Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change

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
CPUE	Catch-per-unit-effort
D-UVC	Distance-sampling underwater visual census
EEZ	Exclusive Economic Zone
g	gram(s)
GDP	Gross Domestic Product
GPS	Global Positioning System
GR	Government Revenue
ha	hectare
ICCAI	International Climate Change Adaptation Initiative (Australia)
IPCC	Intergovernmental Panel on Climate Change
IRD	Institut de Recherche pour le Développement
m	metre(s)
mm	millimetre(s)
MCRMP	Millennium Coral Reef Mapping Project
MICS	Marshall Islands Conservation Society
MIMRA	Marshall Islands Marine Resource Authority
MPA	Marine Protected Area
n	number (sample size)
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
SD	Standard deviation
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, the Secretariat of the Pacific Community (SPC) is implementing the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project with funding assistance from the Australian Government's International Climate Change Adaptation Initiative (ICCAI). This project aims to assist Pacific Island Countries and Territories (PICTs) to determine whether changes are occurring in the productivity of coastal fisheries and, if changes are found, to identify the extent to which such changes are due to climate change, as opposed to other causative factors. This report presents the results of first re-survey for the project conducted in Majuro Atoll, Republic of the Marshall Islands (RMI), in July and August, 2013. Results are compared against those from the baseline survey of Majuro Atoll conducted in 2011.

Survey Design

Survey work at Majuro Atoll covered six disciplines, including monitoring of water temperature, assessments of finfish and invertebrate resources and benthic habitats, creel surveys and biological monitoring of key reef fishes, and was conducted by staff from SPC's Coastal Fisheries Science and Management Section and the Marshall Islands Marine Resource Authority (MIMRA). The fieldwork included capacity development of local counterparts by providing training in survey design and methodologies, data collection and entry, and data analysis.

Benthic Habitat Assessments

Benthic habitats of Majuro Atoll were surveyed using two complementary approaches: a broad-scale method, using manta tows, and a fine-scale method, using a photoquadrat analysis. Manta tows were conducted at three sites: Ajeltake, Laura and Majuro. A slight increase in live coral was evident at the Majuro site, while a coral algae regime shift was evident from 2011 to 2013 at the Laura and Ajeltake sites, with the cover of algae exceeding that of live coral.

Fine-scale assessments of benthic habitats were conducted at five sites, including three regions open to fishing (Laura 1, Laura 2 and Majuro sites), and two areas closed to fishing (Drenmeo MPA and Woja MPA). Between 6 and 12 fifty metre transects were established at each site, with transects covering back, lagoon and outer reef habitats. Approximately 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 point-count software. In contrast to the broadscale results, few differences were observed in benthic habitat composition at the study sites.

Finfish Surveys

Finfish resources and their supporting habitats of Majuro Atoll were surveyed using distance-sampling underwater visual census (D-UVC) methodology, conducted at the same sites as the benthic habitat assessments. The following key observations were made:

- Finfish diversity was found to be consistently higher in 2013 compared to 2011 for most stations and habitats. It is unclear whether these changes are a result of different surveyor skill or experience levels or whether they represent 'real' changes in finfish populations.
- In terms of density, few statistically significant differences were evident among the 2011 and 2013 surveys at each site. Differences that were observed showed little consistency among groups, sites or habitats. Accordingly, it is likely that these differences represent natural variations in finfish density, rather than being indicative of long-terms trends. Further monitoring at the established sites is warranted to accurately define long-term trends in finfish density.
- Few differences were observed in both density and biomass of fish within protected areas relative to comparably-situated areas open to fishing. This finding suggests that under their current design the MPAs are ineffective in protecting fish populations and should be re-designed. That the MPAs were found to have a significant positive effect on the density of several invertebrate species (see below) suggests that while they may be effective in prohibiting fishing and protecting site-attached species within their boundaries, they are likely too small to protect more mobile organisms such as fishes.

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).

Manta tow assessments were conducted along the Laura, Majuro and Ajeltake regions of Majuro Atoll. In general, densities of invertebrates observed during manta tows were low during all surveys, with only *H. atra* observed in densities greater than 150 individuals/ha. The following differences were observed amongst surveys:

- Densities of the sea cucumber *Thelenota anax* at the Majuro site appeared significantly lower in the 2013 survey than in 2011;
- Densities of the giant clam *Tridacna maxima* at the Laura site appeared significantly lower in 2013 relative to the PROCFish surveys of the region in 2007;
- Densities of the giant clam *Tridacna squamosa* at the Laura site appeared significantly lower in both 2011 and 2013 relative to the PROCFish surveys in 2007.

Reef-benthos transects (RBt) were used to assess invertebrate resources at finer-spatial scales. Eighteen RBt monitoring stations (6 x 40 m replicates) were established around Majuro Atoll, with 6 stations in each of the Laura and Majuro sites, and three stations in each of the Drenmeo MPA and Woja MPA sites.

Invertebrate diversity at RBt stations was higher in 2013 than 2011 for all monitoring sites. In terms of mean densities, the following differences were observed amongst surveys:

- Densities of the sea cucumber *Bohadschia argus* at the Drenmeo MPA site appeared significantly lower in the 2013 survey than in 2011;

- Densities of the sea cucumber *Holothuria atra* were significantly higher within the Woja MPA site than all other sites;
- Densities of the gastropod genus *Turbo* were significantly higher within the Woja MPA site than stations completed within the Laura site in both 2011 and 2013.

Futher monitoring is warranted to assess changes in invertebrate populations over time.

Creel surveys

Five surveys where bottom fishing was the main fishing activity were completed. On average, bottom fishing trips involved 3.4 fishers and lasted on average 6.8 hours. The average catch per trip was 29.18 kg, or 51.2 individual fish. Catch-per-unit effort 2.24 fish/fisher/hour, or 1.27 kg/fisher/hour. Bottom fishing took place mainly in the main pass near Irooj Islet, around the back and patch reefs near Rongrong Islet and along the back reefs of Woja. The catch was dominated by the families Serranidae, Lethrinidae and Lutjanidae. A total of 247 individual fishes representing 20 species were observed in the handline catch, the most common of which were *Epinephelus polyphekadion* (representing 51% of total catch by number and 47% of the total catch by weight), *Epinephelus maculatus* (9% of total catch by number and 14% of the total catch by weight), *Lutjanus gibbus* (9% of total catch by number and 5% of the total catch by weight) and *Lethrinus erythropterus* (6% of the total catch by both number and weight).

Eight surveys where spearfishing was the main fishing activity were completed. On average, spearfishing trips involved 5.1 fishers, with a mean duration of 5.1 hours. On average, spearfishing trips involved 5.1 fishers and lasted a mean duration of 4.4 hours. The average catch was 55.86 kg, or 186.1 individual fish per trip. Catch-per-unit effort was 8.73 fish/fisher/hour, or 2.59 kg/fisher/hour. As with handlining, fishing was mainly conducted around the main pass near Irooj Islet, the back and patch reefs of the north-west of the atoll near Rongrong Islet and along the back reefs of Woja and Ajeltake. A total of 1498 individual fishes from 62 species and 14 families were observed in the spearfishing catch, with members of the Acanthuridae, Siganidae, Holocentridae and Serranidae dominating the total catch by both abundance and weight. The most common finfish species caught were *Siganus argenteus* (representing 24% of total catch by abundance and 17% by weight), *Acanthurus lineatus* (18% of total catch by abundance and 11% by weight), *Naso lituratus* (7% of the total catch by both abundance and weight) and *Myripristis berndti* (5% of total catch by abundance and 3% by weight).

During the creel surveys perception data were collected from lead fishers. The majority of fishers surveyed indicated that they had seen changes in the fishery in the last few years, with 67% of all respondents stating they considered their catches had decreased compared to five years ago, and 83% of all respondents stating the sizes of fish had decrease compared to five years ago.

Biological monitoring of key reef species

Biological monitoring of key reef fish species at Majuro Atoll was included for the first time during the 2013 survey, and focused on two commercially harvested species: humpback red snapper (*Lutjanus gibbus*) and orangespine unicornfish (*Naso lituratus*) and two ‘control’ species: redfin butterflyfish (*Chaetodon lunulatus*) and striated surgeonfish (*Ctenochaetus striatus*). Demographic parameters, including von Bertalanffy growth function parameters and total, natural and fishing mortality rates were determined for each species to provide a baseline for Majuro Atoll. Fishing mortality of the two commercially harvested species was slightly below the recommended maximum rate of fishing mortality (F_{opt}) indicating that these species are fished near their optimum levels.

Management recommendations for improving the resilience of coastal fisheries of Majuro Atoll

Monitoring potential effects of chronic disturbances such as climate change is a challenging prospect that requires the generation of an extensive time series of data and regional cooperation and comparison amongst standardised datasets and indicators. Nevertheless, several key management recommendations, outlined below, are prescribed from the current study that will help improve the resilience of the coastal fisheries of Majuro Atoll to both long-term (e.g. climate change) and short-term (e.g. overfishing) stressors:.

1. Expand the network of locally managed Marine Protected Areas;
2. Place restrictions on destructive or highly efficient fishing practices, in particular night-time spearfishing;
3. Assess and monitor grouper catches;
4. Protect sharks and other ecologically-significant species;
5. Maintain the national closure of sea cucumber fisheries;
6. Develop and implement coastal fisheries management plan / regulations;
7. Dissemination of relevant scientific knowledge to key stakeholders and the general public.

1. Introduction

Project Background

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

The purpose of this project is to assist PICTs to:

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

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

   i. Determine whether changes to the productivity of coastal fisheries are occurring, and identify the extent to which such changes could be due to climate change, 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 change are occurring to 'ground truth' projections; and

   iii. Assess the effects of adaptive management to maintain the productivity and increase resilience of coastal fisheries to external stressors.

The Approach

Monitoring impacts of climate change on coastal fisheries is a complex challenge. To facilitate this task, a set of monitoring methods was selected from the SPC expert workshop 'Vulnerability and Adaptation of Coastal Fisheries to Climate Change: Monitoring Indicators and Survey Design for Implementation in the Pacific' (Noumea, 19th–22nd April 2010) of scientists and representatives of many PICTs. These methods include monitoring of water temperature using temperature loggers, finfish and invertebrate resources, benthic habitats, catch and fishing patterns and biological monitoring of key reef finfish species (Table 1). In parallel, SPC is currently implementing database backend and software to facilitate data entry, analysis and sharing between national stakeholders and the scientific community as well as providing long-term storage of monitoring data.

Five pilot sites were selected for monitoring: 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), requests from countries, as well as their geographical location.

This report presents the results of the second round of field surveys for the project conducted in Majuro Atoll, Republic of the Marshall Islands (RMI), in July-August 2013, by a team from SPC's Coastal Fisheries Science and Management Section and staff from Marshall Islands Marine Resource Authority (MIMRA). Collected data are compared agints those of the baseline survey at Majuro conducted in 2011 (Moore et al. 2012). Recommendations for management and future monitoring events are also provided.

Table 1 Summary of activities and variables measured during the monitoring program in Majuro Atoll, Republic of the Marshall Islands, 2013.

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

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 the 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 of the 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).

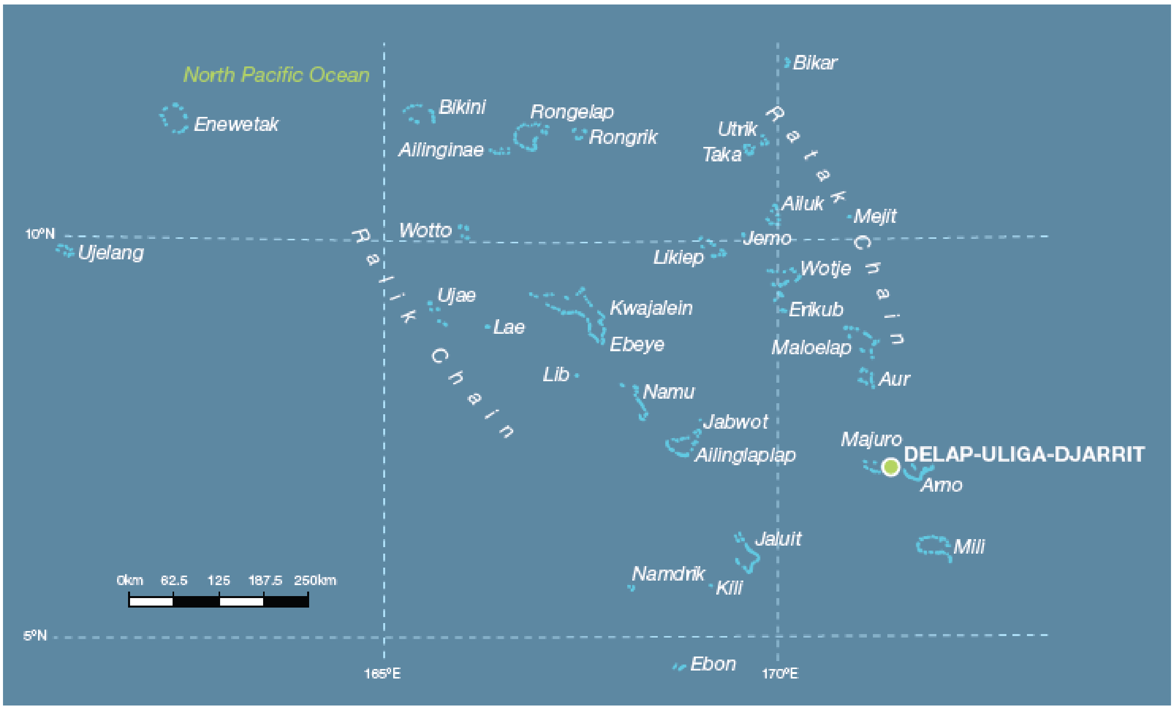


Figure 1 Republic of the Marshall Islands (from PCCSP 2011).

Fisheries

National Oceanic Fisheries

The 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 the RMI. The 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).

National Coastal Fisheries

The coastal fisheries of the 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 2). The commercial component of this catch was an estimated 950 tonnes, while the subsistence catch was 2,800 tonnes (Gillet 2009) (Table 2). Approximately 64% of the total catch is estimated to be made up of demersal fish (Bell et al. 2011) (Table 3).

Table 2 Annual fisheries and aquaculture harvest in the RMI, 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. Nationally, fresh fish consumption averages well in excess of the regional average of 35 kg per person per year (Pinca et al. 2009). Coastal fish species are harvested by a variety of methods, including netting, handlining, trolling and spearfishing. 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 reef and lagoon-associated species. MIMRA continues to provide the transport vessels to collect fish from the rural fish bases, with fish either landed in Majuro or Ebeye for marketing (Chapman 2004b).

Table 3 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 the 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 RMI 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 RMI (PCCSP 2011) (Table 4).

