabulated in Appendix 11.

Table 23 Summary of reef-benthos transect stations established within the Laura and Majuro monitoring sites.

Site	Number of stations	Number of replicates	Area surveyed (m^2)
Laura	5	30	1,200
Majuro	5	30	1,200

Habitats supporting invertebrates

The habitat at RBT stations of both Laura and Majuro was dominated by live and dead coral, sand and rubble (Figure 34). RBT stations at Majuro supported a significantly higher percent cover of live coral ($P < 0.001$), and lower percent cover of dead coral ($P < 0.001$) than those at Laura (Figure 34). The higher percent of coral cover of the RBT surveys relative to the manta tow surveys reflects the targeted, fine-scale nature of the RBT methodology. A full list of percent cover of each habitat variable recorded during the RBT surveys as presented as Appendix 12.

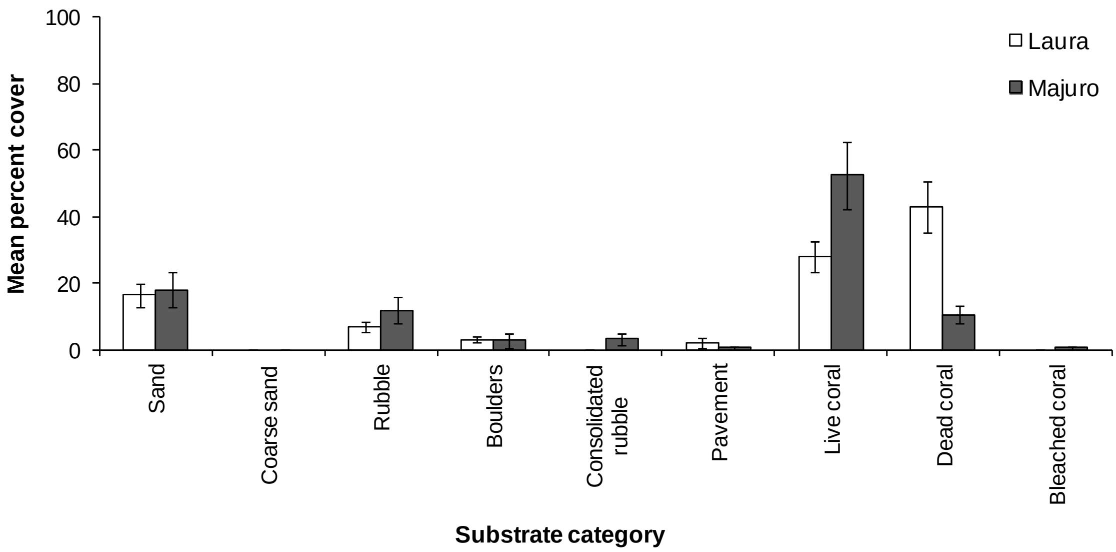

Figure 34 Mean percent cover (± SE) of each major substrate category at reef-benthos transect stations at Laura and Majuro, 2011.

Invertebrate surveys

A total of 17 species, were recorded during the reef-benthos surveys, with 11 species recorded from Laura and 10 species recorded from Majuro. Individual species observed in the highest mean densities during the RBT surveys at Laura included the sea cucumber

Holothuria atra (608.33±424.84 individuals/ha) and the gastropod *Conomurex luhuanus*[6] (225.00±184.75 individuals/ha), while at Majuro *C. luhuanus* (2800.00±1830.46 individuals/ha) and the sea cucumber *Bohadschia argus* (58.33±58.33 individuals/ha) were observed in the highest density. The mean density of *H. atra* was significantly higher at Laura than Majuro ($P < 0.001$), while the mean density of *C. luhuanus* was significantly higher at Majuro than Laura ($P = 0.004$) (Figure 35). Numbers of trochus (*T. niloticus*) observed in the RBT surveys at both the Laura and Majuro sites were well below the benchmark of 500 individual/ha that indicates a healthy stock (Figure 35; Appendix 14) (Tardy et al. 2009). No crown-of-thorns starfish were observed during the RBT surveys at either site. A full list of densities of individual species observed during the RBT surveys at each site is presented as Appendix 14. No differences in mean size were evident for species common to both Laura and Majuro monitoring sites (Table 24).

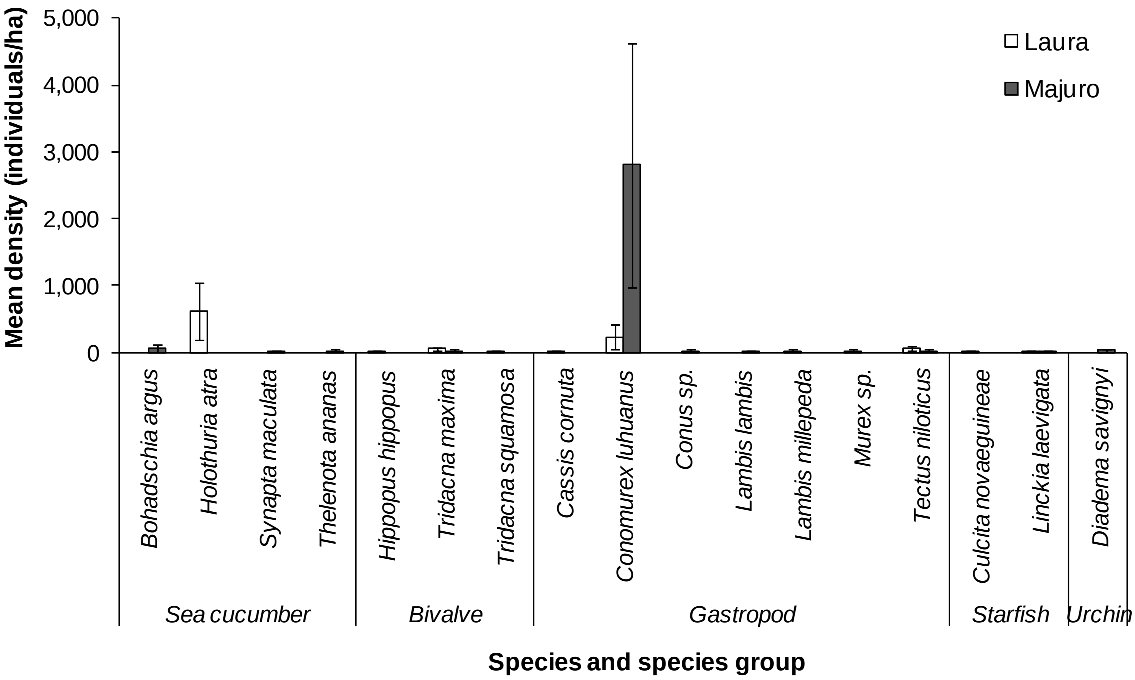

Figure 35 Overall mean density of invertebrate families (± SE) observed during reef-benthos transects at Laura and Majuro, 2011.

[6] This species was formerly known as *Strombus luhuanus*

Table 24 Mean size (± SE) of measured invertebrates during reef-benthos transects at Laura and Majuro, 2011. Only those species with ≥ 5 individuals measured at a site are presented.

Group	Species	Mean size (mm)	
		Laura	Majuro
Sea cucumber	*Holothuria atra*	203.8±8.2	-
Bivalve	*Tridacna maxima*	89.8±13.5	-
Gastropod	*Conomurex luhuanus*	34.2±1.0	37.8±2.6
	Tectus niloticus	94.9±7.2	-

Comparisons with PROCFish (2007) surveys

As with the manta tow surveys, a greater number of individual invertebrate species were observed during the PROCFish (2007) survey relative to the current study (Table 22), which likely results from greater survey effort in the former study (22 RBT stations were completed during PROCFish compared to five for the current survey). In contrast to the manta tow surveys, there appeared to be no difference in mean density of giant clam species (*Hippopus hippopus*, *Tridacna maxima* and *T. squamosa*) between the PROCFish surveys and the current study (Table 25). Again, 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 among survey locations. Further monitoring is required to determine whether these differences are consistent over time.

Table 25 Comparison of mean density of invertebrate species recorded during reef-benthos transects at Laura during the current (2011) survey and PROCFish surveys in 2007.

Group	Species	Mean density (individual/ha±SE)	
		2011 survey	PROCFISH 2007
Sea cucumber	*Bohadschia argus*	-	3.79±2.61
	Holothuria atra	608.33±424.84	4500.00±3626.22
	Holothuria edulis	-	18.94±18.94
	Holothuria nobilis	-	1.89±1.89
	Synapta sp.	-	5.68±5.68
Bivalve	*Hippopus hippopus*	16.67±10.21	9.47±4.69
	Pinctada margaritifera	-	1.89±1.89
	Spondylus sp.	-	1.89±1.89
	Tridacna maxima	50.00±30.62	113.64±43.54
	Tridacna squamosa	16.67±10.21	3.79±2.61
Crustacean	*Gonodactylus* sp.	-	1.89±1.89
	Panulirus penicillatus	-	1.89±1.89
	Saron sp.	-	7.58±3.51
	Stenopus hispidus	-	1.89±1.89
	Thalassina sp.	-	43.56±14.88
Gastropod	*Astralium* sp.	-	1.89±1.89
	Bursa granularis	-	3.79±2.61
	Cassis cornuta	8.33±8.33	-
	Cerithium nodulosum	-	3.79±2.61
	Chicoreus brunneus	-	3.79±3.79
	Coralliophila sp.	-	1.89±1.89
	Conomurex luhuanus	225.00±184.75	126.89±63.62
	Conus distans	-	9.47±6.09
	Conus flavidus	-	1.89±1.89
	Conus lividus	-	5.68±4.15
	Conus miles	-	3.79±3.79
	Conus miliaris	-	3.79±2.61
	Conus pulicarius	-	1.89±1.89
	Cypraea tigris	-	3.79±2.61
	Harpa amouretta	-	1.89±1.89
	Harpago chiragra	-	13.26±8.40
	Lambis lambis	-	26.52±10.81
	Lambis millepeda	25.00±16.67	-
	Lambis scorpius	-	1.89±1.89

Group	Species	Mean density (individual/ha±SE)	
		2011 survey	**PROCFISH 2007**
	Mauritia scurra[7]	-	1.89±1.89
	Mauritia arabica[8]	-	3.79±3.79
	Monetaria caputserpensis[9]	-	1.89±1.89
	Monetaria moneta[10]	-	24.62±11.84
	Murex sp.	25.00±16.67	-
	Rhinoclavis aspera	-	3.79±2.61
	Tectus niloticus	58.33±40.82	49.24±21.52
	Thais aculeata	-	3.79±3.79
	Trochus maculatus	-	17.05±8.07
	Turbo argyrostomus	-	13.26±6.93
	Vasum sp.	-	1.89±1.89
	Vasum turbinellus	-	3.79±2.61
Starfish	*Acanthaster planci*	-	13.26±7.94
	Archaster sp.	-	3.79±2.61
	Culcita novaeguineae	16.67±10.21	1.89±1.89
	Linckia laevigata	16.67±10.21	9.47±5.44
Urchin	*Echinothrix diadema*	-	9.47±7.72
	Echinometra mathaei	-	3.79±3.79
	Mespilia globulus	-	1.89±1.89

[7] This species was formerly known as *Cypraea scurra*
[8] This species was formerly known as *Cypraea arabica*
[9] This species was formerly known as *Cypraea caputserpensis*
[10] This species was formerly known as *Cypraea moneta*

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 of both finfish and invertebrate surveys. A total of ten officers were trained: five from MIMRA, two from CMI, two from MCIS, and one from RMIEPA (Table 26). The training initially consisted of classroom sessions where assessment methods and survey forms were explained in detail and slideshows of species photos were presented for identification. This was followed by field activities where the trainees practiced a method, as well as species identification. Only when the results of the trainees were consistent with senior project staff were the trainees able to participate in the baseline assessment.