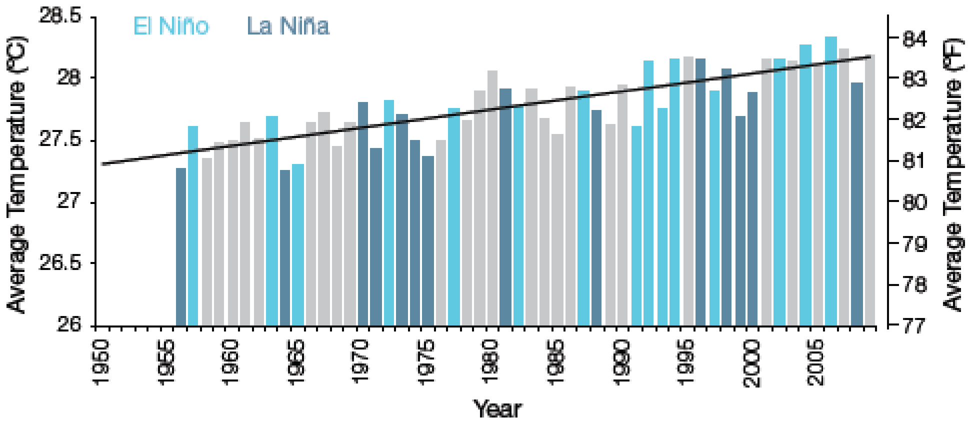


Figure 2 Mean annual air temperature at Majuro (1956–2009) (from PCCSP 2011).

Table 4 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 RMI 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 RMI (PCCSP 2011) (Table 5).

Table 5 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 (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 the 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 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 RMI, resulting in declines in the quality and area of all habitats (Table 6). Accordingly, all coastal fisheries categories in the 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 7) (Bell et al. 2011).

Table 6 Projected changes in coastal fish habitat in the 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 7 Projected changes to coastal fisheries production in the 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. Implementation of the Project in the Republic of the Marshall Islands

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 the 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;

- Majuro Atoll contains a number of marine protected areas (MPAs) (such as the Woja MPA and the Drenmeo MPA), which allow for decoupling of the effects of over-fishing against other factors (i.e. climate change);

- 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 (Figure 3). Majuro Atoll consists of approximately 9.7 km^2 of land area and encloses a lagoon of approximately 295 km^2. 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).

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 per person per year, more than double the regional average of approximately 35 kg per person per year (Pinca et al. 2009). Consumption of invertebrates (edible meat weight only) was approximately 5 kg per person per 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).

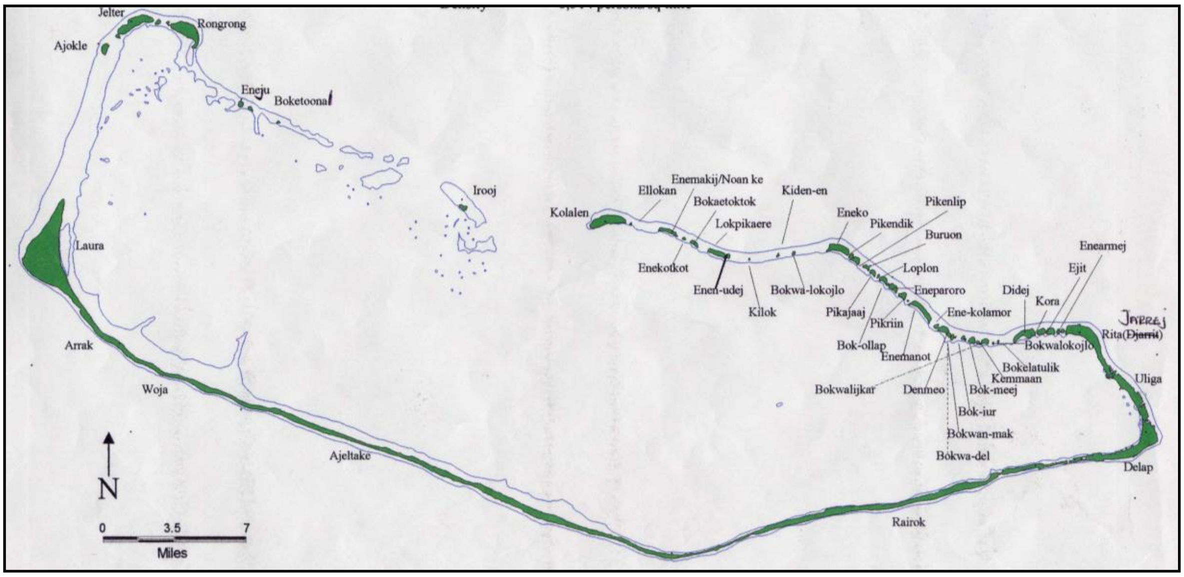


Figure 3 Majuro Atoll.

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, four 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) reef flat: top of barrier reef between the reef crest and back-reef slope;
3) back-reef: inner/lagoon side of outer reef/main reef body; and
4) outer-reef: ocean-side of fringing or barrier reefs.

A Comparative Approach Only

The collected data form part of a time-series to examine temporal changes in coastal habitat and fishery resources. It should be stressed that due to the comparative design of the project, the methodologies used, and the number of sites and habitats examined, the data provided in this report should only be used in a comparative manner to explore differences in coastal fisheries productivity over time. In general, these data should not be considered as indicative of the actual available fisheries resources.

3. Monitoring of Water Temperature

Methodologies

To monitor sea surface temperatures at a local scale, two RBR TR1060 temperature loggers were deployed in May 2011 on the western side of Majuro Atoll, with one established inside the lagoon and one on the outer reef. The loggers were calibrated to an accuracy of ±0.002ºC and programmed to record temperature every five minutes. Loggers were housed in a PVC tube with holes to allow flow of water and encased in a concrete block (Figure 4). These blocks were then secured to the sea floor using rebars. Due to obvious battery life flaws in the RBR TR1060 loggers, a third logger (Sea-Bird SBE 56) was installed in the lagoon in August 2012, using the same housing system (Table 8). This logger was retrieved, and a second Sea-Bird SBE 56 was deployed, in July 2013.

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

Table 8 Details of sea surface temperature loggers deployed at Majuro Atoll.

Details	Majuro 1	Majuro 2	Majuro 3
Deployment date	17/05/2011	17/05/2011	27/8/2012
Logger type	RBR TR1060	RBR TR1060	Seabird SBE 56
Location	Laura, Majuro Atoll	Laura, Majuro Atoll	Laura, Majuro Atoll
Habitat	Lagoon	Outer	Lagoon
Longitude	171.054299E	171.045127E	171.045127E
Latitude	7.192523N	7.198610N	7.198610N
Depth	10 m	19 m	10 m
Status	Removed	Removed	Active

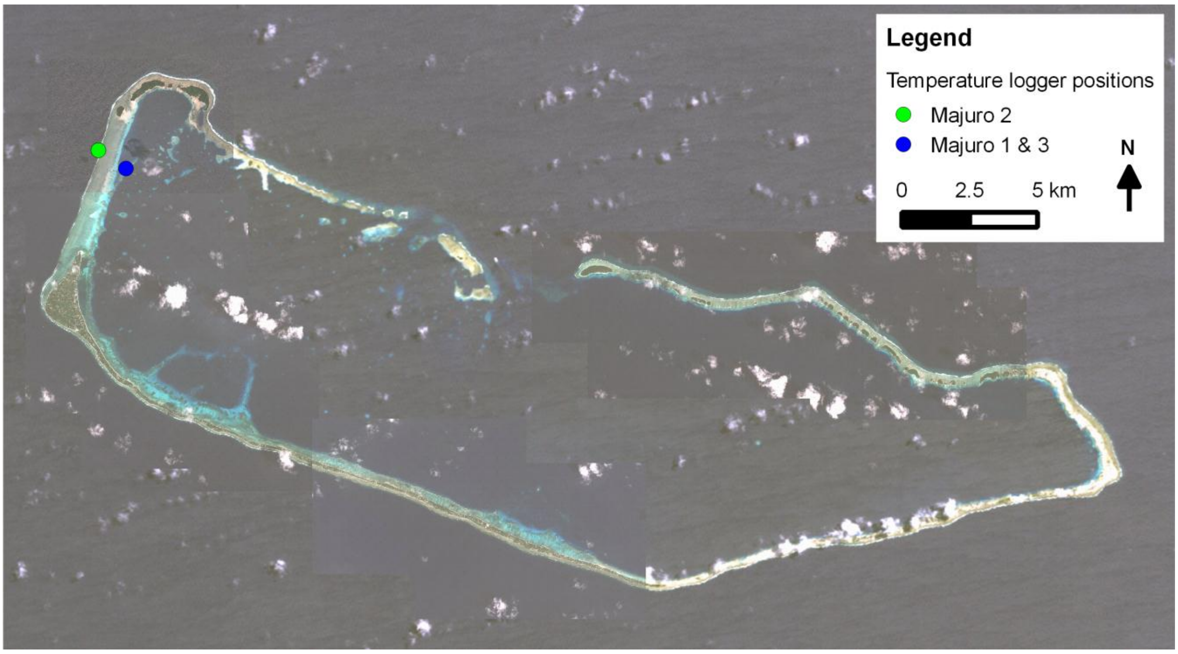


Figure 5 Location of water temperature loggers deployed in Majuro Atoll.

Results

Both RBR TR1060 loggers collected temperature data for approximately 4 months before failing (Figure 6). These loggers have subsequently been removed.

The Seabird SBE 56 collected water temperature data within the lagoon continuously from its deployment in August 2012 to its retrieval in July 2013. A maximum average daily water temperature of 30.04°C was observed in August 2012, while a minimum average daily temperature of 27.73°C was observed in February 2013 (Figure 6). The maximum recorded temperature was 30.31°C, reached in September 2012, while the minimum recorded temperature was 27.40°C, reached in February 2012. This logger will be continuously retrieved and re-deployed to maintain water temperature monitoring within the atoll.

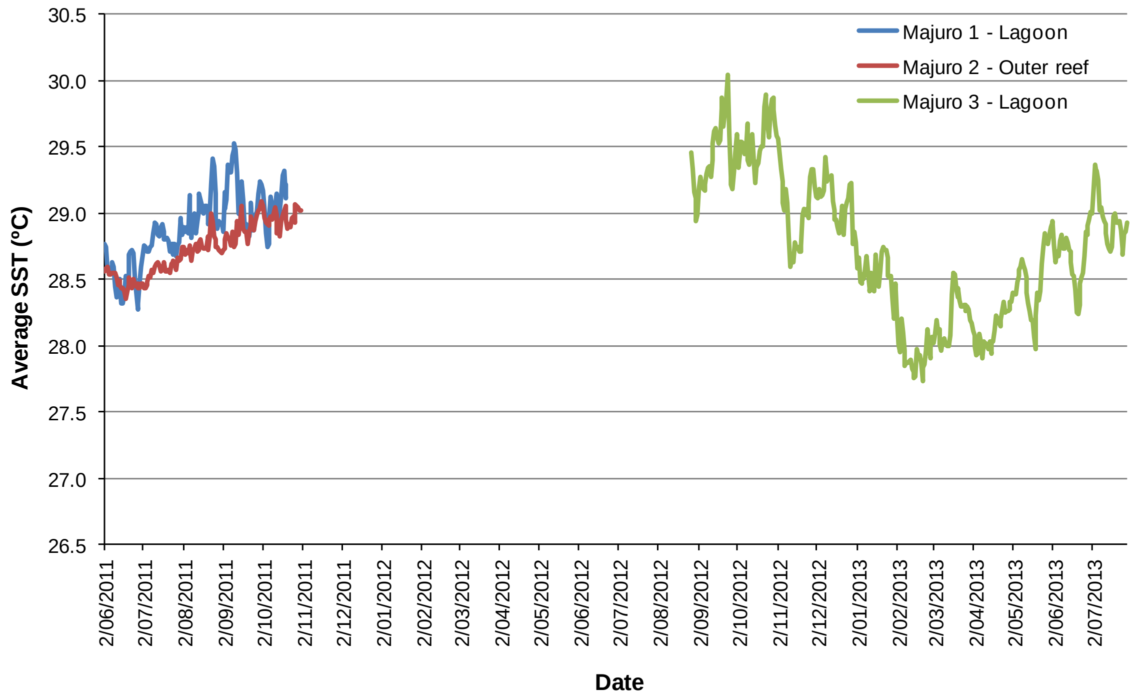


Figure 6 Mean sea surface temperate (SST) recorded at Majuro Atoll, 2nd June 2011 to 29th July 2013.

4. Finfish Assessments

Methodologies

Data collection

Fish on reef habitats were surveyed using distance-sampling underwater visual census (D-UVC) methodology. Finfish assessments were conducted at five sites around Majuro Atoll: Drenmeo MPA, Laura 1, Laura 2, Majuro and Woja MPA (Figure 7). Within each site, finfish assessments typically focused on up to four habitats (reef flat, back reef, lagoon reefs and outer reefs) (where present), with up to three replicate 50 m transects surveyed in each habitat at each of the five sites. Individual transects were situated parallel to the reef crest and were directed towards the next consecutive transects. Each transect 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 8). Two distance measurements were recorded for a school of fish belonging to the same species and size (D1 and D2; Figure 8), while for individual fish only one distance was recorded (D1). Effort was made to ensure that the survey took place under the same tidal state and moon phase as the baseline survey. Regular review of identification books and cross-checks between divers after the dive ensured that accurate and consistent data were collected. Following collection, all data were reviewed. Data considered unreliable were removed from the dataset prior to analysis.

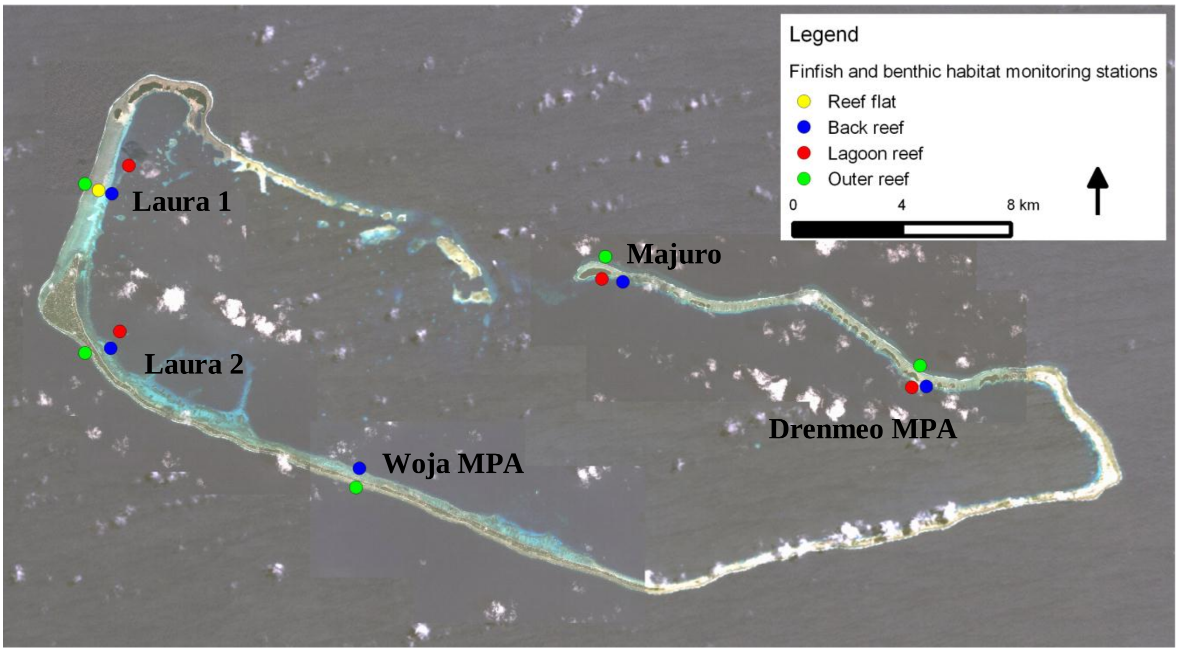


Figure 7 Location of finfish and fine-scale benthic habitat monitoring sites at Majuro Atoll.

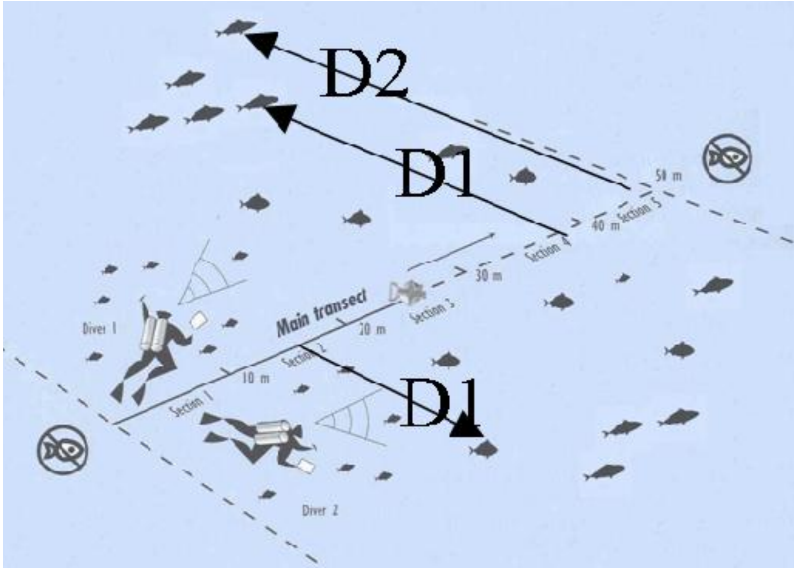


Figure 8 Diagram portraying the D-UVC method.

Habitats supporting finfish

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

The substrate types were grouped into the following six categories:

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

Data processing and analysis

Finfish surveys

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

1) richness – the number of families, genera and species counted in D-UVC transects;
2) diversity – mean number of species observed per transect (± SE);
3) mean density (fish/m^2) and mean biomass (g/m^2)– estimated from fish abundance in D-UVC, calculated at a total, functional group, family and individual species level.

Assignment of functional groups

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

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

Summary graphs of mean density and mean biomass (± SE) for each site were generated to further explore patterns in total mean density and mean density of the 18 indicator families and eight functional groups by habitat and survey year. To further explore patterns among surveys, total, family-specific and functional group-specific density data for each individual transect were ln(x+1) transformed to reduce heterogeneity of variances and analysed by a two-way analysis of variance (ANOVA), with survey year (2011 and 2013) and site 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 = 0.025 was used. Biomass data were not compared amongst surveys as the 2011 size estimation data was considered unreliable for biomass calculations. Rather, biomass data from the 2013 surveys were compared amongst sites within habitats using one-way ANOVA. This design allowed for a comparison of each site over time (for density data), and an assessment of the performance of the individual protected areas vs. comparably-situated sites that are open to fishing (i.e. Drenmeo MPA vs. Majuro 'open' sites, Woja MPA vs. Laura 2 'open' sites) (for both density and biomass data). Due to obvious differences in surrounding land use, oceanic influence and tidal flushing among both open to fishing sites and MPA sites, no attempt was made to pool individual sites into broader groups (e.g. 'open' vs. 'closed') in the analyses.

Site results

Drenmeo MPA

Finfish assessments within the Drenmeo MPA in both 2011 and 2013 covered three habitats, with three 50 m transects completed in each habitat (Table 9; Figure 9).

Table 9 Details of finfish monitoring transects within the Drenmeo MPA monitoring site.

Habitat and transect	Latitude (N)	Longitude (E)	Years monitored
Back reef			
T10	7.120633	171.320583	2011, 2013
T11	7.120800	171.321383	2011, 2013
T12	7.120867	171.322117	2011, 2013
Lagoon reef			
T4	7.121267	171.316483	2011, 2013
T5	7.120517	171.316583	2011, 2013
T6	7.120233	171.317450	2011, 2013
Outer reef			
T31	7.126917	171.320333	2011, 2013
T32	7.127683	171.319333	2011, 2013
T33	7.128483	171.318250	2011, 2013

Finfish diversity within the Drenmeo MPA was considerably higher during the 2013 survey relative to 2011 for all three habitats examined (Table 10). In terms of functional groups, browsers were absent from back reef transects, and corallivores were absent from outer reef transects in 2011. In 2013 all habitats showed high functional group diversity, with all functional groups represented (Table 10).

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

Parameter	Back-reef		Lagoon-reef		Outer-reef	
	2011	2013	2011	2013	2011	2013
No. of families	12	20	14	17	10	19
No. of genera	25	45	35	53	28	47
No. of species	40	85	62	116	50	89
Diversity	21±5	46±14	33±8	64±7	27±6	51±5
Functional groups	7/8	8/8	8/8	8/8	7/8	8/8

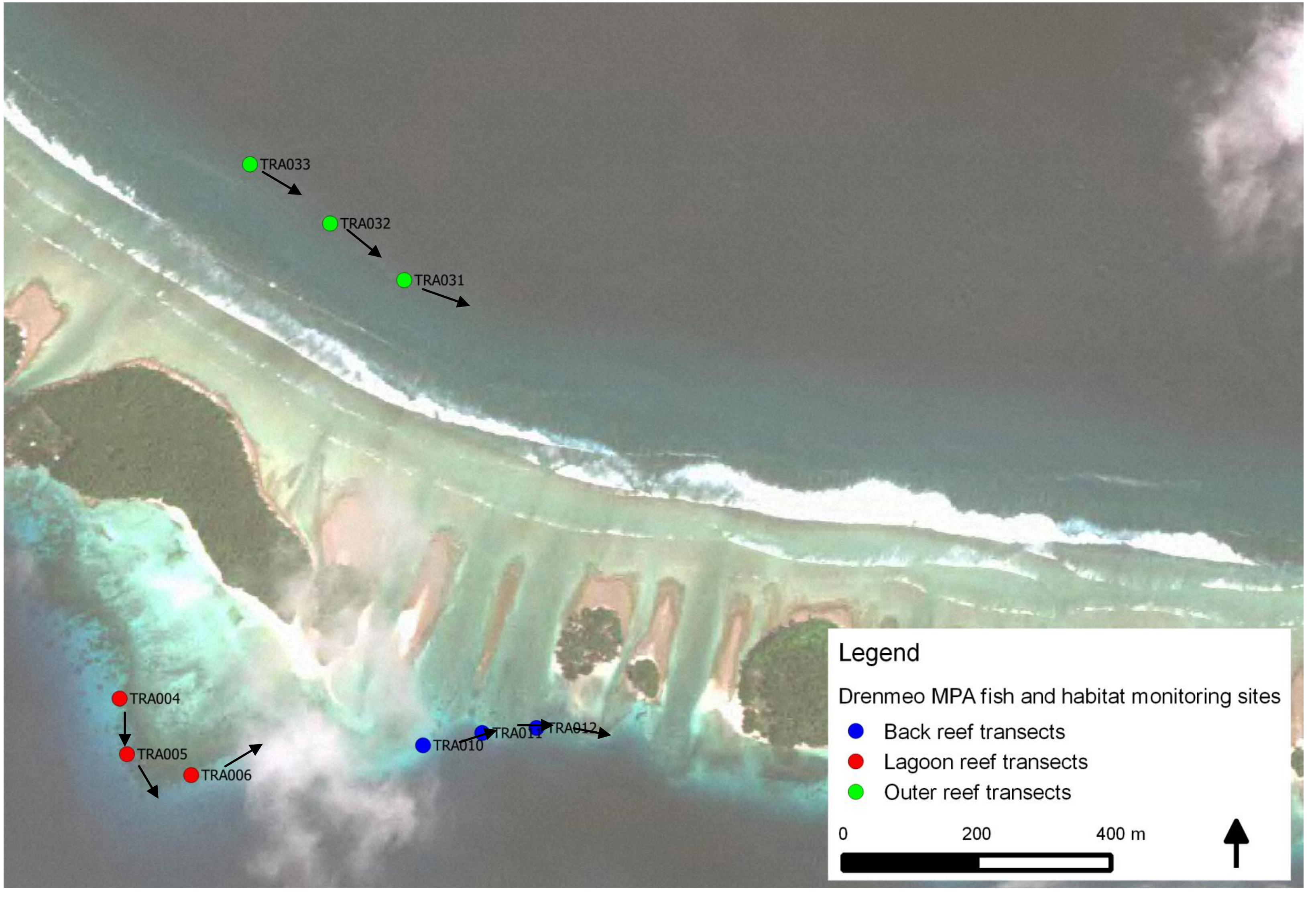


Figure 9 Location of finfish and fine-scale benthic habitat monitoring transects within the Drenmeo MPA monitoring site. Black arrows (not to scale) indicate the approximate direction of transects.

No significant differences in mean total density were observed among surveys for any habitat within the Drenmeo MPA monitoring site (Figure 10). Similarly, no significant differences were observed in densities of the 18 selected families or eight functional groups among sites and surveys for any of the three habitats at P = 0.05 (Figure 11). While mean densities of Labridae and the functional group micro-carnivores on the outer reef appeared lower in 2013 relative to 2011 (Figure 10), these differences were not statistically significant.

When compared against the Majuro site (open to fishing), no significant differences were observed in mean total density or biomass or the density and biomass of the selected indicator families or key functional group at any habitat (data not presented for purposes of brevity).

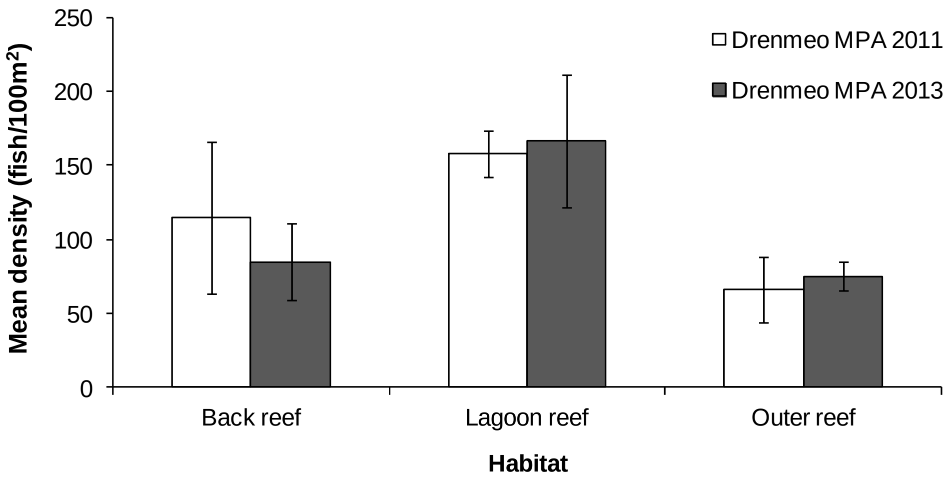


Figure 10 Mean total density of finfish (± SE) among survey years and habitats at the Drenmeo MPA monitoring site.

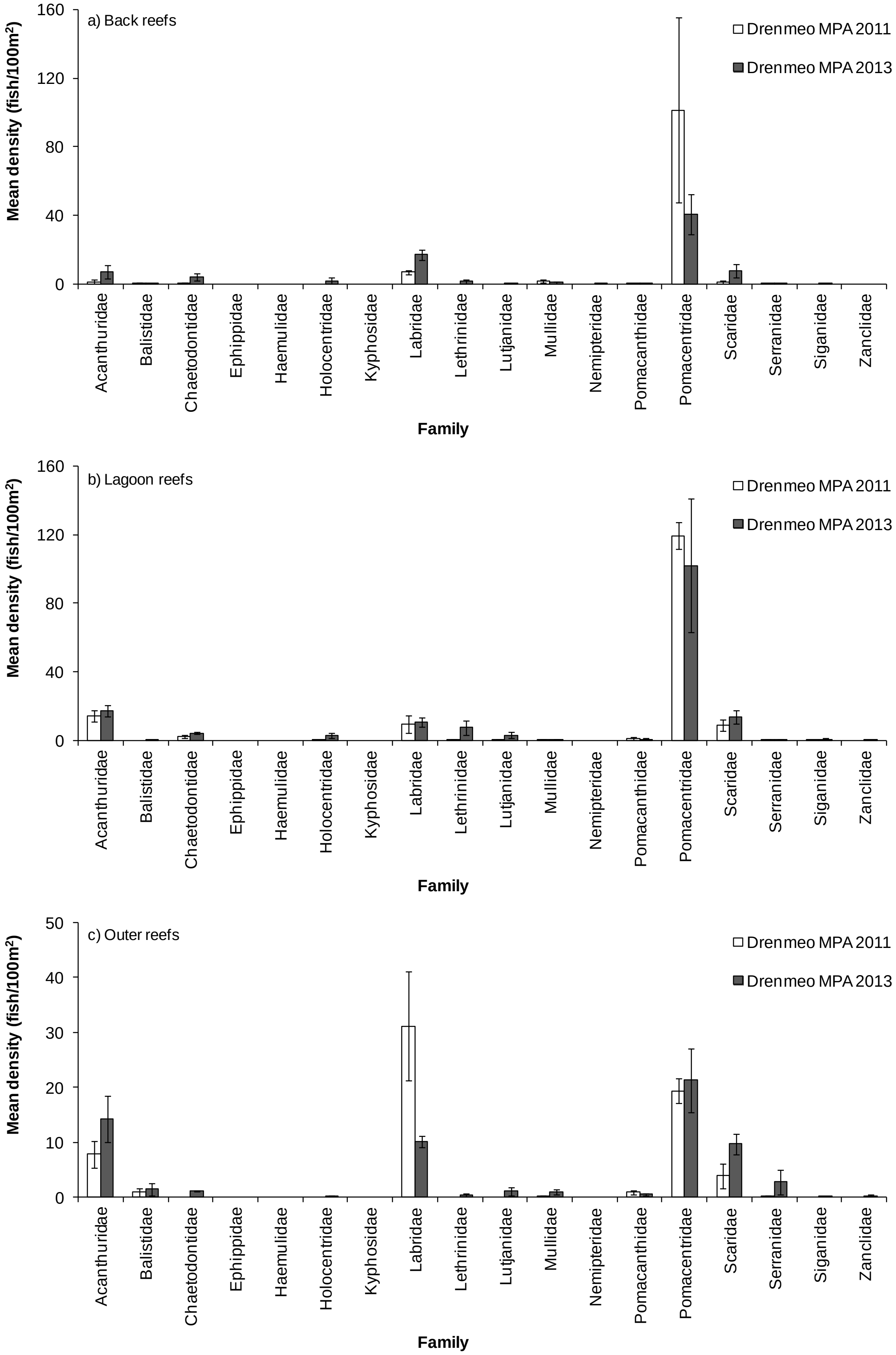


Figure 11 Mean density (± SE) of common finfish families among a) back reef, b) lagoon reef and c) outer reef habitats of the Drenmeo MPA monitoring site during the 2011 and 2013 surveys.