Table 26 List of trainees who participated in the baseline assessment

Name	Title	Organisation
Candice Guavis	Fisheries Officer	MIMRA
Armor Ishoda	Fisheries Officer	MIMRA
Kalena deBrum	Intern	MIMRA
Broderick Menke	Intern	MIMRA
Elji Lenak	Boat Captain	MIMRA
Tabwi Aini	Boat Captain	CMI
Julius Lucky	Intern	CMI
Henry Muller	Conservation Officer	MICS
Alexander Peter	Conservation Officer	MICS
Tamra Heine	Environment Officer	RMIEPA

8. Recommendations for Future Monitoring

The following recommendations are proposed for future monitoring events:

Benthic Habitat and Finfish Assessments

- During the baseline surveys, separate monitoring stations were established for some of the benthic habitat and finfish assessments. For future monitoring events it is recommended that the same stations be used for both the benthic habitat and finfish monitoring. This approach will greatly increase survey efficiency (thus reducing costs), and provide a secondary indicator of habitat health from which to explore relationships between environmental variables and the status of finfish resources.

- Due to strong currents and poor weather two back-reef and one lagoon-reef benthic habitat and finfish transect at the Laura site could not be completed. To balance the survey design, these transects should be established during the re-survey event.

- Depth has been routinely demonstrated to be a significant factor influencing the distribution and abundance of fish and corals (Pittman and Brown 2011; Green 1996; Veron 1986). In the current study, depth varied markedly among transects within a habitat (e.g. 2–15 m for lagoon-reef habitats at Majuro). To avoid pseudoreplication issues associated with replicates being a different depths, it is recommended that depth be standardised among transects within a habitat during future monitoring events (e.g. 10m of outer-reef environments).

- The substantial differences observed in densities and biomass of those families common to the current study and the PROCFish survey is of considerable concern, as it indicates a significant reduction in finfish populations over a short-term period. It is strongly recommended that survey stations be established at the same positions as those examined during the PROCFish study, to rule out any possible spatial differences. Furthermore, to ensure that these contrasting results, and results of future surveys, were not a result of differences in observer skill or experience, the use of non-observer based monitoring techniques, such as videography, in conjunction with the D-UVC surveys are recommended.

Invertebrate Surveys

- For this baseline study, manta tow surveys were conducted on back-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 Laura and Majuro sites, where conditions permit.

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Appendix 1 GPS positions of benthic habitat assessments

Station ID	Habitat	Transect name	Longitude (E)	Latitude (N)
Laura 1	Back-reef	Rb4	171.0481167	7.1844833
	Back-reef	Rb5	171.0482667	7.1838333
	Back-reef	Rb6	171.0480667	7.1849500
	Lagoon-reef	Rl1	171.0505167	7.1850000
	Lagoon-reef	Rl2	171.0501500	7.1845833
	Lagoon-reef	Rl3	171.0495000	7.1833667
	Outer-reef	Rs7	171.0469500	7.2042833
	Outer-reef	Rs8	171.0468000	7.2037333
	Outer-reef	Rs9	171.0465667	7.2032667
Laura 2	Back-reef	Rb7	171.0500167	7.1335000
	Back-reef	Rb8	171.0502667	7.1328000
	Back-reef	Rb9	171.0503000	7.1322667
	Lagoon-reef	Rl4	171.0498167	7.1365167
	Lagoon-reef	Rl5	171.0500500	7.1364500
	Lagoon-reef	Rl6	171.0503167	7.1354667
	Outer-reef	Rs1	171.0404000	7.1335333
	Outer-reef	Rs2	171.0401333	7.1338167
	Outer-reef	Rs3	171.0399667	7.1340333
Majuro 1	Back-reef	Rb4	171.2204667	7.1556500
	Back-reef	Rb6	171.2177333	7.1570500
	Lagoon-reef	Rl1	171.2134000	7.1565000
	Lagoon-reef	Rl2	171.2134833	7.1562000
	Lagoon-reef	Rl3	171.2151000	7.1563000
	Outer-reef	Rs7	171.2135667	7.1639500
	Outer-reef	Rs8	171.2140000	7.1638500
	Outer-reef	Rs9	171.2120833	7.1640167
Majuro 2	Back-reef	Rb4	171.3220500	7.1208500
	Back-reef	Rb5	171.3214000	7.1208333
	Back-reef	Rb6	171.3221167	7.1208500
	Lagoon-reef	Rl1	171.3164667	7.1205167
	Lagoon-reef	Rl2	171.3164500	7.1210167
	Lagoon-reef	Rl3	171.3174000	7.1202000
	Outer-reef	Rs7	171.3199500	7.1266167
	Outer-reef	Rs8	171.3202333	7.1267000
	Outer-reef	Rs9	171.3182000	7.1284667

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

Campaign |________________| Site |__________________________| Diver |__|__| Transect |__|__|__|

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

ST	SCIENTIFIC NAME	NBER	LGT	D1	D2	COMMENTS

Appendix 3 Form used to assess habitats supporting finfish

Campaign |________________| **Site** |__________________________| **Diver** |__|__| **Transect** |__|__|__|

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

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

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

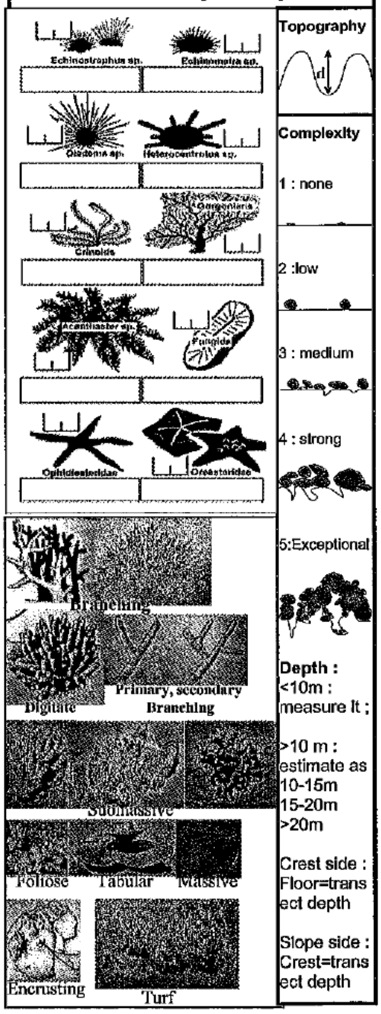
	current	oceanic influence	terrigenous influence
none	☐	☐	☐
medium	☐	☐	☐
strong	☐	☐	☐

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

Remarks:

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

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



Appendix 4 GPS positions of finfish D-UVC transects

Station ID	Habitat	Transect name	Longitude (E)	Latitude (N)
Laura 1	Back-reef	T25	171.046183	7.186200
	Back-reef	T26	171.046083	7.185967
	Lagoon-reef	T13	171.055233	7.193183
	Lagoon-reef	T14	171.054667	7.192950
	Lagoon-reef	T15	171.052667	7.190400
	Outer-reef	T19	171.041533	7.188133
	Outer-reef	T20	171.041383	7.187750
	Outer-reef	T21	171.041133	7.187033
Laura 2	Back-reef	T27	171.046417	7.184050
	Back-reef	T28	171.046300	7.183750
	Lagoon-reef	T16	171.052583	7.134817
	Lagoon-reef	T18	171.050050	7.134833
	Outer-reef	T22	171.041733	7.134683
	Outer-reef	T23	171.040633	7.133000
	Outer-reef	T24	171.042550	7.130700
Majuro 1	Back-reef	T7	171.220467	7.155667
	Back-reef	T8	171.219967	7.155900
	Back-reef	T9	171.223733	7.157067
	Lagoon-reef	T1	171.213400	7.156500
	Lagoon-reef	T2	171.213483	7.156217
	Lagoon-reef	T3	171.215100	7.156300
	Outer-reef	T34	171.213567	7.163950
	Outer-reef	T35	171.214000	7.163850
	Outer-reef	T36	171.212083	7.164017
Majuro 2	Back-reef	T10	171.321517	7.120867
	Back-reef	T11	171.321417	7.120850
	Back-reef	T12	171.322117	7.120850
	Lagoon-reef	T4	171.316483	7.120517
	Lagoon-reef	T5	171.316450	7.121017
	Lagoon-reef	T6	171.317400	7.120200
	Outer-reef	T31	171.319950	7.126617
	Outer-reef	T32	171.320233	7.126700
	Outer-reef	T33	171.318200	7.128417

Appendix 5 Mean density and biomass of finfish families recorded in Laura by habitat

Habitat	Family	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back-reef	Acanthuridae	0.041	0.019	1.338	0.539
Back-reef	Balistidae	0.003	0.001	0.264	0.164
Back-reef	Callionymidae	0.001	0.001	0.003	0.003
Back-reef	Chaetodontidae	0.004	0.002	0.096	0.055
Back-reef	Gobiidae	0.001	0.001	0.002	0.002
Back-reef	Labridae	0.055	0.014	0.137	0.040
Back-reef	Lutjanidae	0.001	0.001	0.262	0.262
Back-reef	Mullidae	0.009	0.003	0.063	0.011
Back-reef	Pomacentridae	0.091	0.025	0.177	0.086
Back-reef	Scaridae	0.002	0.001	0.017	0.011
Back-reef	Serranidae	0.004	0.002	0.183	0.113
Lagoon-reef	Acanthuridae	0.101	0.020	11.307	5.378
Lagoon-reef	Balistidae	0.001	0.000	0.069	0.040
Lagoon-reef	Chaetodontidae	0.014	0.008	0.581	0.347
Lagoon-reef	Labridae	0.086	0.027	0.679	0.203
Lagoon-reef	Lethrinidae	0.000	0.000	0.154	0.154
Lagoon-reef	Lutjanidae	0.001	0.001	0.053	0.053
Lagoon-reef	Mullidae	0.016	0.004	0.991	0.432
Lagoon-reef	Pomacanthidae	0.002	0.001	0.132	0.128
Lagoon-reef	Pomacentridae	0.484	0.121	1.826	0.486
Lagoon-reef	Scaridae	0.035	0.009	3.550	1.349
Lagoon-reef	Serranidae	0.001	0.001	0.039	0.033
Lagoon-reef	Zanclidae	0.000	0.000	0.067	0.067
Outer-reef	Acanthuridae	0.198	0.032	16.740	4.385
Outer-reef	Balistidae	0.027	0.011	3.042	1.327
Outer-reef	Caesionidae	0.015	0.010	1.445	0.993
Outer-reef	Carangidae	0.003	0.002	1.396	0.814
Outer-reef	Chaetodontidae	0.028	0.002	1.664	0.434
Outer-reef	Cirrhitidae	0.004	0.002	0.167	0.128
Outer-reef	Haemulidae	0.003	0.003	0.415	0.415
Outer-reef	Holocentridae	0.123	0.064	16.433	8.435
Outer-reef	Labridae	0.051	0.013	1.629	0.420
Outer-reef	Lethrinidae	0.021	0.020	5.806	5.700
Outer-reef	Lutjanidae	0.002	0.001	0.321	0.164
Outer-reef	Microdesmidae	0.001	0.001	0.000	0.000
Outer-reef	Mullidae	0.001	0.000	0.220	0.162
Outer-reef	Pomacanthidae	0.028	0.009	0.596	0.185
Outer-reef	Pomacentridae	0.743	0.171	2.347	0.685
Outer-reef	Scaridae	0.028	0.005	2.459	0.347

Habitat	Family	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer-reef	Serranidae	1.357	0.642	0.701	0.236
Outer-reef	Zanclidae	0.004	0.003	0.589	0.459

Appendix 6 Mean density and biomass of finfish families recorded in Majuro by habitat

Habitat	Family	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back-reef	Acanthuridae	0.159	0.083	2.829	0.846
Back-reef	Balistidae	0.007	0.002	0.312	0.109
Back-reef	Chaetodontidae	0.008	0.002	0.272	0.125
Back-reef	Cirrhitidae	0.005	0.002	0.020	0.013
Back-reef	Gobiidae	0.002	0.001	0.002	0.001
Back-reef	Labridae	0.114	0.025	1.432	0.738
Back-reef	Mullidae	0.038	0.012	0.488	0.106
Back-reef	Pomacanthidae	0.003	0.001	0.011	0.007
Back-reef	Pomacentridae	1.295	0.294	3.111	1.375
Back-reef	Scaridae	0.014	0.006	0.262	0.088
Back-reef	Scorpaenidae	0.000	0.000	0.006	0.006
Back-reef	Serranidae	0.009	0.004	0.344	0.174
Lagoon-reef	Acanthuridae	0.116	0.020	7.782	1.572
Lagoon-reef	Balistidae	0.001	0.001	0.022	0.014
Lagoon-reef	Chaetodontidae	0.036	0.006	2.005	0.679
Lagoon-reef	Cirrhitidae	0.001	0.001	0.019	0.011
Lagoon-reef	Holocentridae	0.001	0.001	0.563	0.563
Lagoon-reef	Labridae	0.061	0.028	0.729	0.288
Lagoon-reef	Lethrinidae	0.003	0.002	0.476	0.322
Lagoon-reef	Lutjanidae	0.019	0.016	2.951	2.591
Lagoon-reef	Mullidae	0.006	0.002	0.184	0.111
Lagoon-reef	Pomacanthidae	0.011	0.005	0.171	0.090
Lagoon-reef	Pomacentridae	1.504	0.353	7.858	2.993
Lagoon-reef	Scaridae	0.079	0.030	2.618	1.265
Lagoon-reef	Serranidae	0.007	0.003	0.202	0.069
Lagoon-reef	Siganidae	0.001	0.001	0.013	0.013
Lagoon-reef	Zanclidae	0.001	0.001	0.101	0.101
Outer-reef	Acanthuridae	0.094	0.022	4.332	1.802
Outer-reef	Balistidae	0.009	0.003	0.755	0.201
Outer-reef	Chaetodontidae	0.002	0.001	0.077	0.051
Outer-reef	Cirrhitidae	0.010	0.002	0.229	0.166
Outer-reef	Labridae	0.147	0.041	1.637	1.240
Outer-reef	Lutjanidae	0.003	0.003	2.303	2.303
Outer-reef	Mullidae	0.001	0.001	0.127	0.112
Outer-reef	Pomacanthidae	0.005	0.001	0.023	0.005
Outer-reef	Pomacentridae	0.107	0.032	0.144	0.034
Outer-reef	Scaridae	0.020	0.008	5.274	3.735
Outer-reef	Serranidae	0.002	0.001	0.072	0.046

Appendix 7 Mean density and biomass of all fish species recorded in Laura by habitat

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back	Acanthuridae	*Acanthurus blochii*	0.001	0.001	0.053	0.053
Back	Acanthuridae	*Acanthurus nigrofuscus*	0.001	0.001	0.002	0.002
Back	Acanthuridae	*Acanthurus olivaceus*	0.001	0.001	0.033	0.033
Back	Acanthuridae	*Acanthurus* sp.	0.002	0.001	0.169	0.152
Back	Acanthuridae	*Acanthurus triostegus*	0.013	0.005	0.530	0.273
Back	Acanthuridae	*Ctenochaetus striatus*	0.003	0.003	0.023	0.023
Back	Acanthuridae	*Ctenochaetus strigosus*	0.002	0.001	0.015	0.010
Back	Acanthuridae	*Naso lituratus*	0.001	0.001	0.001	0.001
Back	Acanthuridae	*Zebrasoma scopas*	0.018	0.015	0.512	0.296
Back	Balistidae	*Rhinecanthus aculeatus*	0.003	0.001	0.264	0.164
Back	Callionymidae	*Synchiropus ocellatus*	0.001	0.001	0.003	0.003
Back	Chaetodontidae	*Chaetodon auriga*	0.002	0.001	0.011	0.010
Back	Chaetodontidae	*Chaetodon ornatissimus*	0.001	0.001	0.049	0.049
Back	Chaetodontidae	*Chaetodon speculum*	0.001	0.001	0.006	0.006
Back	Chaetodontidae	*Hemitaurichthys thompsoni*	0.001	0.001	0.030	0.030
Back	Gobiidae	*Gnatholepis anjerensis*	0.001	0.001	0.002	0.002
Back	Labridae	*Cheilinus chlorourus*	0.001	0.001	0.005	0.005
Back	Labridae	*Gomphosus varius*	0.001	0.001	0.001	0.001
Back	Labridae	*Halichoeres melanurus*	0.002	0.002	0.010	0.010
Back	Labridae	*Halichoeres scapularis*	0.001	0.001	0.003	0.003
Back	Labridae	*Halichoeres* sp.	0.001	0.001	0.001	0.001
Back	Labridae	*Halichoeres trimaculatus*	0.013	0.008	0.038	0.025
Back	Labridae	*Labroides bicolor*	0.001	0.001	0.002	0.002
Back	Labridae	*Labroides dimidiatus*	0.010	0.005	0.011	0.006
Back	Labridae	*Labroides* sp.	0.003	0.002	0.007	0.004
Back	Labridae	*Macropharyngodon meleagris*	0.002	0.002	0.002	0.002
Back	Labridae	*Pseudocheilinus evanidus*	0.001	0.001	0.000	0.000
Back	Labridae	*Pseudocheilinus hexataenia*	0.001	0.001	0.002	0.002
Back	Labridae	*Stethojulis bandanensis*	0.002	0.001	0.003	0.002
Back	Labridae	*Stethojulis strigiventer*	0.005	0.003	0.009	0.006
Back	Labridae	*Thalassoma hardwicke*	0.008	0.007	0.021	0.018
Back	Labridae	*Thalassoma lunare*	0.001	0.001	0.002	0.002
Back	Labridae	*Thalassoma lutescens*	0.001	0.001	0.002	0.001
Back	Labridae	*Thalassoma purpureum*	0.001	0.001	0.005	0.005
Back	Labridae	*Thalassoma quinquevittatum*	0.002	0.001	0.005	0.003
Back	Labridae	*Thalassoma* sp.	0.002	0.001	0.006	0.004
Back	Lutjanidae	*Lutjanus monostigma*	0.001	0.001	0.262	0.262
Back	Mullidae	*Parupeneus barberinus*	0.002	0.001	0.033	0.020
Back	Mullidae	*Parupeneus bifasciatus*	0.001	0.001	0.010	0.010
Back	Mullidae	*Parupeneus cyclostomus*	0.002	0.002	0.008	0.008