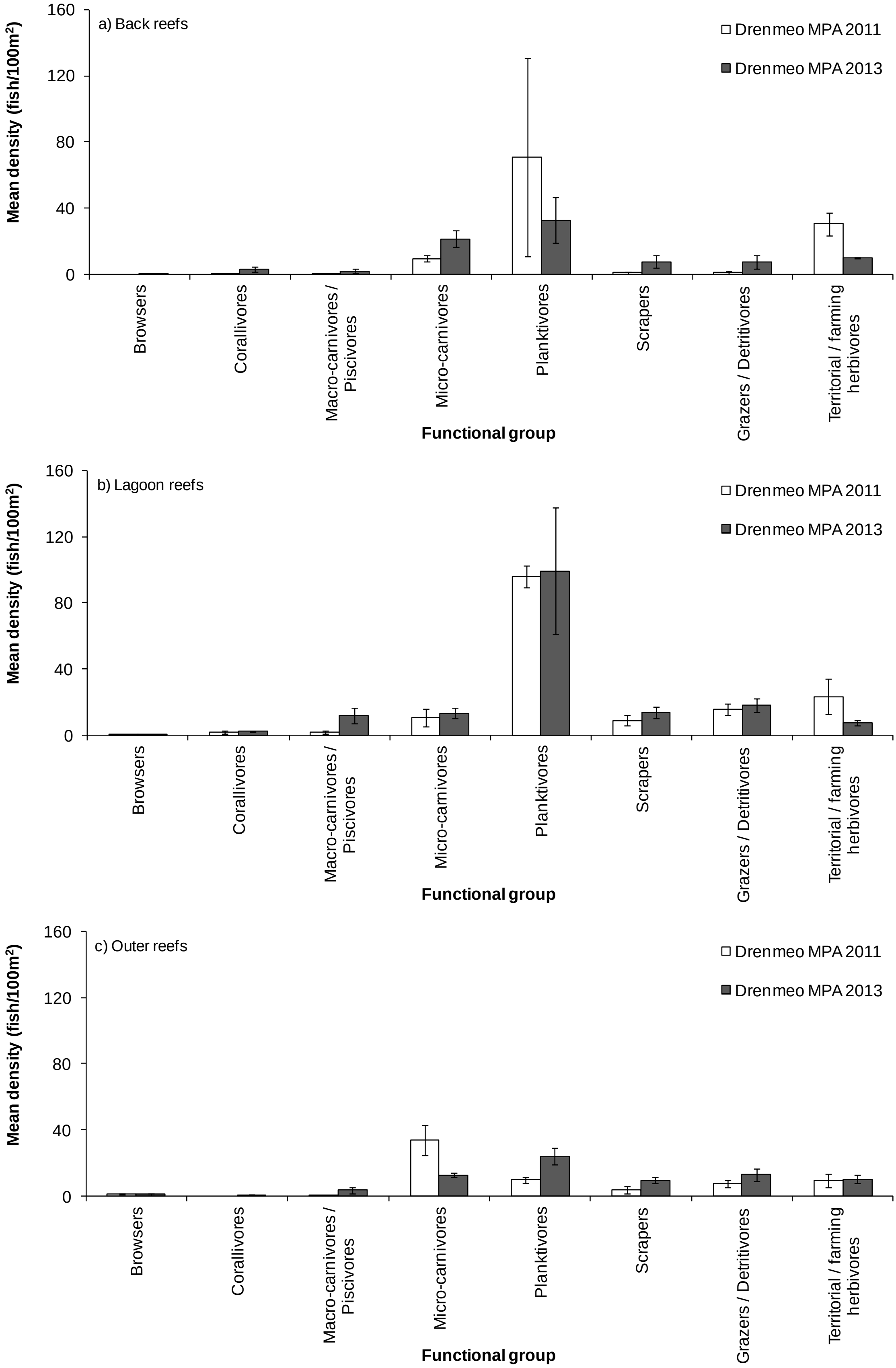


Figure 12 Mean densities (± SE) of key functional groups among a) back reef, b) lagoon reef and c) outer reef habitats of the Drenmeo MPA monitoring site during the 2011 and 2013 surveys.

Laura 1

Finfish assemblages of the Laura 1 site have been monitored at four habitats during the project (Table 11; Figure 13). Reef flat, lagoon reef and outer reef habitats were surveyed in both 2011 and 2013, while the finfish assemblages of back reef habitats were surveyed for the first time in 2013 (Table 11).

Table 11 Details of finfish monitoring transects within the Laura 1 monitoring site.

Habitat and transect	Latitude (N)	Longitude (E)	Years monitored
Reef flat			
T25	7.186417	171.046800	2011, 2013
T26	7.186033	171.046150	2013
T27	7.184917	171.046150	2011, 2013
Back reef			
T43	7.184933	171.050417	2013
T44	7.183833	171.050067	2013
T45	7.183133	171.049567	2013
Lagoon reef			
T13	7.194767	171.057183	2011, 2013
T14	7.194283	171.056067	2011, 2013
T15	7.193183	171.055233	2011, 2013
Outer reef			
T19	7.190083	171.042333	2011, 2013
T20	7.188200	171.041483	2011, 2013
T21	7.187050	171.041067	2011, 2013

Finfish diversity within the Laura 1 monitoring site was considerably higher during the 2013 survey relative to 2011 for all habitats examined (Table 12). Relative to other habitats, transects on the reef flat had low functional groups diversity, with corallivores and macro-carnivores/piscivores absent in 2011 and browsers absent in 2013. Browsers were absent on the lagoon reef in 2011. In 2013, all functional groups were represented on the back, lagoon and outer reef habitats (Table 12).

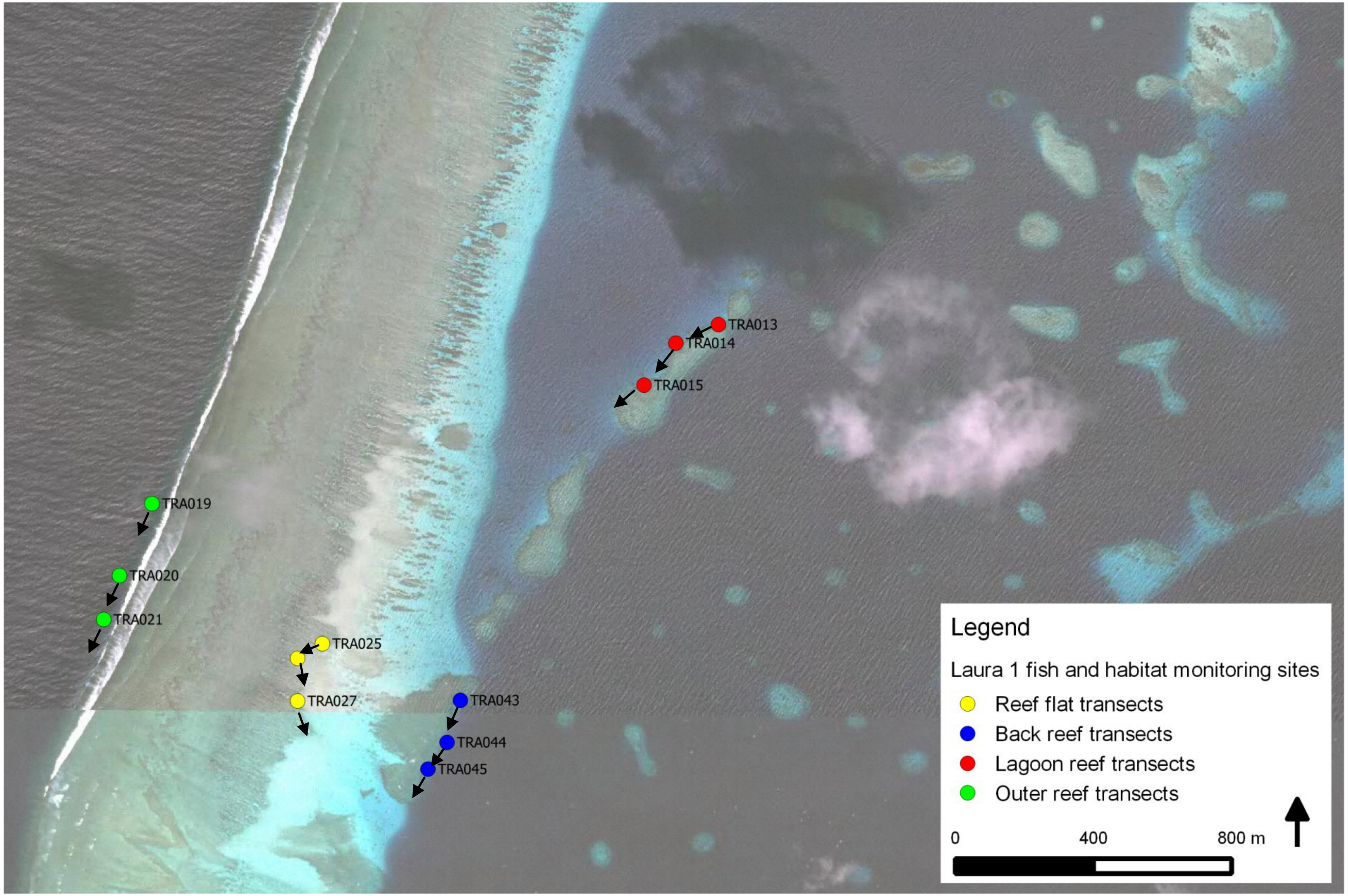


Figure 13 Location of finfish and fine-scale benthic habitat monitoring transects within the Laura 1 monitoring site. Black arrows (not to scale) indicate the approximate direction of transects.

Table 12 Total number of families, genera and species, and diversity of finfish observed at reef flat, back, lagoon and outer reef habitats of the Laura 1 monitoring site, 2011 & 2013.

Parameter	Reef-flat		Back-reef		Lagoon-reef		Outer-reef	
	2011	2013	2011	2013	2011	2013	2011	2013
No. of families	8	13	-	19	10	19	16	22
No. of genera	21	27	-	52	28	42	46	60
No. of species	34	43	-	111	54	93	94	117
Diversity	25±5	27±2	-	68±5	26±3	54±1	50±13	70±5
Functional groups	6/8	7/8	-	8/8	7/8	8/8	8/8	8/8

No significant differences in mean total density were apparent among surveys for any of the habitats examined within the Laura 1 monitoring site (Figure 14). Mean densities of Zanclidae on the lagoon reef transects were slightly (yet significantly) higher in 2013 than 2011 (P = 0.027) (Figure 15). On the outer reef, mean densities of Lutjanidae were higher in 2013 relative to 2011 (P = 0.011), while mean densities of Holocentridae were lower (P = 0.005). Mean densities of Serranidae on the outer reef appeared lower in 2013 relative to 2011 (Figure 15), mainly resulting from decreases in densities of *Pseudanthias bartlettorum*, *P. dispar* and *P. pascalus*, however, these declines were not statistically significant.

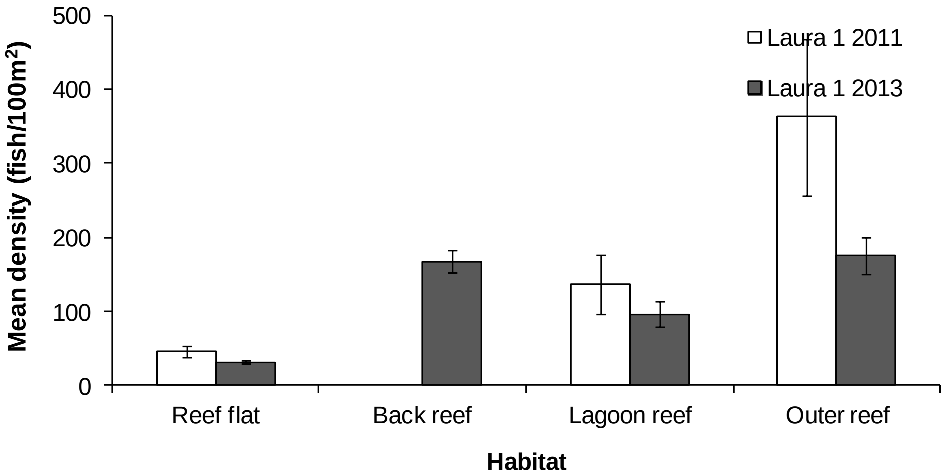


Figure 14 Mean total density of finfish (± SE) among survey years and habitats at the Laura 1 monitoring site.

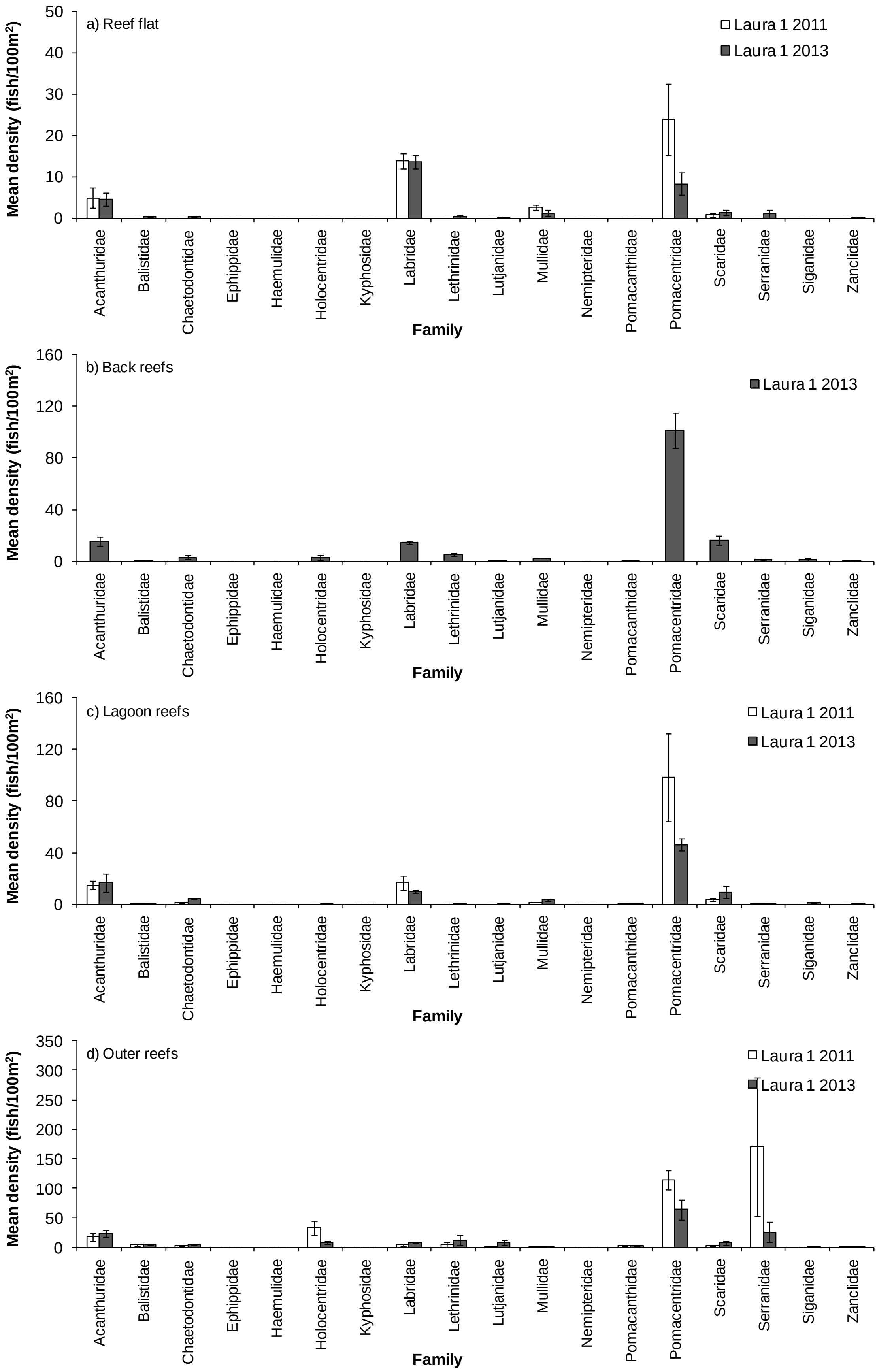


Figure 15 Mean densities (± SE) of common finfish families among a) reef flat, b) back reef, c) lagoon reef and d) outer reef habitats of the Laura 1 monitoring site during the 2011 and 2013 surveys.