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back	Mullidae	*Parupeneus multifasciatus*	0.005	0.003	0.012	0.009
Back	Pomacentridae	*Amblyglyphidodon aureus*	0.001	0.001	0.001	0.001
Back	Pomacentridae	*Chrysiptera biocellata*	0.051	0.032	0.041	0.024
Back	Pomacentridae	*Dascyllus aruanus*	0.002	0.002	0.002	0.002
Back	Pomacentridae	*Plectroglyphidodon leucozonus*	0.001	0.001	0.002	0.002
Back	Pomacentridae	*Pomacentrus coelestis*	0.029	0.015	0.119	0.099
Back	Pomacentridae	*Pomacentrus grammorhynchus*	0.002	0.002	0.002	0.002
Back	Pomacentridae	*Pomacentrus pavo*	0.003	0.003	0.005	0.005
Back	Pomacentridae	*Pomacentrus vaiuli*	0.004	0.002	0.005	0.003
Back	Scaridae	*Chlorurus sordidus*	0.002	0.002	0.012	0.012
Back	Scaridae	*Scarus globiceps*	0.001	0.001	0.005	0.005
Back	Serranidae	*Epinephelus melanostigma*	0.002	0.001	0.173	0.111
Back	Serranidae	*Epinephelus merra*	0.002	0.002	0.010	0.010
Lagoon	Acanthuridae	*Acanthurus nigricans*	0.003	0.002	0.687	0.561
Lagoon	Acanthuridae	*Acanthurus nigricauda*	0.003	0.003	0.710	0.710
Lagoon	Acanthuridae	*Acanthurus nigroris*	0.001	0.001	0.012	0.012
Lagoon	Acanthuridae	*Acanthurus triostegus*	0.001	0.001	0.007	0.007
Lagoon	Acanthuridae	*Ctenochaetus striatus*	0.072	0.011	6.632	4.660
Lagoon	Acanthuridae	*Naso lituratus*	0.002	0.002	0.624	0.624
Lagoon	Acanthuridae	*Zebrasoma scopas*	0.019	0.010	2.634	1.416
Lagoon	Balistidae	*Rhinecanthus aculeatus*	0.001	0.000	0.069	0.040
Lagoon	Chaetodontidae	*Chaetodon auriga*	0.001	0.001	0.189	0.189
Lagoon	Chaetodontidae	*Chaetodon citrinellus*	0.001	0.001	0.041	0.041
Lagoon	Chaetodontidae	*Chaetodon ephippium*	0.000	0.000	0.063	0.063
Lagoon	Chaetodontidae	*Chaetodon lunula*	0.000	0.000	0.006	0.006
Lagoon	Chaetodontidae	*Chaetodon lunulatus*	0.008	0.007	0.177	0.120
Lagoon	Chaetodontidae	*Chaetodon plebeius*	0.000	0.000	0.002	0.002
Lagoon	Chaetodontidae	*Chaetodon reticulatus*	0.000	0.000	0.020	0.020
Lagoon	Chaetodontidae	*Chaetodon vagabundus*	0.000	0.000	0.002	0.002
Lagoon	Chaetodontidae	*Heniochus acuminatus*	0.001	0.001	0.027	0.027
Lagoon	Chaetodontidae	*Heniochus chrysostomus*	0.000	0.000	0.055	0.055
Lagoon	Labridae	*Anampses twistii*	0.000	0.000	0.003	0.003
Lagoon	Labridae	*Cheilinus chlorourus*	0.001	0.000	0.003	0.003
Lagoon	Labridae	*Cheilinus fasciatus*	0.000	0.000	0.248	0.248
Lagoon	Labridae	*Cheilinus* sp.	0.001	0.001	0.073	0.049
Lagoon	Labridae	*Cheilinus trilobatus*	0.001	0.001	0.002	0.002
Lagoon	Labridae	*Cheilinus undulatus*	0.000	0.000	0.054	0.054
Lagoon	Labridae	*Gomphosus varius*	0.009	0.007	0.027	0.018
Lagoon	Labridae	*Halichoeres hortulanus*	0.001	0.001	0.007	0.005
Lagoon	Labridae	*Halichoeres melanurus*	0.004	0.004	0.014	0.014
Lagoon	Labridae	*Halichoeres scapularis*	0.001	0.001	0.013	0.013

Habitat	Family	Species	Density (fish/m²)	SE density	Biomass (g/m²)	SE biomass
Lagoon	Labridae	*Hemigymnus melapterus*	0.001	0.001	0.018	0.016
Lagoon	Labridae	*Labroides bicolor*	0.002	0.002	0.003	0.003
Lagoon	Labridae	*Labroides dimidiatus*	0.014	0.009	0.072	0.062
Lagoon	Labridae	*Macropharyngodon meleagris*	0.002	0.002	0.003	0.003
Lagoon	Labridae	*Pseudocheilinus hexataenia*	0.014	0.010	0.015	0.012
Lagoon	Labridae	*Stethojulis bandanensis*	0.006	0.004	0.014	0.009
Lagoon	Labridae	*Stethojulis strigiventer*	0.002	0.001	0.003	0.002
Lagoon	Labridae	*Thalassoma hardwicke*	0.010	0.006	0.022	0.011
Lagoon	Labridae	*Thalassoma lunare*	0.002	0.002	0.023	0.023
Lagoon	Labridae	*Thalassoma lutescens*	0.005	0.002	0.018	0.006
Lagoon	Labridae	*Thalassoma quinquevittatum*	0.006	0.004	0.021	0.011
Lagoon	Labridae	*Thalassoma* sp.	0.001	0.001	0.009	0.009
Lagoon	Lethrinidae	*Monotaxis grandoculis*	0.000	0.000	0.154	0.154
Lagoon	Lutjanidae	*Lutjanus fulvus*	0.001	0.001	0.053	0.053
Lagoon	Mullidae	*Parupeneus barberinoides*	0.001	0.001	0.083	0.083
Lagoon	Mullidae	*Parupeneus barberinus*	0.004	0.002	0.773	0.499
Lagoon	Mullidae	*Parupeneus multifasciatus*	0.010	0.004	0.091	0.051
Lagoon	Mullidae	*Parupeneus* sp.	0.001	0.001	0.043	0.028
Lagoon	Pomacanthidae	*Centropyge bicolor*	0.000	0.000	0.032	0.032
Lagoon	Pomacanthidae	*Centropyge flavissimus*	0.001	0.000	0.030	0.026
Lagoon	Pomacanthidae	*Pomacanthus* sp.	0.000	0.000	0.070	0.070
Lagoon	Pomacentridae	*Abudefduf septemfasciatus*	0.001	0.001	0.012	0.012
Lagoon	Pomacentridae	*Abudefduf* sp.	0.010	0.010	0.023	0.023
Lagoon	Pomacentridae	*Abudefduf vaigiensis*	0.010	0.005	0.031	0.015
Lagoon	Pomacentridae	*Amphiprion perideraion*	0.001	0.001	0.002	0.002
Lagoon	Pomacentridae	*Chromis agilis*	0.000	0.000	0.010	0.010
Lagoon	Pomacentridae	*Chromis margaritifer*	0.001	0.001	0.020	0.020
Lagoon	Pomacentridae	*Chromis viridis*	0.059	0.046	0.179	0.110
Lagoon	Pomacentridae	*Chrysiptera biocellata*	0.087	0.060	0.528	0.455
Lagoon	Pomacentridae	*Chrysiptera brownriggii*	0.003	0.003	0.002	0.002
Lagoon	Pomacentridae	*Chrysiptera traceyi*	0.022	0.016	0.014	0.011
Lagoon	Pomacentridae	*Dascyllus aruanus*	0.010	0.006	0.054	0.043
Lagoon	Pomacentridae	*Dascyllus melanurus*	0.002	0.002	0.047	0.047
Lagoon	Pomacentridae	*Dascyllus reticulatus*	0.002	0.002	0.005	0.005
Lagoon	Pomacentridae	*Neoglyphidodon melas*	0.011	0.011	0.039	0.039
Lagoon	Pomacentridae	*Plectroglyphidodon dickii*	0.002	0.002	0.003	0.003
Lagoon	Pomacentridae	*Plectroglyphidodon lacrymatus*	0.009	0.008	0.050	0.041
Lagoon	Pomacentridae	*Pomacentrus coelestis*	0.161	0.070	0.348	0.242
Lagoon	Pomacentridae	*Pomacentrus pavo*	0.002	0.002	0.008	0.008
Lagoon	Pomacentridae	*Pomacentrus simsiang*	0.026	0.013	0.053	0.026
Lagoon	Pomacentridae	*Pomacentrus* sp.	0.062	0.055	0.390	0.288

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Lagoon	Pomacentridae	*Pomacentrus vaiuli*	0.004	0.003	0.007	0.007
Lagoon	Scaridae	*Chlorurus bleekeri*	0.001	0.001	0.025	0.025
Lagoon	Scaridae	*Chlorurus microrhinos*	0.001	0.001	0.401	0.401
Lagoon	Scaridae	*Chlorurus sordidus*	0.021	0.007	1.015	0.533
Lagoon	Scaridae	*Chlorurus* sp.	0.001	0.001	1.096	1.096
Lagoon	Scaridae	*Scarus dimidiatus*	0.000	0.000	0.066	0.066
Lagoon	Scaridae	*Scarus ghobban*	0.001	0.001	0.015	0.015
Lagoon	Scaridae	*Scarus globiceps*	0.003	0.003	0.014	0.014
Lagoon	Scaridae	*Scarus* sp.	0.007	0.006	0.919	0.770
Lagoon	Serranidae	*Epinephelus merra*	0.001	0.001	0.039	0.033
Lagoon	Zanclidae	*Zanclus cornutus*	0.000	0.000	0.067	0.067
Outer	Acanthuridae	*Acanthurus blochii*	0.004	0.004	0.103	0.103
Outer	Acanthuridae	*Acanthurus gahhm*	0.001	0.001	0.060	0.060
Outer	Acanthuridae	*Acanthurus guttatus*	0.001	0.001	0.057	0.036
Outer	Acanthuridae	*Acanthurus nigricans*	0.047	0.010	3.207	0.957
Outer	Acanthuridae	*Ctenochaetus striatus*	0.061	0.018	5.269	1.784
Outer	Acanthuridae	*Ctenochaetus strigosus*	0.002	0.002	0.000	0.000
Outer	Acanthuridae	*Naso lituratus*	0.047	0.027	6.408	3.493
Outer	Acanthuridae	*Naso unicornis*	0.000	0.000	0.039	0.039
Outer	Acanthuridae	*Zebrasoma scopas*	0.035	0.011	1.597	0.719
Outer	Balistidae	*Balistapus undulatus*	0.007	0.003	0.416	0.158
Outer	Balistidae	*Melichthys niger*	0.013	0.007	1.833	0.947
Outer	Balistidae	*Melichthys vidua*	0.007	0.004	0.724	0.429
Outer	Balistidae	*Rhinecanthus aculeatus*	0.001	0.001	0.069	0.069
Outer	Caesionidae	*Caesio* sp.	0.005	0.005	0.248	0.248
Outer	Caesionidae	*Caesio teres*	0.005	0.005	0.792	0.792
Outer	Caesionidae	*Pterocaesio tile*	0.005	0.003	0.405	0.266
Outer	Carangidae	*Caranx melampygus*	0.003	0.002	1.396	0.814
Outer	Chaetodontidae	*Chaetodon auriga*	0.001	0.001	0.125	0.079
Outer	Chaetodontidae	*Chaetodon baronessa*	0.001	0.001	0.016	0.016
Outer	Chaetodontidae	*Chaetodon ephippium*	0.001	0.001	0.064	0.064
Outer	Chaetodontidae	*Chaetodon lineolatus*	0.001	0.001	0.031	0.031
Outer	Chaetodontidae	*Chaetodon lunula*	0.001	0.001	0.022	0.020
Outer	Chaetodontidae	*Chaetodon lunulatus*	0.002	0.001	0.175	0.087
Outer	Chaetodontidae	*Chaetodon ornatissimus*	0.001	0.001	0.068	0.060
Outer	Chaetodontidae	*Chaetodon reticulatus*	0.003	0.002	0.228	0.166
Outer	Chaetodontidae	*Chaetodon* sp.	0.003	0.003	0.087	0.056
Outer	Chaetodontidae	*Chaetodon trifascialis*	0.003	0.001	0.169	0.093
Outer	Chaetodontidae	*Chaetodon ulietensis*	0.001	0.001	0.042	0.025
Outer	Chaetodontidae	*Chaetodon unimaculatus*	0.000	0.000	0.064	0.064
Outer	Chaetodontidae	*Forcipiger flavissimus*	0.001	0.000	0.027	0.020

Habitat	**Family**	**Species**	**Density (fish/m^2)**	**SE density**	**Biomass (g/m^2)**	**SE biomass**
Outer	Chaetodontidae	*Forcipiger longirostris*	0.001	0.001	0.011	0.005
Outer	Chaetodontidae	*Heniochus acuminatus*	0.003	0.001	0.248	0.124
Outer	Chaetodontidae	*Heniochus chrysostomus*	0.003	0.003	0.288	0.288
Outer	Cirrhitidae	*Paracirrhites arcatus*	0.001	0.001	0.047	0.047
Outer	Cirrhitidae	*Paracirrhites forsteri*	0.003	0.001	0.121	0.083
Outer	Haemulidae	*Plectorhinchus gibbosus*	0.003	0.003	0.415	0.415
Outer	Holocentridae	*Myripristis adusta*	0.025	0.017	1.184	0.831
Outer	Holocentridae	*Myripristis berndti*	0.014	0.009	1.604	1.358
Outer	Holocentridae	*Myripristis murdjan*	0.019	0.017	2.171	2.112
Outer	Holocentridae	*Myripristis pralinia*	0.025	0.025	3.384	3.384
Outer	Holocentridae	*Myripristis* sp.	0.040	0.038	7.648	6.997
Outer	Holocentridae	*Sargocentron* sp.	0.001	0.001	0.442	0.346
Outer	Labridae	*Cheilinus chlorourus*	0.001	0.000	0.039	0.037
Outer	Labridae	*Cheilinus fasciatus*	0.003	0.002	0.718	0.386
Outer	Labridae	*Epibulus insidiator*	0.002	0.001	0.427	0.239
Outer	Labridae	*Gomphosus varius*	0.001	0.001	0.017	0.017
Outer	Labridae	*Halichoeres hortulanus*	0.003	0.002	0.058	0.030
Outer	Labridae	*Halichoeres melanurus*	0.001	0.001	0.002	0.002
Outer	Labridae	*Halichoeres prosopeion*	0.003	0.003	0.009	0.009
Outer	Labridae	*Hemigymnus melapterus*	0.001	0.001	0.273	0.179
Outer	Labridae	*Labroides bicolor*	0.001	0.001	0.001	0.000
Outer	Labridae	*Labroides dimidiatus*	0.021	0.009	0.015	0.005
Outer	Labridae	*Thalassoma hardwicke*	0.002	0.001	0.005	0.003
Outer	Labridae	*Thalassoma lutescens*	0.012	0.005	0.066	0.028
Outer	Lethrinidae	*Lethrinus* sp.	0.001	0.001	0.089	0.089
Outer	Lethrinidae	*Monotaxis grandoculis*	0.020	0.020	5.717	5.717
Outer	Lutjanidae	*Aphareus furca*	0.000	0.000	0.035	0.035
Outer	Lutjanidae	*Lutjanus fulviflammus*	0.000	0.000	0.021	0.021
Outer	Lutjanidae	*Lutjanus fulvus*	0.001	0.001	0.170	0.170
Outer	Lutjanidae	*Macolor niger*	0.001	0.001	0.095	0.095
Outer	Microdesmidae	*Nemateleotris helfrichi*	0.001	0.001	0.000	0.000
Outer	Mullidae	*Parupeneus cyclostomus*	0.000	0.000	0.163	0.163
Outer	Mullidae	*Parupeneus multifasciatus*	0.000	0.000	0.057	0.057
Outer	Pomacanthidae	*Centropyge bicolor*	0.001	0.001	0.039	0.039
Outer	Pomacanthidae	*Centropyge flavissimus*	0.016	0.005	0.113	0.046
Outer	Pomacanthidae	*Centropyge loriculus*	0.004	0.003	0.024	0.020
Outer	Pomacanthidae	*Pomacanthus imperator*	0.000	0.000	0.234	0.234
Outer	Pomacanthidae	*Pomacanthus sp.*	0.005	0.005	0.006	0.006
Outer	Pomacanthidae	*Pygoplites diacanthus*	0.001	0.001	0.179	0.091
Outer	Pomacentridae	*Amblyglyphidodon aureus*	0.025	0.011	0.061	0.026
Outer	Pomacentridae	*Amblyglyphidodon curacao*	0.002	0.002	0.027	0.027

Habitat	Family	Species	Density (fish/m²)	SE density	Biomass (g/m²)	SE biomass
Outer	Pomacentridae	*Amphiprion clarkii*	0.001	0.001	0.002	0.002
Outer	Pomacentridae	*Amphiprion* sp.	0.001	0.001	0.019	0.019
Outer	Pomacentridae	*Chromis acares*	0.086	0.043	0.027	0.013
Outer	Pomacentridae	*Chromis analis*	0.001	0.001	0.003	0.003
Outer	Pomacentridae	*Chromis margaritifer*	0.248	0.087	0.645	0.325
Outer	Pomacentridae	*Chromis ternatensis*	0.039	0.036	0.168	0.162
Outer	Pomacentridae	*Chromis xanthura*	0.015	0.011	0.165	0.127
Outer	Pomacentridae	*Chrysiptera* sp.	0.016	0.011	0.030	0.019
Outer	Pomacentridae	*Chrysiptera traceyi*	0.008	0.004	0.003	0.002
Outer	Pomacentridae	*Plectroglyphidodon lacrymatus*	0.011	0.005	0.088	0.033
Outer	Pomacentridae	*Pomacentrus coelestis*	0.016	0.014	0.068	0.066
Outer	Pomacentridae	*Pomacentrus moluccensis*	0.001	0.001	0.004	0.004
Outer	Pomacentridae	*Pomacentrus pavo*	0.031	0.031	0.197	0.197
Outer	Pomacentridae	*Pomacentrus* sp.	0.241	0.138	0.838	0.479
Outer	Pomacentridae	*Pomacentrus vaiuli*	0.001	0.001	0.002	0.002
Outer	Scaridae	*Chlorurus bleekeri*	0.001	0.001	0.211	0.211
Outer	Scaridae	*Chlorurus sordidus*	0.018	0.005	0.640	0.173
Outer	Scaridae	*Chlorurus* sp.	0.000	0.000	0.148	0.148
Outer	Scaridae	*Scarus globiceps*	0.003	0.002	0.313	0.144
Outer	Scaridae	*Scarus schlegeli*	0.001	0.001	0.097	0.097
Outer	Scaridae	*Scarus* sp.	0.005	0.002	1.050	0.463
Outer	Serranidae	*Cephalopholis argus*	0.000	0.000	0.002	0.002
Outer	Serranidae	*Cephalopholis urodeta*	0.001	0.001	0.077	0.063
Outer	Serranidae	*Epinephelus merra*	0.001	0.001	0.205	0.130
Outer	Serranidae	*Pseudanthias bartlettorum*	0.113	0.067	0.024	0.015
Outer	Serranidae	*Pseudanthias dispar*	0.048	0.048	0.006	0.006
Outer	Serranidae	*Pseudanthias pascalus*	1.193	0.599	0.387	0.212
Outer	Zanclidae	*Zanclus cornutus*	0.004	0.003	0.589	0.459

Appendix 8 Mean density and biomass of all fish recorded in Majuro by habitat

Habitat	Family	Species	Density (fish/m²)	SE density	Biomass (g/m²)	SE biomass
Back	Acanthuridae	*Acanthurus nigricans*	0.008	0.008	0.011	0.011
Back	Acanthuridae	*Acanthurus nigricauda*	0.001	0.001	0.016	0.016
Back	Acanthuridae	*Acanthurus olivaceus*	0.001	0.001	0.046	0.046
Back	Acanthuridae	*Acanthurus* sp.	0.000	0.000	0.009	0.009
Back	Acanthuridae	*Acanthurus triostegus*	0.003	0.002	0.286	0.264
Back	Acanthuridae	*Ctenochaetus striatus*	0.038	0.019	0.561	0.266
Back	Acanthuridae	*Ctenochaetus strigosus*	0.076	0.051	0.208	0.114
Back	Acanthuridae	*Zebrasoma flavescens*	0.017	0.017	0.005	0.005
Back	Acanthuridae	*Zebrasoma scopas*	0.015	0.009	1.687	0.955
Back	Acanthuridae	*Zebrasoma veliferum*	0.000	0.000	0.000	0.000
Back	Balistidae	*Melichthys niger*	0.001	0.001	0.036	0.036
Back	Balistidae	*Melichthys vidua*	0.002	0.002	0.019	0.019
Back	Balistidae	*Pseudobalistes fuscus*	0.000	0.000	0.035	0.035
Back	Balistidae	*Rhinecanthus aculeatus*	0.003	0.001	0.056	0.056
Back	Balistidae	*Rhinecanthus rectangulus*	0.001	0.000	0.107	0.068
Back	Balistidae	*Rhinecanthus* sp.	0.000	0.000	0.049	0.049
Back	Balistidae	*Sufflamen bursa*	0.000	0.000	0.009	0.009
Back	Chaetodontidae	*Chaetodon citrinellus*	0.001	0.001	0.001	0.001
Back	Chaetodontidae	*Chaetodon lunulatus*	0.001	0.001	0.094	0.094
Back	Chaetodontidae	*Chaetodon plebeius*	0.001	0.001	0.003	0.003
Back	Chaetodontidae	*Chaetodon rafflesii*	0.001	0.001	0.000	0.000
Back	Chaetodontidae	*Chaetodon reticulatus*	0.001	0.001	0.020	0.019
Back	Chaetodontidae	*Chaetodon* sp.	0.001	0.001	0.133	0.101
Back	Chaetodontidae	*Chaetodon trifascialis*	0.001	0.001	0.022	0.022
Back	Cirrhitidae	*Paracirrhites arcatus*	0.004	0.002	0.005	0.003
Back	Cirrhitidae	*Paracirrhites forsteri*	0.001	0.000	0.015	0.013
Back	Gobiidae	*Valenciennea strigata*	0.002	0.001	0.002	0.001
Back	Labridae	*Anampses* sp.	0.000	0.000	0.008	0.008
Back	Labridae	*Cheilinus chlorourus*	0.001	0.000	0.005	0.003
Back	Labridae	*Cheilinus fasciatus*	0.001	0.001	0.041	0.041
Back	Labridae	*Cheilinus* sp.	0.001	0.001	0.002	0.001
Back	Labridae	*Coris gaimard*	0.009	0.006	0.058	0.034
Back	Labridae	*Gomphosus varius*	0.002	0.001	0.098	0.090
Back	Labridae	*Halichoeres hortulanus*	0.005	0.002	0.037	0.024
Back	Labridae	*Halichoeres prosopeion*	0.002	0.002	0.006	0.006
Back	Labridae	*Halichoeres scapularis*	0.003	0.002	0.006	0.003
Back	Labridae	*Halichoeres* sp.	0.015	0.009	0.891	0.736
Back	Labridae	*Halichoeres trimaculatus*	0.033	0.013	0.142	0.060
Back	Labridae	*Hemigymnus melapterus*	0.000	0.000	0.002	0.002
Back	Labridae	*Labroides dimidiatus*	0.016	0.009	0.016	0.010
Back	Labridae	*Labroides* sp.	0.000	0.000	0.031	0.031