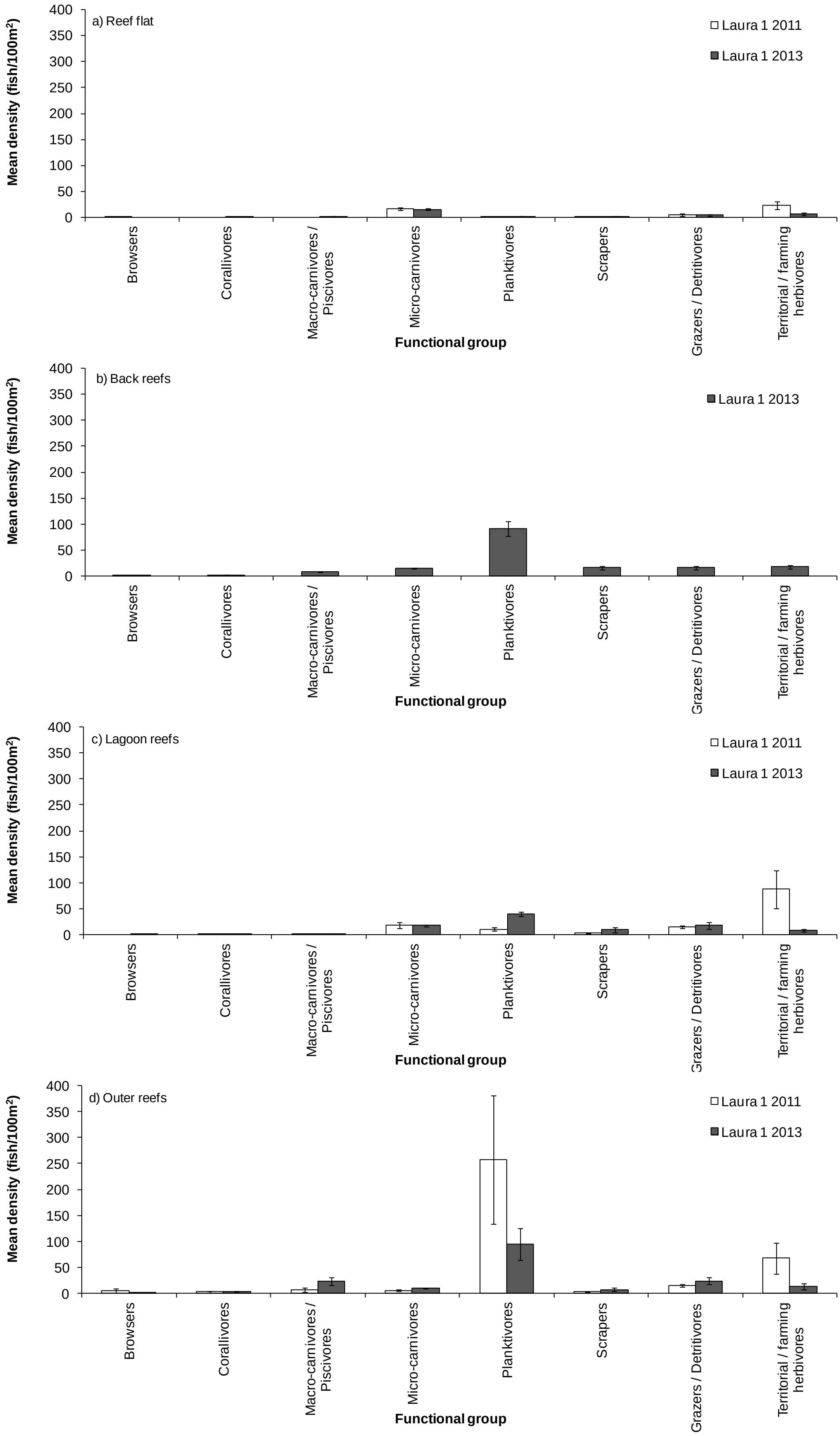


Figure 16 Mean densities (± SE) of key functional groups among a) reef flat, b) back reef, c) lagoon reef and d) outer reef habitats of the Laura 1 monitoring site during the 2011 and 2013 surveys.

Laura 2

Finfish assemblages of the Laura 2 site have been monitored at three reef zones during the project (Table 13; Figure 17). Back reef and outer reef habitats were surveyed in 2011 and 2013, while benthic habitats of lagoon reef habitats were surveyed for the first time in 2013.

Table 13 Details of finfish monitoring transects within the Laura 2 monitoring site.

Habitat and transect	Latitude (N)	Longitude (E)	Years monitored
Back reef			
T16	7.132083	171.050517	2011, 2013
T17	7.133600	171.050033	2011, 2013
T18	7.134783	171.049983	2011, 2013
Lagoon reef			
T28	7.139183	171.053083	2013
T29	7.138683	171.052383	2013
T30	7.139133	171.052067	2013
Outer reef			
T22	7.133017	171.040733	2011, 2013
T23	7.132033	171.041500	2011, 2013
T24	7.130833	171.042367	2011, 2013

Consistent with other monitoring sites, finfish diversity and the number of families, genera and species observed within the Laura 2 site was considerably higher during the 2013 survey relative to 2011 for all habitats examined (Table 14). The number of functional groups present was similar among surveys, with only browsers absent from the back reef of this site in 2013 (Table 14; Figure 20).

Table 14 Total number of families, genera and species, and diversity of finfish observed at back, lagoon and outer reef habitats of the Laura 2 monitoring site, 2011 and 2013.

Parameter	Back-reef		Lagoon-reef		Outer-reef	
	2011	2013	2011	2013	2011	2013
No. of families	10	17	-	23	17	21
No. of genera	25	41	-	54	40	58
No. of species	41	88	-	103	70	110
Diversity	24±1	48±2	-	59±7	36±12	66±6
Functional groups	8/8	7/8	-	8/8	8/8	8/8

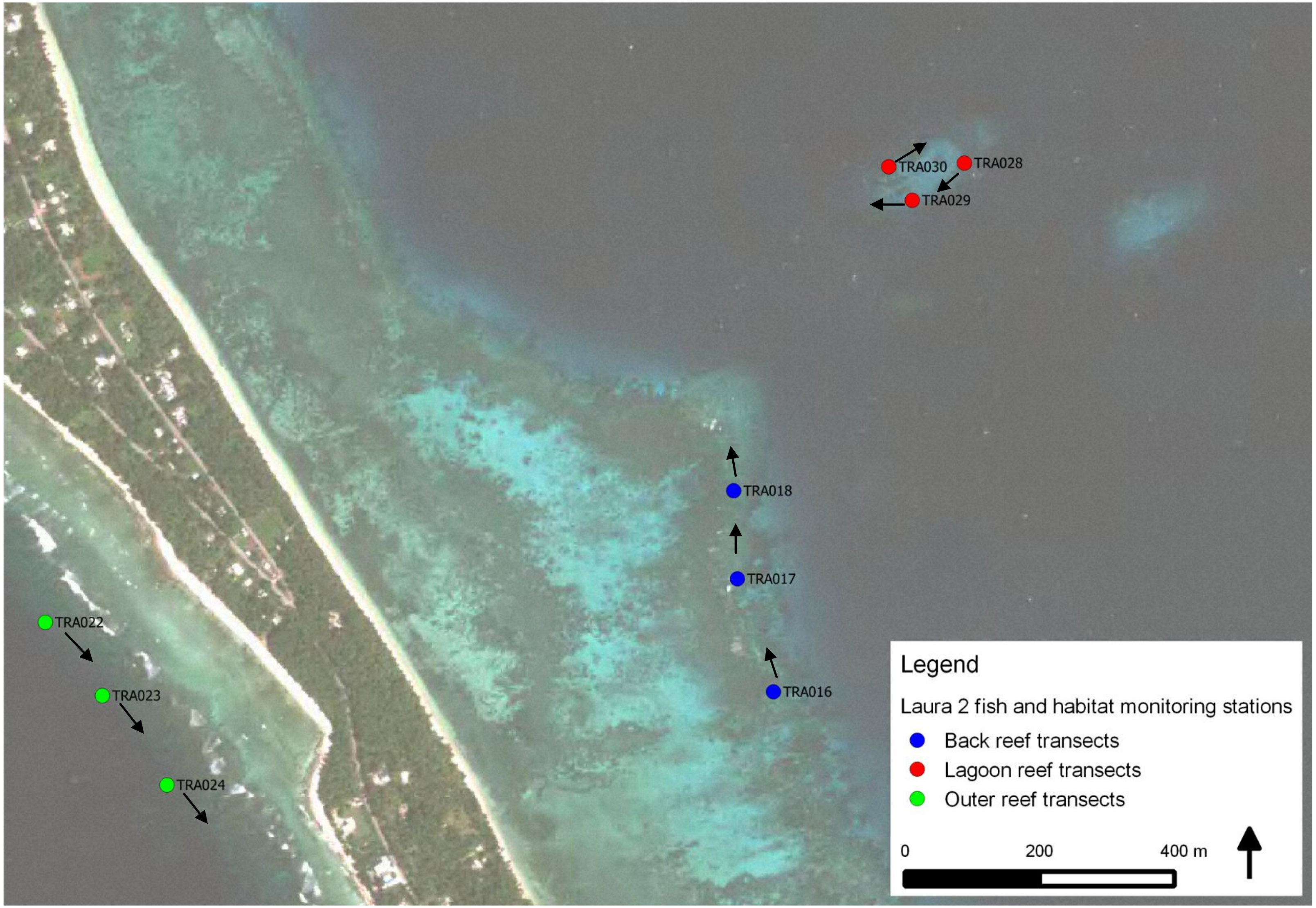


Figure 17 Location of finfish and fine-scale benthic habitat monitoring transects within the Laura 2 monitoring site. Black arrows (not to scale) indicate the approximate direction of transects.

No significant differences were observed in mean total density among surveys for any habitat within the Laura 2 monitoring site (Figure 18). Similarly, no significant differences were evident in densities of any of the individual indicator families or functional groups on any reef habitat among the 2011 and 2013 surveys (Figure 19; Figure 20). Densities of Serranidae on outer reefs appeared lower during the 2013 surveys relative to 2011, mainly due to decreases in densities of *Pseudanthias bartlettorum* and *P. pascalus,* however these declines were not significant at P = 0.05.

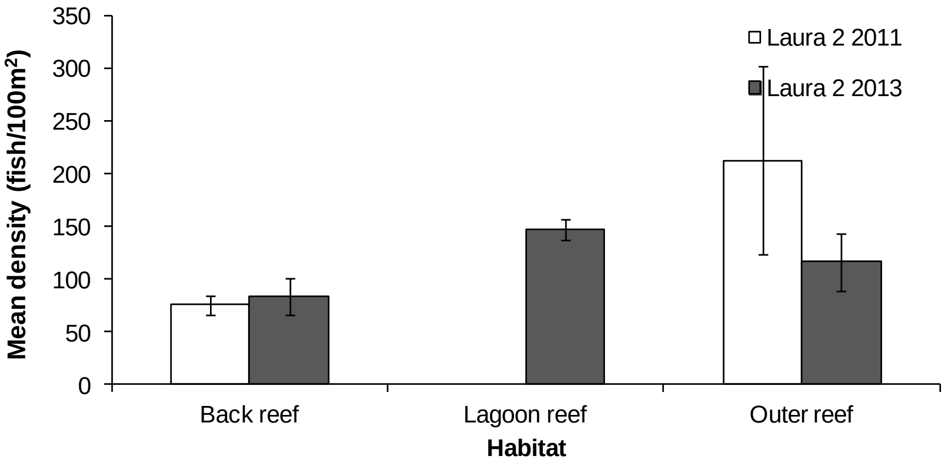


Figure 18 Mean total density of finfish (± SE) among survey years and habitats at the Laura 2 monitoring site.