Habitat	Family	Species	Density (fish/m²)	SE density	Biomass (g/m²)	SE biomass
Back	Labridae	*Macropharyngodon meleagris*	0.009	0.008	0.011	0.011
Back	Labridae	*Stethojulis bandanensis*	0.002	0.001	0.004	0.001
Back	Labridae	*Stethojulis strigiventer*	0.002	0.002	0.003	0.002
Back	Labridae	*Thalassoma hardwicke*	0.000	0.000	0.000	0.000
Back	Labridae	*Thalassoma lutescens*	0.007	0.003	0.065	0.023
Back	Labridae	*Thalassoma* sp.	0.001	0.001	0.002	0.002
Back	Mullidae	*Parupeneus barberinus*	0.001	0.001	0.031	0.021
Back	Mullidae	*Parupeneus cyclostomus*	0.001	0.000	0.007	0.006
Back	Mullidae	*Parupeneus multifasciatus*	0.028	0.011	0.217	0.111
Back	Mullidae	*Parupeneus* sp.	0.008	0.004	0.233	0.108
Back	Pomacanthidae	*Centropyge bicolor*	0.000	0.000	0.000	0.000
Back	Pomacanthidae	*Centropyge flavissimus*	0.002	0.001	0.011	0.007
Back	Pomacentridae	*Abudefduf* sp.	0.001	0.001	0.145	0.145
Back	Pomacentridae	*Abudefduf vaigiensis*	0.005	0.005	0.008	0.008
Back	Pomacentridae	*Amphiprion clarkii*	0.003	0.003	0.002	0.002
Back	Pomacentridae	*Amphiprion tricinctus*	0.004	0.004	0.004	0.003
Back	Pomacentridae	*Chromis margaritifer*	0.002	0.001	0.001	0.001
Back	Pomacentridae	*Chromis viridis*	0.165	0.149	0.055	0.028
Back	Pomacentridae	*Chrysiptera biocellata*	0.005	0.003	0.005	0.004
Back	Pomacentridae	*Chrysiptera* sp.	0.039	0.034	0.159	0.153
Back	Pomacentridae	*Chrysiptera traceyi*	0.001	0.001	0.001	0.001
Back	Pomacentridae	*Dascyllus aruanus*	0.026	0.018	0.042	0.035
Back	Pomacentridae	*Dascyllus trimaculatus*	0.004	0.003	0.008	0.006
Back	Pomacentridae	*Plectroglyphidodon johnstonianus*	0.000	0.000	0.001	0.001
Back	Pomacentridae	*Plectroglyphidodon lacrymatus*	0.001	0.001	0.002	0.002
Back	Pomacentridae	*Pomacentrus coelestis*	1.019	0.345	2.655	1.313
Back	Pomacentridae	*Pomacentrus simsiang*	0.011	0.007	0.017	0.010
Back	Pomacentridae	*Pomacentrus vaiuli*	0.009	0.005	0.006	0.004
Back	Scaridae	*Chlorurus bleekeri*	0.002	0.002	0.018	0.018
Back	Scaridae	*Chlorurus sordidus*	0.011	0.004	0.235	0.082
Back	Scaridae	*Scarus globiceps*	0.001	0.001	0.007	0.007
Back	Scaridae	*Scarus* sp.	0.000	0.000	0.002	0.002
Back	Scorpaenidae	*Pterois radiata*	0.000	0.000	0.006	0.006
Back	Serranidae	*Cephalopholis urodeta*	0.001	0.001	0.012	0.012
Back	Serranidae	*Epinephelus merra*	0.008	0.004	0.332	0.172
Lagoon	Acanthuridae	*Acanthurus lineatus*	0.001	0.001	0.377	0.377
Lagoon	Acanthuridae	*Acanthurus nigricans*	0.003	0.002	0.285	0.280
Lagoon	Acanthuridae	*Acanthurus nigrofuscus*	0.003	0.003	0.402	0.402
Lagoon	Acanthuridae	*Acanthurus olivaceus*	0.000	0.000	0.015	0.015
Lagoon	Acanthuridae	*Acanthurus* sp.	0.005	0.002	0.555	0.247
Lagoon	Acanthuridae	*Ctenochaetus striatus*	0.067	0.011	3.269	0.919
Lagoon	Acanthuridae	*Naso lituratus*	0.001	0.000	0.007	0.005
Lagoon	Acanthuridae	*Naso unicornis*	0.001	0.000	0.312	0.286

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Lagoon	Acanthuridae	*Zebrasoma flavescens*	0.001	0.001	0.048	0.045
Lagoon	Acanthuridae	*Zebrasoma scopas*	0.034	0.011	2.511	1.522
Lagoon	Acanthuridae	*Zebrasoma veliferum*	0.000	0.000	0.001	0.001
Lagoon	Balistidae	*Balistapus undulatus*	0.001	0.001	0.013	0.013
Lagoon	Balistidae	*Rhinecanthus aculeatus*	0.000	0.000	0.009	0.009
Lagoon	Chaetodontidae	*Chaetodon auriga*	0.003	0.002	0.253	0.143
Lagoon	Chaetodontidae	*Chaetodon ephippium*	0.000	0.000	0.004	0.004
Lagoon	Chaetodontidae	*Chaetodon lineolatus*	0.000	0.000	0.005	0.005
Lagoon	Chaetodontidae	*Chaetodon lunula*	0.001	0.001	0.071	0.051
Lagoon	Chaetodontidae	*Chaetodon lunulatus*	0.010	0.003	0.229	0.085
Lagoon	Chaetodontidae	*Chaetodon mertensii*	0.000	0.000	0.004	0.004
Lagoon	Chaetodontidae	*Chaetodon meyeri*	0.001	0.001	0.039	0.039
Lagoon	Chaetodontidae	*Chaetodon ornatissimus*	0.002	0.002	0.327	0.327
Lagoon	Chaetodontidae	*Chaetodon reticulatus*	0.002	0.001	0.090	0.072
Lagoon	Chaetodontidae	*Chaetodon* sp.	0.004	0.004	0.149	0.137
Lagoon	Chaetodontidae	*Chaetodon trifascialis*	0.005	0.003	0.309	0.266
Lagoon	Chaetodontidae	*Chaetodon ulietensis*	0.003	0.001	0.125	0.071
Lagoon	Chaetodontidae	*Chaetodon unimaculatus*	0.001	0.001	0.310	0.310
Lagoon	Chaetodontidae	*Chelmon rostratus*	0.001	0.001	0.033	0.033
Lagoon	Chaetodontidae	*Heniochus acuminatus*	0.000	0.000	0.037	0.037
Lagoon	Chaetodontidae	*Heniochus chrysostomus*	0.001	0.001	0.020	0.020
Lagoon	Cirrhitidae	*Paracirrhites arcatus*	0.001	0.001	0.018	0.012
Lagoon	Cirrhitidae	*Paracirrhites forsteri*	0.000	0.000	0.001	0.001
Lagoon	Holocentridae	*Sargocentron* sp.	0.001	0.001	0.563	0.563
Lagoon	Labridae	*Cheilinus chlorourus*	0.001	0.001	0.055	0.036
Lagoon	Labridae	*Cheilinus fasciatus*	0.002	0.001	0.087	0.039
Lagoon	Labridae	*Cheilinus* sp.	0.002	0.001	0.063	0.061
Lagoon	Labridae	*Cheilinus undulatus*	0.000	0.000	0.009	0.009
Lagoon	Labridae	*Cirrhilabrus exquisitus*	0.001	0.001	0.005	0.005
Lagoon	Labridae	*Gomphosus varius*	0.001	0.001	0.008	0.008
Lagoon	Labridae	*Halichoeres hortulanus*	0.001	0.001	0.009	0.008
Lagoon	Labridae	*Halichoeres* sp.	0.010	0.006	0.328	0.213
Lagoon	Labridae	*Halichoeres trimaculatus*	0.001	0.001	0.001	0.001
Lagoon	Labridae	*Hemigymnus melapterus*	0.001	0.000	0.052	0.051
Lagoon	Labridae	*Labrichthys unilineatus*	0.001	0.001	0.006	0.006
Lagoon	Labridae	*Labroides bicolor*	0.003	0.002	0.013	0.008
Lagoon	Labridae	*Labroides dimidiatus*	0.031	0.022	0.048	0.033
Lagoon	Labridae	*Thalassoma hardwicke*	0.004	0.003	0.012	0.009
Lagoon	Labridae	*Thalassoma lunare*	0.000	0.000	0.003	0.003
Lagoon	Labridae	*Thalassoma lutescens*	0.003	0.001	0.030	0.016
Lagoon	Lethrinidae	*Monotaxis grandoculis*	0.003	0.002	0.476	0.322
Lagoon	Lutjanidae	*Lutjanus fulviflammus*	0.001	0.001	0.135	0.135
Lagoon	Lutjanidae	*Lutjanus gibbus*	0.017	0.017	2.636	2.636

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Lagoon	Lutjanidae	*Lutjanus monostigma*	0.001	0.001	0.180	0.180
Lagoon	Mullidae	*Parupeneus bifasciatus*	0.002	0.002	0.013	0.013
Lagoon	Mullidae	*Parupeneus multifasciatus*	0.004	0.002	0.172	0.114
Lagoon	Pomacanthidae	*Centropyge bicolor*	0.001	0.001	0.007	0.007
Lagoon	Pomacanthidae	*Centropyge flavissimus*	0.010	0.005	0.133	0.066
Lagoon	Pomacanthidae	*Pygoplites diacanthus*	0.000	0.000	0.031	0.031
Lagoon	Pomacentridae	*Abudefduf septemfasciatus*	0.003	0.003	0.015	0.015
Lagoon	Pomacentridae	*Abudefduf* sp.	0.190	0.118	1.317	0.918
Lagoon	Pomacentridae	*Abudefduf vaigiensis*	0.046	0.017	0.198	0.072
Lagoon	Pomacentridae	*Amblyglyphidodon aureus*	0.017	0.008	0.042	0.021
Lagoon	Pomacentridae	*Amblyglyphidodon curacao*	0.001	0.001	0.013	0.013
Lagoon	Pomacentridae	*Amphiprion melanopus*	0.005	0.005	0.007	0.007
Lagoon	Pomacentridae	*Amphiprion tricinctus*	0.001	0.001	0.001	0.001
Lagoon	Pomacentridae	*Chromis margaritifer*	0.025	0.020	0.115	0.099
Lagoon	Pomacentridae	*Chromis* sp.	0.031	0.024	0.141	0.110
Lagoon	Pomacentridae	*Chromis ternatensis*	0.193	0.124	0.247	0.162
Lagoon	Pomacentridae	*Chromis viridis*	0.341	0.192	1.929	1.291
Lagoon	Pomacentridae	*Chromis xanthura*	0.014	0.007	0.136	0.083
Lagoon	Pomacentridae	*Chrysiptera* sp.	0.028	0.011	0.145	0.049
Lagoon	Pomacentridae	*Chrysiptera traceyi*	0.119	0.049	0.186	0.085
Lagoon	Pomacentridae	*Chrysiptera unimaculata*	0.003	0.003	0.017	0.017
Lagoon	Pomacentridae	*Dascyllus aruanus*	0.095	0.034	0.331	0.150
Lagoon	Pomacentridae	*Dascyllus melanurus*	0.004	0.004	0.056	0.056
Lagoon	Pomacentridae	*Pomacentrus coelestis*	0.354	0.305	2.911	2.838
Lagoon	Pomacentridae	*Pomacentrus simsiang*	0.015	0.014	0.017	0.014
Lagoon	Pomacentridae	*Pomacentrus vaiuli*	0.015	0.013	0.026	0.023
Lagoon	Pomacentridae	*Stegastes nigricans*	0.003	0.003	0.006	0.006
Lagoon	Scaridae	*Cetoscarus bicolor*	0.000	0.000	0.054	0.054
Lagoon	Scaridae	*Chlorurus sordidus*	0.057	0.027	1.045	0.620
Lagoon	Scaridae	*Chlorurus* sp.	0.000	0.000	0.005	0.005
Lagoon	Scaridae	*Hipposcarus longiceps*	0.001	0.001	0.010	0.007
Lagoon	Scaridae	*Scarus dimidiatus*	0.000	0.000	0.007	0.007
Lagoon	Scaridae	*Scarus ghobban*	0.000	0.000	0.021	0.021
Lagoon	Scaridae	*Scarus globiceps*	0.013	0.008	0.121	0.067
Lagoon	Scaridae	*Scarus niger*	0.000	0.000	0.011	0.011
Lagoon	Scaridae	*Scarus* sp.	0.006	0.003	1.343	0.696
Lagoon	Serranidae	*Anyperodon* sp.	0.000	0.000	0.013	0.013
Lagoon	Serranidae	*Cephalopholis argus*	0.000	0.000	0.017	0.017
Lagoon	Serranidae	*Cephalopholis urodeta*	0.001	0.001	0.032	0.032
Lagoon	Serranidae	*Epinephelus merra*	0.001	0.001	0.097	0.051
Lagoon	Serranidae	*Pseudanthias pascalus*	0.004	0.003	0.042	0.027
Lagoon	Siganidae	*Siganus vulpinus*	0.001	0.001	0.013	0.013
Lagoon	Zanclidae	*Zanclus cornutus*	0.001	0.001	0.101	0.101

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Acanthuridae	*Acanthurus achilles*	0.002	0.002	0.013	0.013
Outer	Acanthuridae	*Acanthurus lineatus*	0.001	0.001	0.313	0.311
Outer	Acanthuridae	*Acanthurus maculiceps*	0.001	0.001	0.004	0.004
Outer	Acanthuridae	*Acanthurus nigricans*	0.000	0.000	0.003	0.003
Outer	Acanthuridae	*Acanthurus* sp.	0.016	0.011	1.292	0.774
Outer	Acanthuridae	*Ctenochaetus striatus*	0.057	0.017	1.899	0.987
Outer	Acanthuridae	*Ctenochaetus strigosus*	0.000	0.000	0.000	0.000
Outer	Acanthuridae	*Naso lituratus*	0.005	0.002	0.608	0.589
Outer	Acanthuridae	*Zebrasoma scopas*	0.011	0.005	0.200	0.091
Outer	Balistidae	*Balistapus undulatus*	0.004	0.004	0.113	0.094
Outer	Balistidae	*Melichthys niger*	0.001	0.001	0.099	0.099
Outer	Balistidae	*Melichthys vidua*	0.001	0.001	0.241	0.189
Outer	Balistidae	*Rhinecanthus aculeatus*	0.002	0.001	0.253	0.184
Outer	Balistidae	*Rhinecanthus rectangulus*	0.000	0.000	0.049	0.049
Outer	Balistidae	*Sufflamen bursa*	0.000	0.000	0.000	0.000
Outer	Chaetodontidae	*Chaetodon citrinellus*	0.001	0.001	0.027	0.027
Outer	Chaetodontidae	*Chaetodon* sp.	0.001	0.001	0.029	0.029
Outer	Chaetodontidae	*Heniochus acuminatus*	0.001	0.001	0.021	0.021
Outer	Cirrhitidae	*Paracirrhites arcatus*	0.008	0.003	0.104	0.052
Outer	Cirrhitidae	*Paracirrhites forsteri*	0.002	0.001	0.125	0.122
Outer	Labridae	*Anampses twistii*	0.000	0.000	0.001	0.001
Outer	Labridae	*Cheilinus chlorourus*	0.000	0.000	0.000	0.000
Outer	Labridae	*Cheilinus* sp.	0.000	0.000	0.000	0.000
Outer	Labridae	*Epibulus insidiator*	0.000	0.000	0.109	0.109
Outer	Labridae	*Gomphosus varius*	0.002	0.001	0.024	0.011
Outer	Labridae	*Halichoeres hortulanus*	0.000	0.000	0.005	0.005
Outer	Labridae	*Halichoeres marginatus*	0.060	0.023	0.156	0.055
Outer	Labridae	*Halichoeres melanurus*	0.006	0.004	0.099	0.074
Outer	Labridae	*Halichoeres scapularis*	0.001	0.001	0.003	0.003
Outer	Labridae	*Halichoeres* sp.	0.011	0.011	0.026	0.026
Outer	Labridae	*Labroides dimidiatus*	0.014	0.006	0.070	0.048
Outer	Labridae	*Labroides* sp.	0.003	0.003	0.003	0.003
Outer	Labridae	*Macropharyngodon meleagris*	0.001	0.001	0.001	0.001
Outer	Labridae	*Stethojulis strigiventer*	0.001	0.000	0.001	0.001
Outer	Labridae	*Thalassoma hardwicke*	0.007	0.007	0.039	0.039
Outer	Labridae	*Thalassoma lutescens*	0.002	0.001	0.031	0.025
Outer	Labridae	*Thalassoma purpureum*	0.001	0.000	0.005	0.003
Outer	Labridae	*Thalassoma quinquevittatum*	0.003	0.003	0.005	0.005
Outer	Labridae	*Thalassoma* sp.	0.034	0.034	1.056	1.056
Outer	Lutjanidae	*Lutjanus gibbus*	0.003	0.003	2.303	2.303
Outer	Mullidae	*Parupeneus multifasciatus*	0.001	0.001	0.127	0.112
Outer	Pomacanthidae	*Centropyge flavissimus*	0.005	0.001	0.023	0.005
Outer	Pomacentridae	*Chromis acares*	0.019	0.009	0.007	0.003

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Pomacentridae	*Chromis margaritifer*	0.008	0.002	0.014	0.006
Outer	Pomacentridae	*Chromis* sp.	0.007	0.004	0.011	0.008
Outer	Pomacentridae	*Chromis viridis*	0.007	0.007	0.013	0.013
Outer	Pomacentridae	*Chrysiptera biocellata*	0.001	0.001	0.000	0.000
Outer	Pomacentridae	*Chrysiptera* sp.	0.004	0.003	0.003	0.002
Outer	Pomacentridae	*Neoglyphidodon melas*	0.007	0.005	0.014	0.011
Outer	Pomacentridae	*Plectroglyphidodon dickii*	0.004	0.003	0.013	0.009
Outer	Pomacentridae	*Plectroglyphidodon johnstonianus*	0.008	0.003	0.014	0.005
Outer	Pomacentridae	*Pomacentrus coelestis*	0.021	0.019	0.028	0.026
Outer	Pomacentridae	*Pomacentrus grammorhynchus*	0.003	0.002	0.002	0.001
Outer	Pomacentridae	*Pomacentrus* sp.	0.015	0.015	0.018	0.018
Outer	Pomacentridae	*Pomacentrus vaiuli*	0.004	0.003	0.007	0.005
Outer	Scaridae	*Bolbometopon muricatum*	0.002	0.002	3.659	3.659
Outer	Scaridae	*Chlorurus bleekeri*	0.001	0.001	0.036	0.036
Outer	Scaridae	*Chlorurus sordidus*	0.016	0.008	1.360	0.666
Outer	Scaridae	*Scarus globiceps*	0.000	0.000	0.007	0.007
Outer	Scaridae	*Scarus* sp.	0.001	0.001	0.212	0.212
Outer	Serranidae	*Cephalopholis urodeta*	0.000	0.000	0.001	0.001
Outer	Serranidae	*Epinephelus merra*	0.000	0.000	0.038	0.038
Outer	Serranidae	*Epinephelus spilotoceps*	0.001	0.001	0.032	0.032