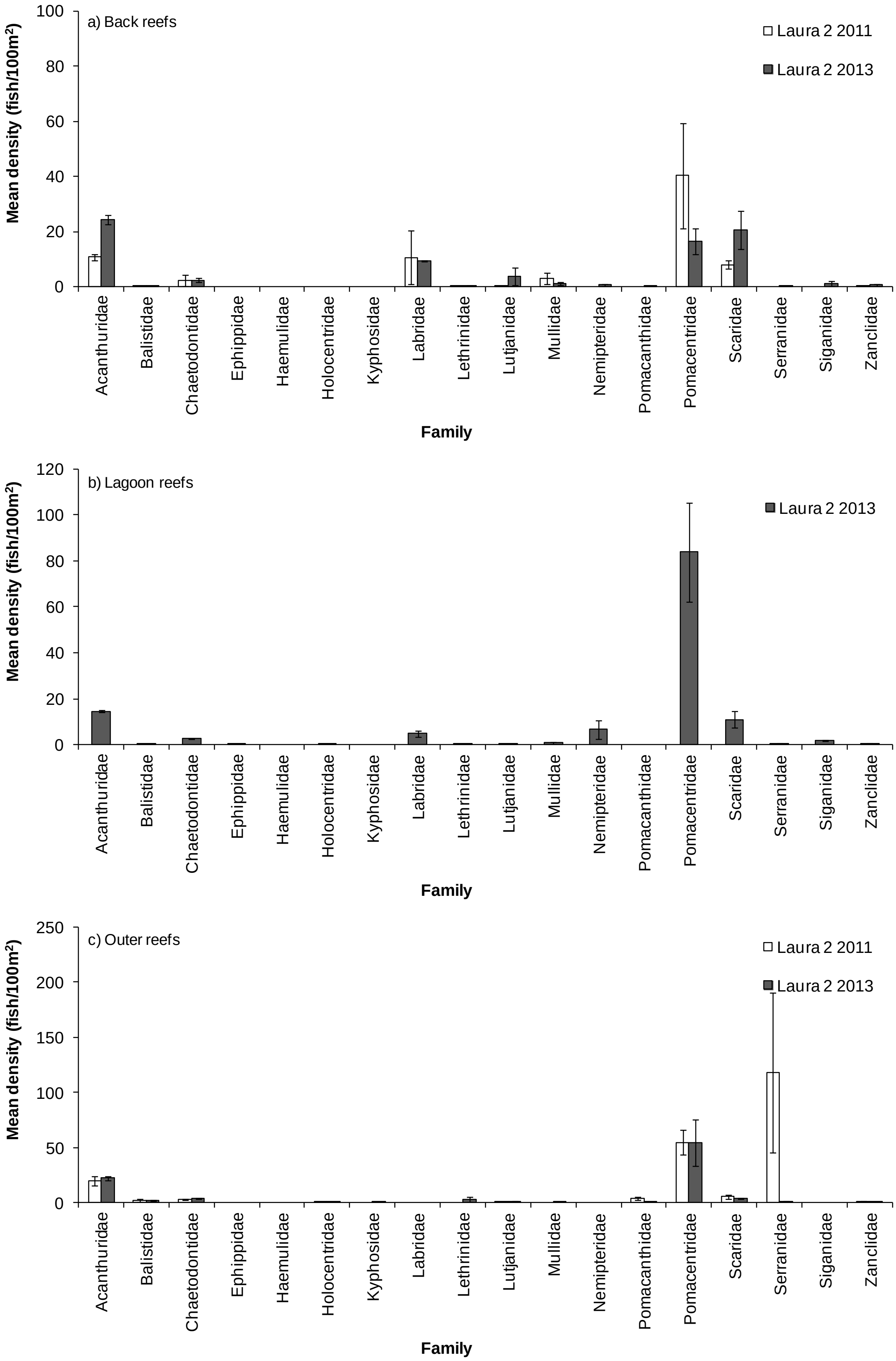


Figure 19 Mean densities (± SE) of common finfish families among a) back reef, b) lagoon reef and c) outer reef habitats of the Laura 2 monitoring site during the 2011 and 2013 surveys.

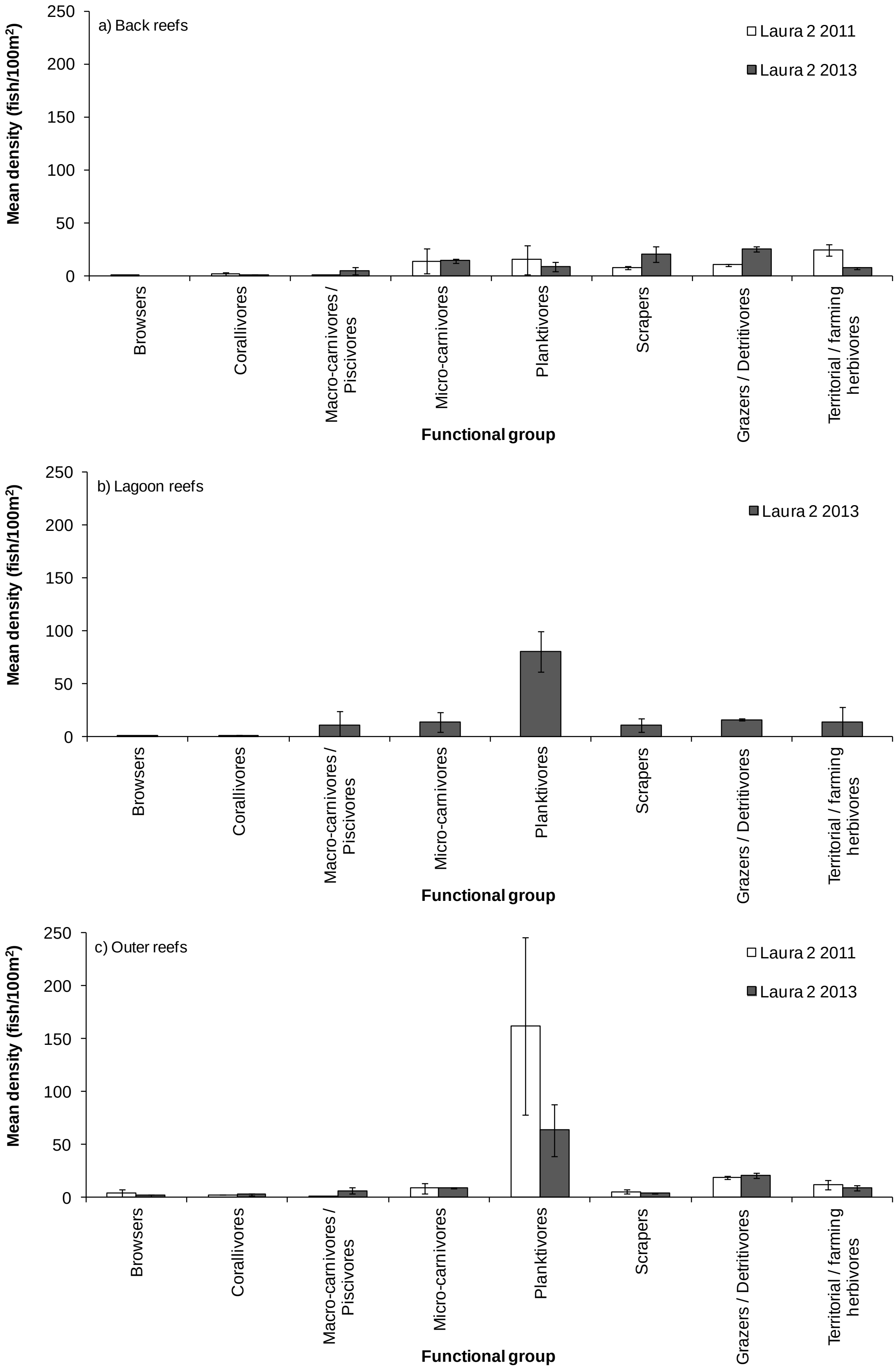


Figure 20 Mean densities (± SE) of key functional groups among a) back reef, b) lagoon reef and c) outer reef habitats of the Laura 2 monitoring site during the 2011 and 2013 surveys.

Majuro

Finfish assessments at the Majuro site in both 2011 and 2013 covered three habitats, with three 50 m transects completed in each habitat (Figure 21; Table 16).

Table 15 Details of finfish monitoring transects within the Majuro monitoring site.

Habitat and transect	Latitude (N)	Longitude (E)	Years monitored
Back reef			
T7	7.155617	171.220450	2011, 2013
T8	7.156150	171.219700	2011, 2013
T9	7.156633	171.218983	2011, 2013
Lagoon reef			
T1	7.156600	171.213450	2011, 2013
T2	7.155850	171.212933	2011, 2013
T3	7.156433	171.215183	2011, 2013
Outer reef			
T34	7.163567	171.215917	2011, 2013
T35	7.163967	171.214633	2011, 2013
T36	7.164167	171.213250	2011, 2013

Consistent with other sites, finfish diversity and the number of families, genera and species observed within the Majuro monitoring site was considerably higher during the 2013 survey relative to 2011 for all habitats examined (Table 16). Most habitats supported all functional groups during both the 2011 and 2013 surveys, with browsers absent from both the back reef and outer reef during the 2011 survey (Table 16).

Table 16 Total number of families, genera and species, and diversity of finfish observed at back, lagoon and outer reef habitats of the Majuro monitoring site, 2011 and 2013.

Parameter	Back-reef		Lagoon-reef		Outer-reef	
	2011	2013	2011	2013	2011	2013
No. of families	11	21	14	20	10	16
No. of genera	34	52	39	55	30	49
No. of species	66	97	72	115	49	96
Diversity	31±4	43±18	41±7	62±6	22±2	58±2
Functional groups	7/8	8/8	8/8	8/8	7/8	8/8

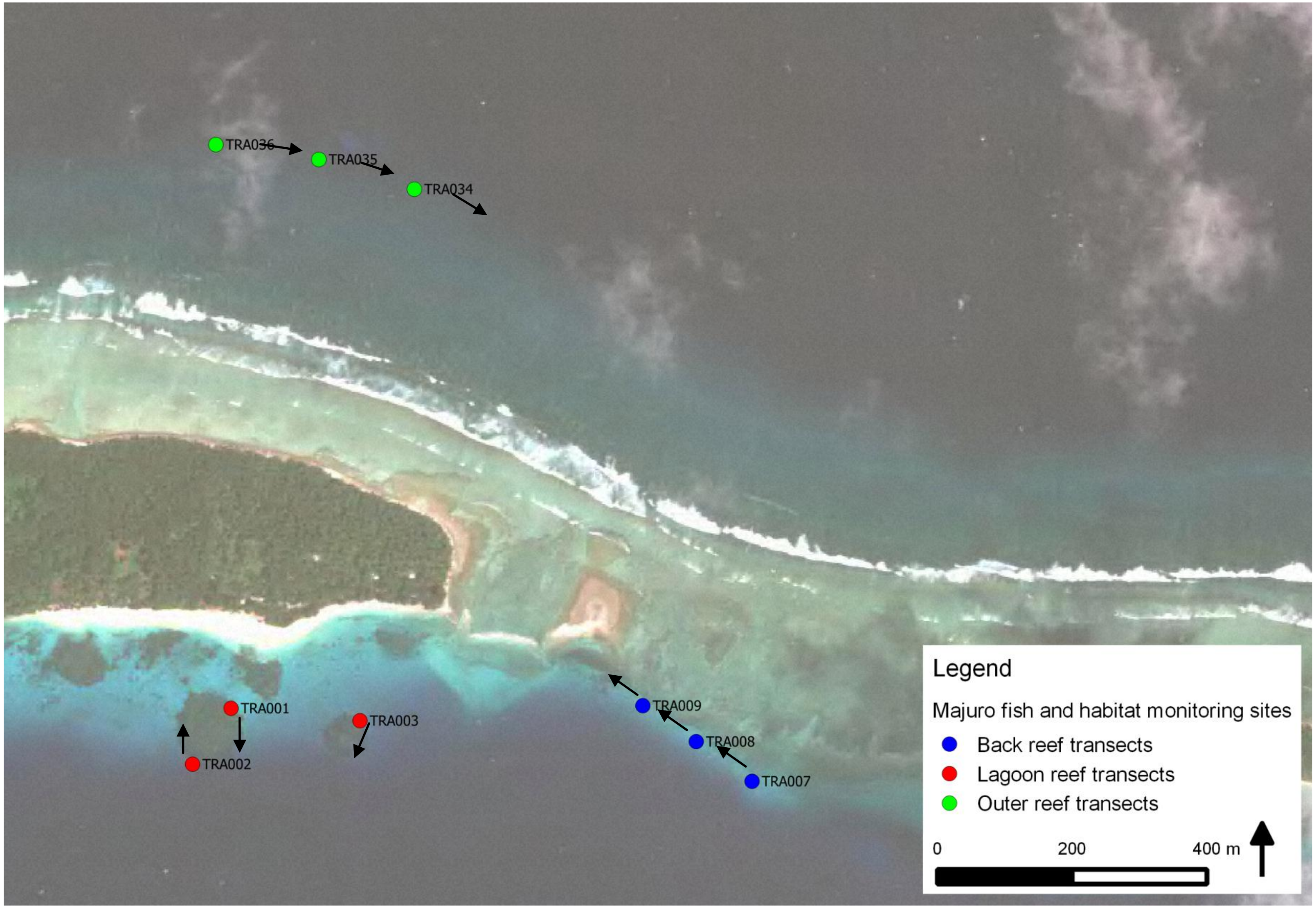


Figure 21 Location of finfish and fine-scale benthic habitat monitoring transects within the Majuro monitoring site. Black arrows (not to scale) indicate the approximate direction of transects.

Mean total density of finfish on back reef transects was significantly lower in 2013 compared to 2011 (P = 0.027), largely resulting from significant declines in the densities of territorial/farming herbivores, specifically the damselfish *Pomacentrus coelestis* (Figure 23; Figure 24).

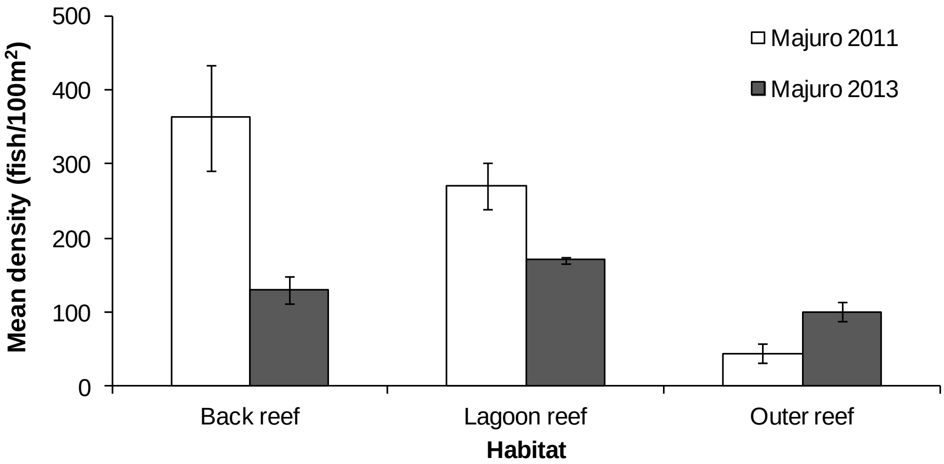


Figure 22 Mean total density of finfish (± SE) among survey years and habitats at the Majuro monitoring site.

No significant differences were observed in mean total density, or the mean density of any of the 18 indicator families or eight functional groups for the lagoon reef habitats of the Majuro site. Mean total densities of finfish assemblages on the outer reef appeared slightly higher in 2013 than 2011, with densities of Chaetodontidae, Scaridae and subsequently the functional group scrapers each exhibiting significant increases in 2013 (P < 0.05) (Figure 23; Figure 24).

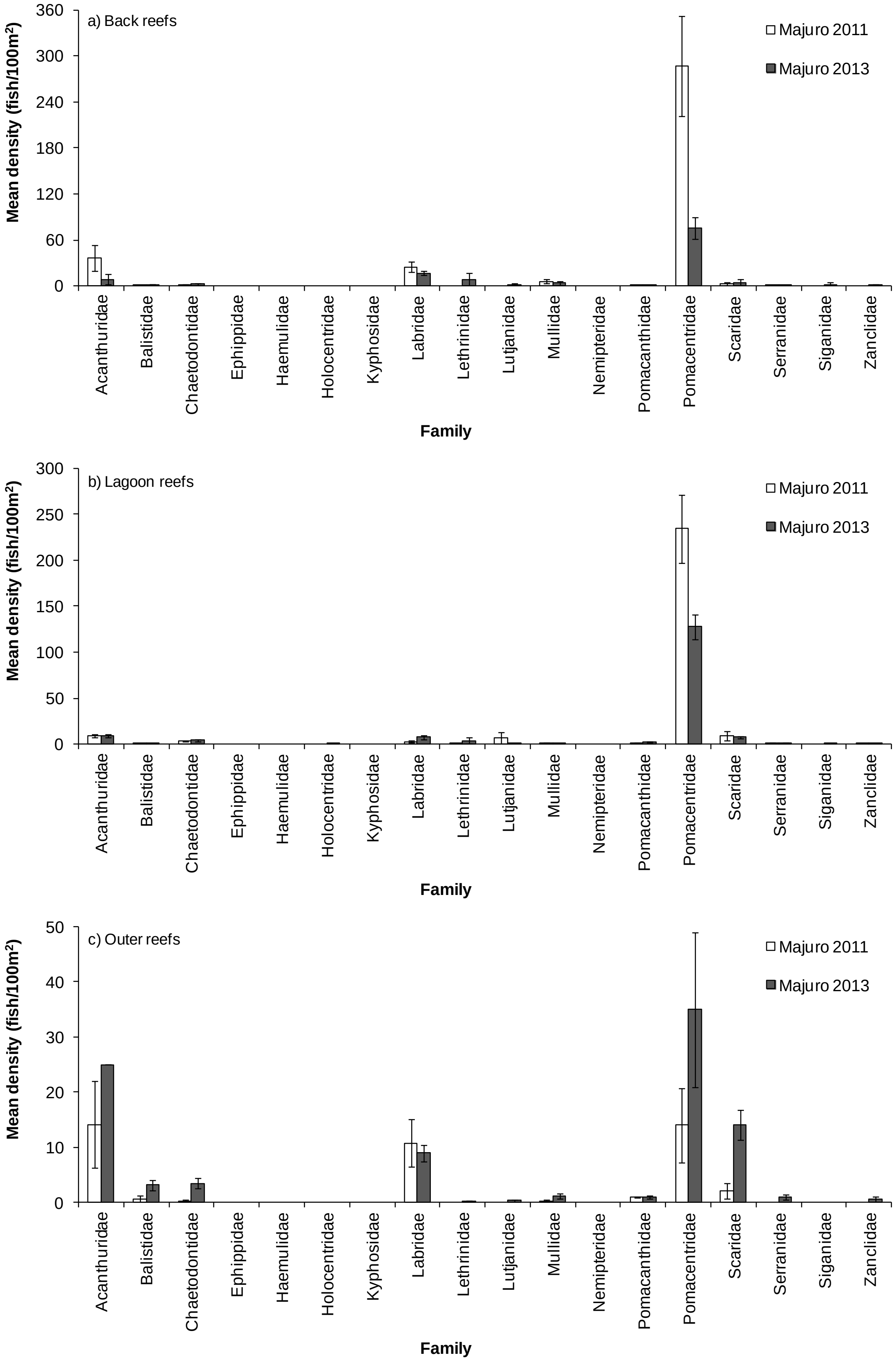


Figure 23 Mean densities (± SE) of common finfish families among a) back reef, b) lagoon reef and c) outer reef habitats of the Majuro monitoring site during the 2011 and 2013 surveys.

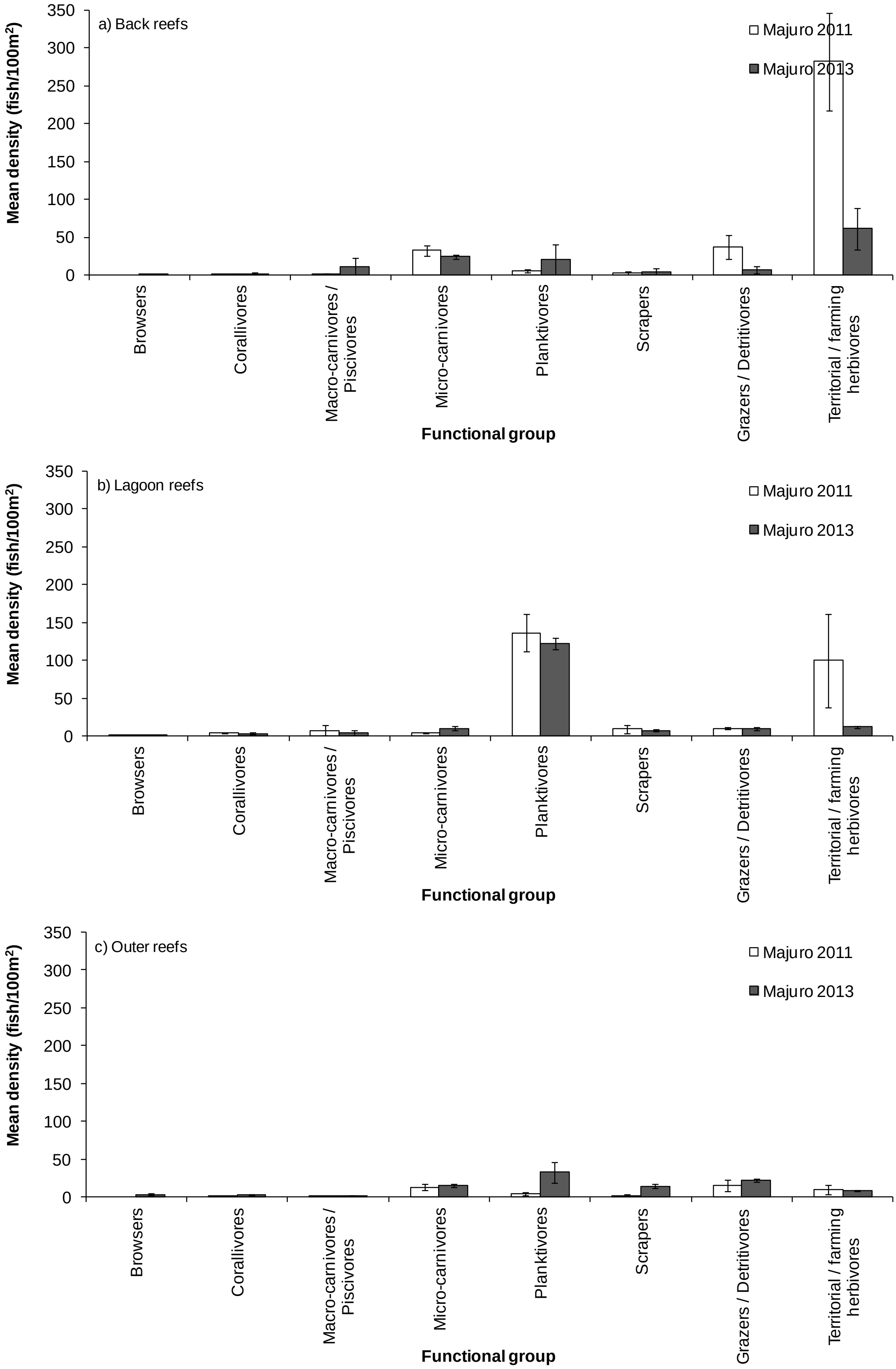


Figure 24 Mean densities (± SE) of key functional groups among a) back reef, b) lagoon reef and c) outer reef habitats of the Majuro monitoring site during the 2011 and 2013 surveys.

Woja MPA

Finfish communities of the Woja MPA were surveyed for the first time in 2013. Three 50 m transects were completed along each of the back reef and outer reefs within the MPA (Table 17; Figure 25). No lagoon reef habitats were available for survey within the MPA.

Table 17 Details of finfish monitoring transects within the Woja MPA monitoring site.

Habitat and transect	Latitude (N)	Longitude (E)	Years monitored
Back reef			
T37	7.094867	171.129783	2013
T38	7.094533	171.131333	2013
T39	7.093683	171.132767	2013
Outer reef			
T40	7.087817	171.130267	2013
T41	7.08735	171.131633	2013
T42	7.086733	171.132783	2013

Finfish diversity was higher within the Woja MPA compared to the Laura 2 site for both back reef and outer reef habitats (Table 18). All functional groups were observed on both the back reef and outer reef of the MPA during the 2013 survey (Table 18).

Table 18 Total number of families, genera and species, and diversity of finfish observed at back and outer reef habitats of the Laura 2 and Woja MPA monitoring sites, 2013.

Parameter	Back-reef		Outer-reef	
	Laura 2 2013	Woja MPA 2013	Laura 2 2013	Woja MPA 2013
No. of families	17	21	21	19
No. of genera	41	51	58	57
No. of species	88	104	110	114
Diversity	48±2	60±4	66±6	73±7
Functional groups	7/8	8/8	8/8	8/8

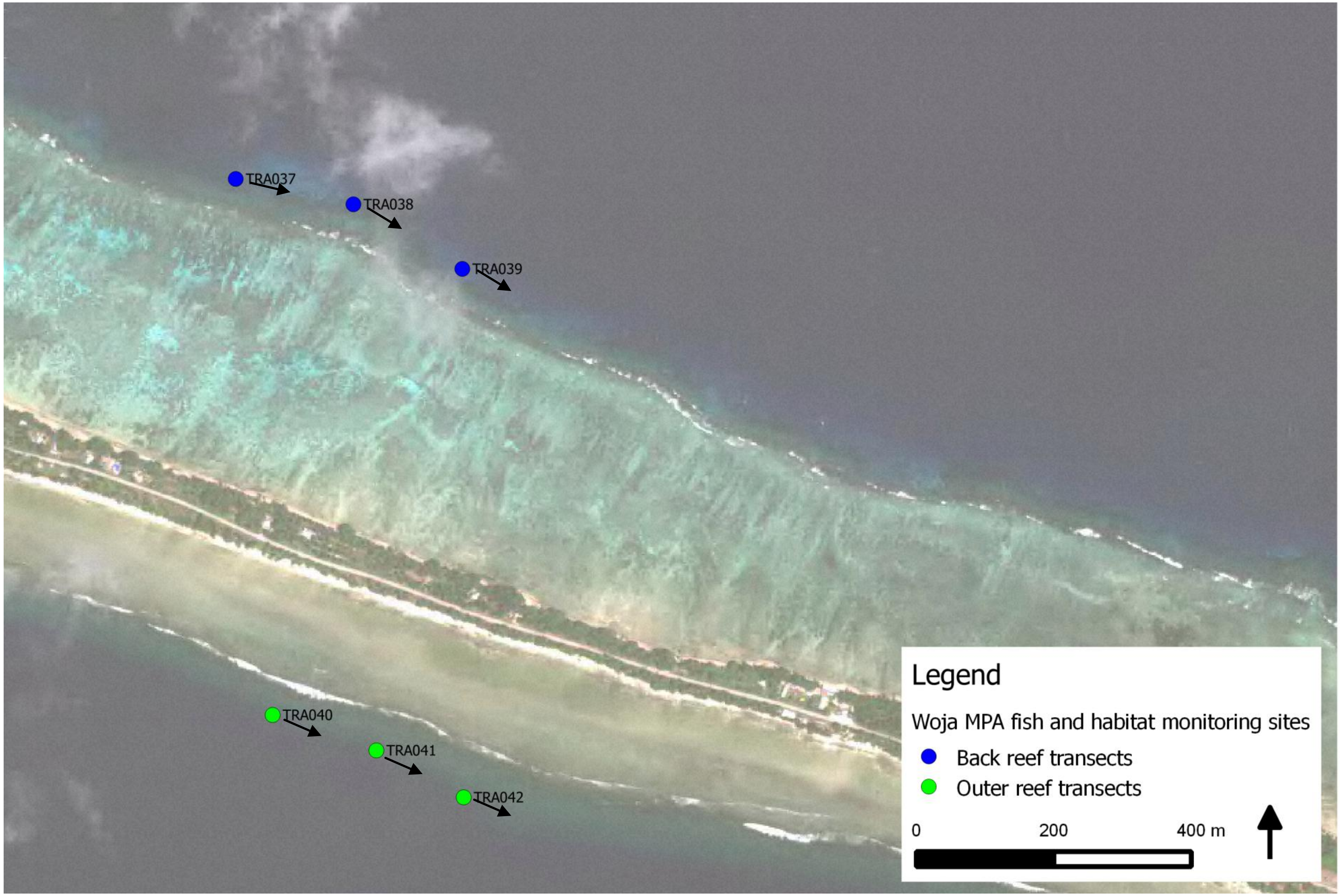


Figure 25 Location of finfish and fine-scale benthic habitat monitoring transects within the Woja MPA monitoring site. Black arrows (not to scale) indicate the approximate direction of transects.

No significant differences were observed in mean total density or density of individual families or functional groups for back reef habitats of the Woja MPA and the comparably-situated Laura 2 site in 2013 (Figure 26). Similarly, no significant differences in mean total density were observed for the outer reef of the Woja MPA and the Laura 2 site. Mean densities of Siganidae however were slightly higher within the MPA ($P = 0.029$), suggesting the MPA offers a degree of protection for this group.

In terms of biomass, no significant differences were observed amongst the Woja MPA and the comparably-situated Laura 2 site in mean total biomass or the biomass of the selected indicator families or key functional group at any habitat (data not presented for purposes of brevity).

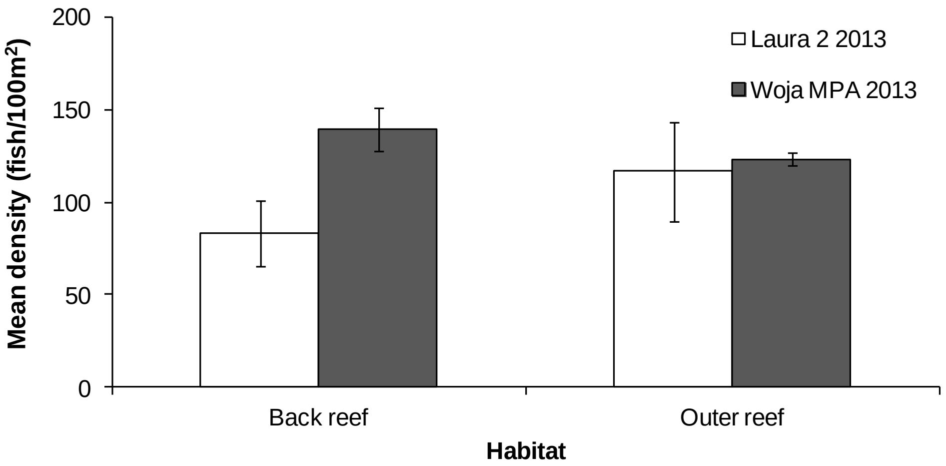


Figure 26 Mean total density of finfish (± SE) among the Laura 2 and Woja MPA monitoring sites, 2013.