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 Laura and Majuro monitoring sites, 2011

Site	Station ID	Replicate	Start Longitude (E)	Start Latitude (N)
Laura	Manta 1	1	171.04365	7.16362
Laura	Manta 1	2	171.04462	7.16593
Laura	Manta 1	3	171.04490	7.16738
Laura	Manta 1	4	171.04527	7.16998
Laura	Manta 1	5	171.04745	7.17195
Laura	Manta 1	6	171.04642	7.17542
Laura	Manta 2	1	171.04963	7.18340
Laura	Manta 2	2	171.04965	7.18633
Laura	Manta 2	3	171.05022	7.18930
Laura	Manta 2	4	171.05085	7.19273
Laura	Manta 2	5	171.05140	7.19708
Laura	Manta 2	6	171.05233	7.19985
Laura	Manta 3	1	171.04987	7.13610
Laura	Manta 3	2	171.05055	7.13262
Laura	Manta 3	3	171.05178	7.12975
Laura	Manta 3	4	171.05368	7.12717
Laura	Manta 3	5	171.05617	7.12517
Laura	Manta 3	6	171.06017	7.12298
Laura	Manta 4	1	171.06242	7.12118
Laura	Manta 4	2	171.06522	7.11938
Laura	Manta 4	3	171.06762	7.11867
Laura	Manta 4	4	171.07012	7.11747
Laura	Manta 4	5	171.07253	7.11620
Laura	Manta 4	6	171.07467	7.11468
Laura	Manta 5	1	171.18233	7.07218
Laura	Manta 5	2	171.18582	7.07213
Laura	Manta 5	3	171.18877	7.07115
Laura	Manta 5	4	171.19188	7.07023
Laura	Manta 5	5	171.19535	7.06970
Laura	Manta 5	6	171.19855	7.06827
Laura	Manta 6	1	171.21008	7.06420
Laura	Manta 6	2	171.21243	7.06203
Laura	Manta 6	3	171.21572	7.06050
Laura	Manta 6	4	171.21892	7.05925
Laura	Manta 6	5	171.22285	7.05773
Laura	Manta 6	6	171.21008	7.06420
Laura	Manta 7	1	171.23708	7.05608
Laura	Manta 7	2	171.24043	7.05645
Laura	Manta 7	3	171.24393	7.05722

Site	Station ID	Replicate	Start Longitude (E)	Start Latitude (N)
Laura	Manta 7	4	171.24747	7.05823
Laura	Manta 7	5	171.25045	7.05992
Laura	Manta 7	6	171.25342	7.06128
Laura	Manta 8	1	171.25938	7.06228
Laura	Manta 8	2	171.26248	7.06415
Laura	Manta 8	3	171.26567	7.06537
Laura	Manta 8	4	171.26895	7.06640
Laura	Manta 8	5	171.27222	7.06707
Laura	Manta 8	6	171.27523	7.06783
Majuro	Manta 10	1	171.21455	7.15730
Majuro	Manta 10	2	171.21707	7.15683
Majuro	Manta 10	3	171.21950	7.15600
Majuro	Manta 10	4	171.22208	7.15515
Majuro	Manta 10	5	171.22495	7.15445
Majuro	Manta 10	6	171.22770	7.15437
Majuro	Manta 11	1	171.23017	7.15382
Majuro	Manta 11	2	171.23263	7.15245
Majuro	Manta 11	3	171.23505	7.15113
Majuro	Manta 11	4	171.23723	7.14945
Majuro	Manta 11	5	171.23953	7.14825
Majuro	Manta 11	6	171.24208	7.14805
Majuro	Manta 12	1	171.24430	7.14665
Majuro	Manta 12	2	171.24430	7.14665
Majuro	Manta 12	3	171.24430	7.14665
Majuro	Manta 12	4	171.24430	7.14665
Majuro	Manta 12	5	171.24430	7.14665
Majuro	Manta 12	6	171.24430	7.14665
Majuro	Manta 13	1	171.26480	7.14660
Majuro	Manta 13	2	171.26757	7.14690
Majuro	Manta 13	3	171.27020	7.14738
Majuro	Manta 13	4	171.27297	7.14767
Majuro	Manta 13	5	171.27572	7.14825
Majuro	Manta 13	6	171.27852	7.14805
Majuro	Manta 14	1	171.28137	7.14833
Majuro	Manta 14	2	171.28418	7.14762
Majuro	Manta 14	3	171.28618	7.14623
Majuro	Manta 14	4	171.28883	7.14497
Majuro	Manta 14	5	171.29073	7.14297
Majuro	Manta 14	6	171.29277	7.14157
Majuro	Manta 15	1	171.29533	7.13922
Majuro	Manta 15	2	171.29533	7.13922
Majuro	Manta 15	3	171.29998	7.13650

Site	Station ID	Replicate	Start Longitude (E)	Start Latitude (N)
Majuro	Manta 15	4	171.30202	7.13478
Majuro	Manta 15	5	171.30380	7.13250
Majuro	Manta 15	6	171.30638	7.13147

Appendix 11 GPS positions of reef-benthos transects conducted at Laura and Majuro, 2011

Site	Station ID	Longitude (E)	Latitude (N)
Laura	RBT 1	171.04203	7.15380
Laura	RBT 2	171.04507	7.16980
Laura	RBT 3	171.04908	7.18270
Laura	RBT 4	171.05118	7.19687
Laura	RBT 5	171.05022	7.13268
Majuro	RBT 7	171.30833	7.13108
Majuro	RBT 8	171.31283	7.12460
Majuro	RBT 9	171.31670	7.12018
Majuro	RBT 10	171.33310	7.11935
Majuro	RBT 11	171.34607	7.12178

Appendix 12 Mean scores (± SE) of each habitat category at the manta tow and reef-benthos transect (RBT) survey sites of Laura and Majuro, 2011.

Habitat category	Manta tow		RBT	
	Laura	Majuro	Laura	Majuro
Relief	2.73±0.20	2.14±0.14	2.47±0.20	2.70±0.28
Complexity	3.17±0.14	2.39±0.15	3.20±0.20	3.00±0.39
Oceanic influence	3.52±0.32	3.31±0.24	3.70±0.20	3.70±0.30
Mud	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Sand	21.98±7.48	84.72±1.78	16.50±3.57	18.17±5.40
Coarse sand	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Rubble	7.08±2.62	2.08±1.00	7.00±1.70	12.00±3.82
Boulders	4.38±2.13	3.47±0.73	3.17±0.81	2.83±2.10
Consolidated rubble	5.52±4.74	0.00±0.00	0.00±0.00	3.33±1.73
Pavement	0.31±0.22	0.00±0.00	2.17±1.62	0.67±0.49
Live coral	27.92±6.19	5.14±0.66	28.17±4.50	52.50±10.08
Dead coral	32.81±7.66	4.58±0.42	43.00±7.63	10.50±2.63
Bleached coral	0.00±0.00	0.00±0.00	0.00±0.00	0.70±0.40
Crustose coralline algae	0.31±0.22	0.00±0.00	3.17±0.76	3.50±1.50
Coralline algae	6.56±1.10	0.00±0.00	10.00±0.83	1.50±0.93
Other algae	2.71±1.11	0.00±0.00	2.67±1.07	7.00±2.00
Seagrass	0.00±0.00	0.00±0.00	0.00±0.00	0.17±0.17
Soft coral	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Sponge	0.13±0.10	0.00±0.00	0.00±0.00	0.00±0.00
Fungids	0.21±0.14	0.00±0.00	0.00±0.00	0.00±0.00
Epiphytes	2.60±0.31	2.03±0.15	2.13±0.43	1.40±0.11
Silt	1.56±0.20	1.00±0.00	1.44±0.25	0.93±0.36

Appendix 13 Mean density (± SE) of individual invertebrate species recorded during manta tow surveys within back-reef habitats of Laura and Majuro, 2011.

Family	Species	Density (individuals/ha)	
		Laura	Majuro
Sea cucumber	*Bohadschia argus*	2.08±1.36	-
	Holothuria atra	235.42±105.22	-
	Holothuria edulis	7.64±7.64	-
	Thelenota ananas	-	0.46±0.46
	Thelenota anax	0.69±0.69	122.22±32.79
Bivalve	*Atrina vexillum*	0.35±0.35	-
	Hippopus hippopus	1.04±0.73	-
	Pinctada margaritifera	0.69±0.45	-
	Tridacna maxima	1.74±1.17	-
Gastropod	*Cassis cornuta*	-	0.46±0.46
	Conus sp.	0.69±0.69	-
	Cypraea tigris	0.35±0.35	-
	Lambis lambis	0.69±0.45	-
	Lambis millepeda	0.35±0.35	-
	Tectus niloticus	3.82±0.90	-
Starfish	*Acanthaster planci*	0.35±0.35	-
	Culcita novaeguineae	1.04±0.75	-
	Linckia laevigata	0.69±0.69	-

Appendix 14 Mean density (± SE) of individual invertebrate species recorded during reef-benthos transects at Laura and Majuro, 2011.

Family	Species	Density (individuals/ha)	
		Laura	Majuro
Sea cucumber	*Bohadschia argus*	-	58.33±58.33
	Holothuria atra	608.33±424.84	-
	Synapta maculata	-	16.67±10.21
	Thelenota ananas	-	25.00±25.00
Bivalve	*Hippopus hippopus*	16.67±10.21	-
	Tridacna maxima	50.00±30.62	25.00±16.67
	Tridacna squamosa	16.67±10.21	-
Gastropod	*Cassis cornuta*	8.33±8.33	-
	Conomurex luhuanus	225.00±184.75	2800±1830.46
	Conus sp.	-	25.00±16.67
	Lambis lambis	-	8.33±8.33
	Lambis millepeda	25.00±16.67	-
	Murex sp.	25.00±16.67	-
	Tectus niloticus	58.33±40.82	25.00±25.00
Starfish	*Culcita novaeguineae*	16.67±10.21	-
	Linckia laevigata	16.67±10.21	8.33±8.33
Urchin	*Diadema savignyi*	-	33.33±24.30