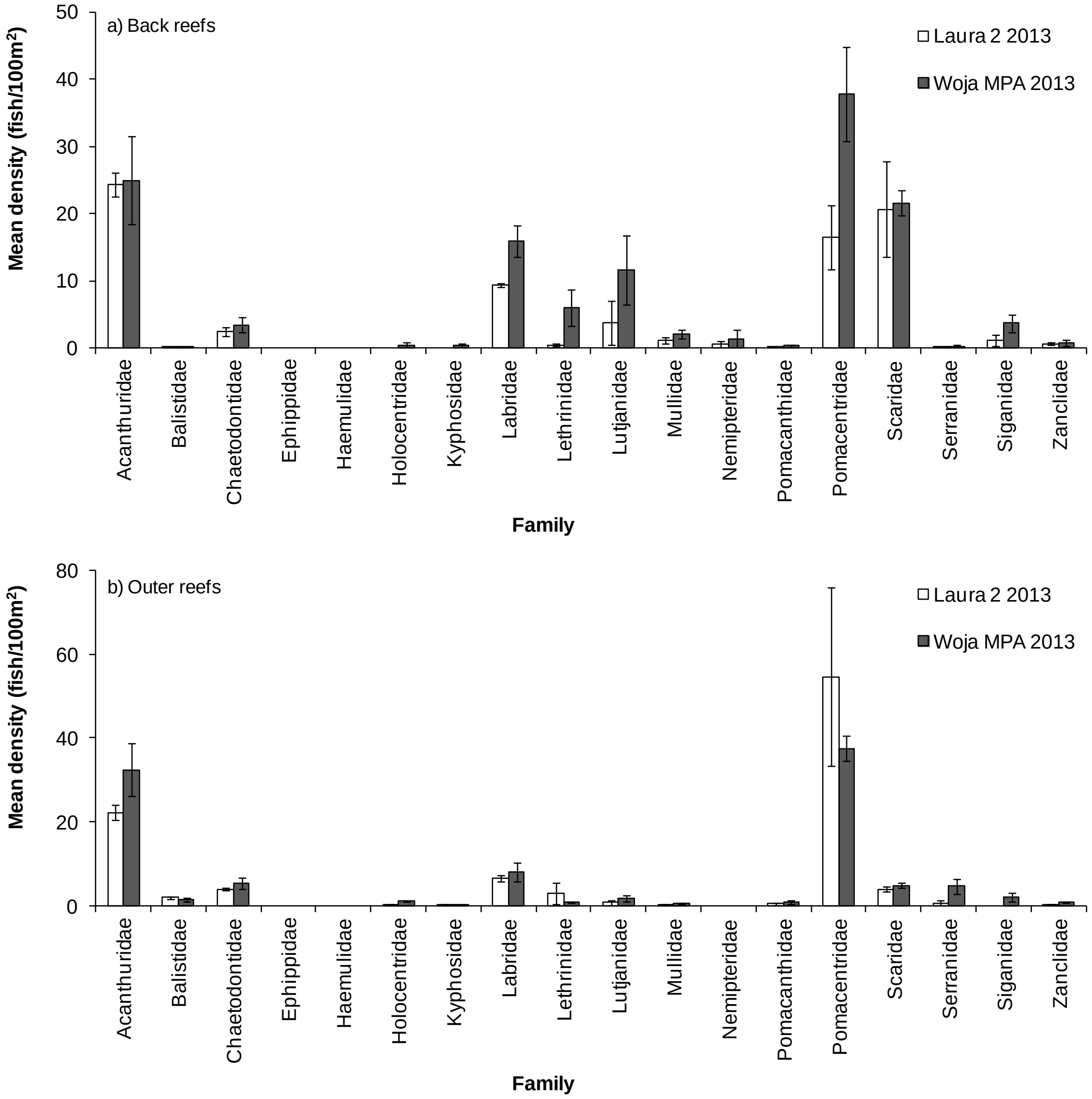


Figure 27 Mean densities (±SE) of common finfish families among a) back reef and b) outer reef habitats of the Laura 2 and Woja MPA monitoring sites during the 2013 survey.

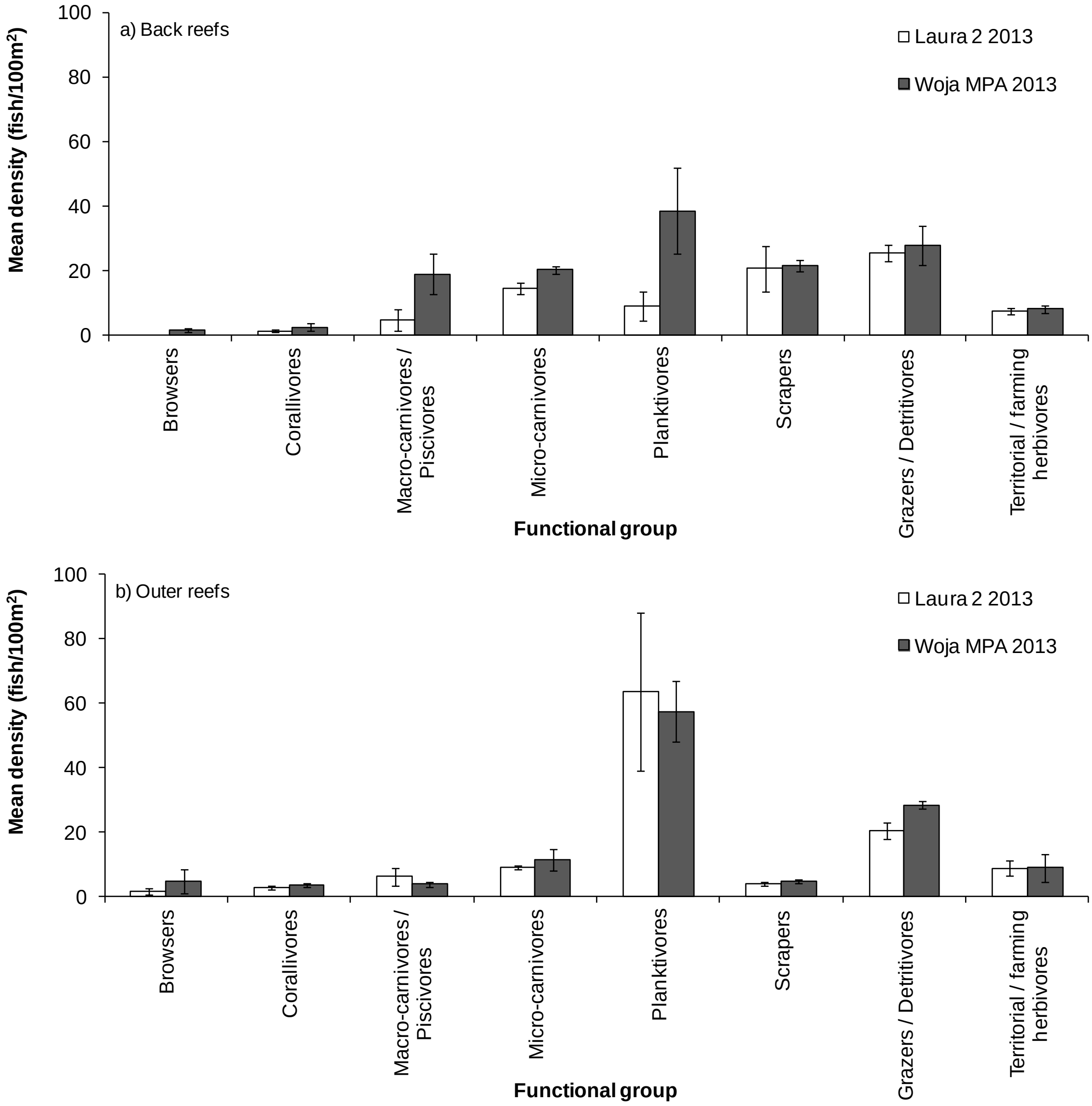


Figure 28 Mean densities (± SE) of key functional groups among a) back reef and b) outer reef habitats of the Laura 2 and Woja MPA monitoring sites during the 2013 survey.

5. Benthic Habitat Assessment

Methodologies

Broad-scale assessments

Data collection

Broadscale benthic habitat assessments were conducted by manta tow at three sites: Ajeltake, Laura and Majuro (Figure 29). Here, a surveyor was towed on a manta board behind a boat at a speed of approximately 3-4 km/h. The surveyor recorded percent cover of substrate types, including live coral, dead coral, bleached coral, coralline algae (e.g. *Halimeda*) and other macroalgae within a 300 m long x 2 m wide transect. Transect lengths were determined using the odometer function within the trip computer option of a Garmin Etrex GPS, and transects were typically conducted at depths of 1–6 metres. Six 300 m manta tow replicates were conducted within each site, with GPS positions recorded at the start and end of each transect to an accuracy of within ten meters.

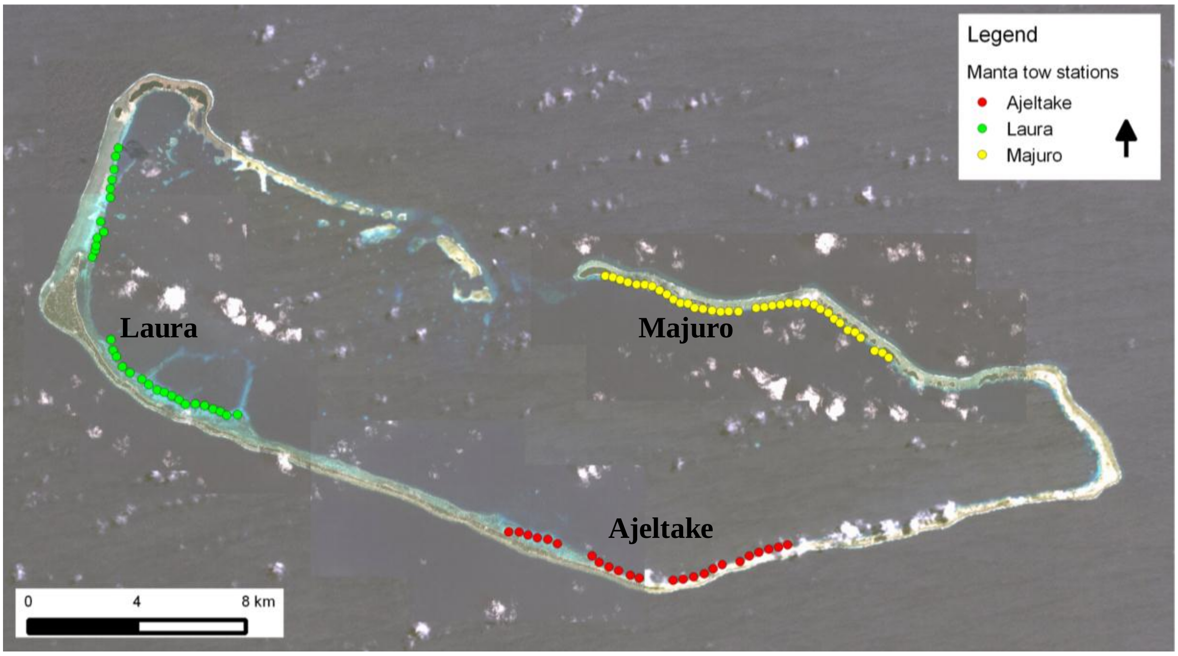


Figure 29 Location of broad-scale (manta tow) benthic habitat monitoring regions at Majuro Atoll. Each point represents a single 300 m replicate within each station.

Data analysis

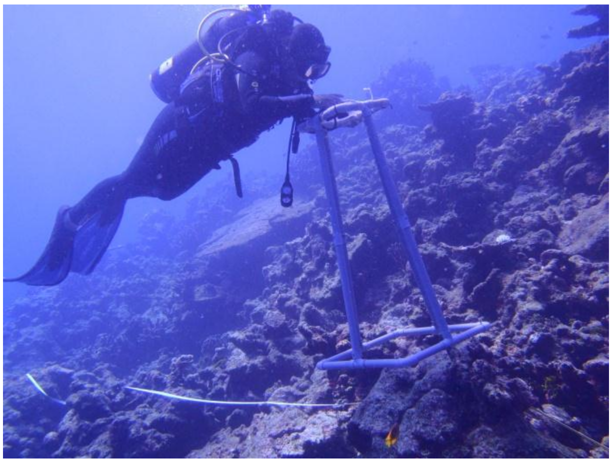
Summary graphs of mean percentage cover (± SE) of each substrate type, based on cover of each individual 300 m x 2m transect, were generated for each site (Ajeltake, Laura and Majuro) and survey year (2011 and 2013).

Fine-scale assessments

Data collection

Fine-scale benthic habitat assessments were conducted using a photoquadrat approach at the same locations and transects as the finfish assessments (Figure 7) and were conducted immediately after the finfish surveys. Up to 50 photographs of the benthos were taken per transect (with one photo taken approximately every metre) using a housed underwater camera and a quadrat frame measuring an area of 0.25 m^2. Transects were laid parallel to the reef. A GPS position was recorded at the beginning of each transect.

Figure 30 Lyla Lemari of the Marshall Islands Marine Resources Authority conducting a photoquadrat survey on the outer reef of the Laura 2 monitoring site.



Data processing and analysis

The habitat photographs were analyzed using SPC software (available online at http://www.spc.int/CoastalFisheries/CPC/BrowseCPC). Using this software, five randomly generated points were created on the downloaded photographs. The substrate under each point was identified based on the following substrate categories:

1. Live hard coral – cover of different types of live hard coral, identified to genus level[1];
2. Other invertebrates – cover 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 – cover of macroalgae *Asparagopsis*, *Blue-green algae*, *Boodlea*, *Bryopsis*, *Chlorodesmis*, *Caulerpa*, *Dictyota*, *Dictosphyrea*, *Galaxura*, *Halimeda*, *Liagora*, *Lobophora*, *Mastophora*, *Microdictyton*, *Neomeris*, *Padina*, *Sargassum*, *Schizothrix*, *Turbinaria*, *Tydemania*, *Ulva*, and *Other macroalgae* (other macroalgae not included in this list);
4. Branching coralline algae – *Amphiroa*, *Jania*, *Branching coralline general*;
5. Crustose coralline algae;
6. Fleshy coralline algae (growing on fixed substrate, e.g. *Peyssonnelia*);
7. Turf algae;
8. Seagrass – cover 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

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

surveyor. Resulting data were extracted to MS Excel and summarized as percentages. Summary graphs of mean percentage cover (± SE) for each site were generated to further explore patterns of each major substrate category by habitat and survey year.

To further explore patterns among surveys, coverage data of each major benthic category in each individual transect were ln(x+1) transformed to reduce heterogeneity of variances and analysed by two-way ANOVA using Statistica 7.1, with survey year (2011 and 2013) and site 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 $P = 0.025$ was used. As with the finfish assessments, this design allowed for a comparison of each site over time, and an assessment of the performance of the individual protected areas vs. comparably-situated sites that are open to fishing (i.e. Drenmeo MPA vs. Majuro 'open' site, Woja MPA vs. Laura 2 'open' site). Due to obvious differences in surrounding land use, oceanic influence and tidal flushing among both open to fishing sites and MPA sites, no attempt was made to pool individual sites into broader groups (e.g. 'open' vs. 'closed') in the analyses.

Results

Broad-scale assessments

Cover of live coral, coralline algae and macroalgae increased slightly at the Majuro site (Figure 31). At both the Ajeltake and Laura sites, benthic composition changed from a coral-dominated state in 2011 to an algae-dominated state in 2013, with the cover of algae (all species combined) exceeding that of live coral in 2013 (Figure 31).

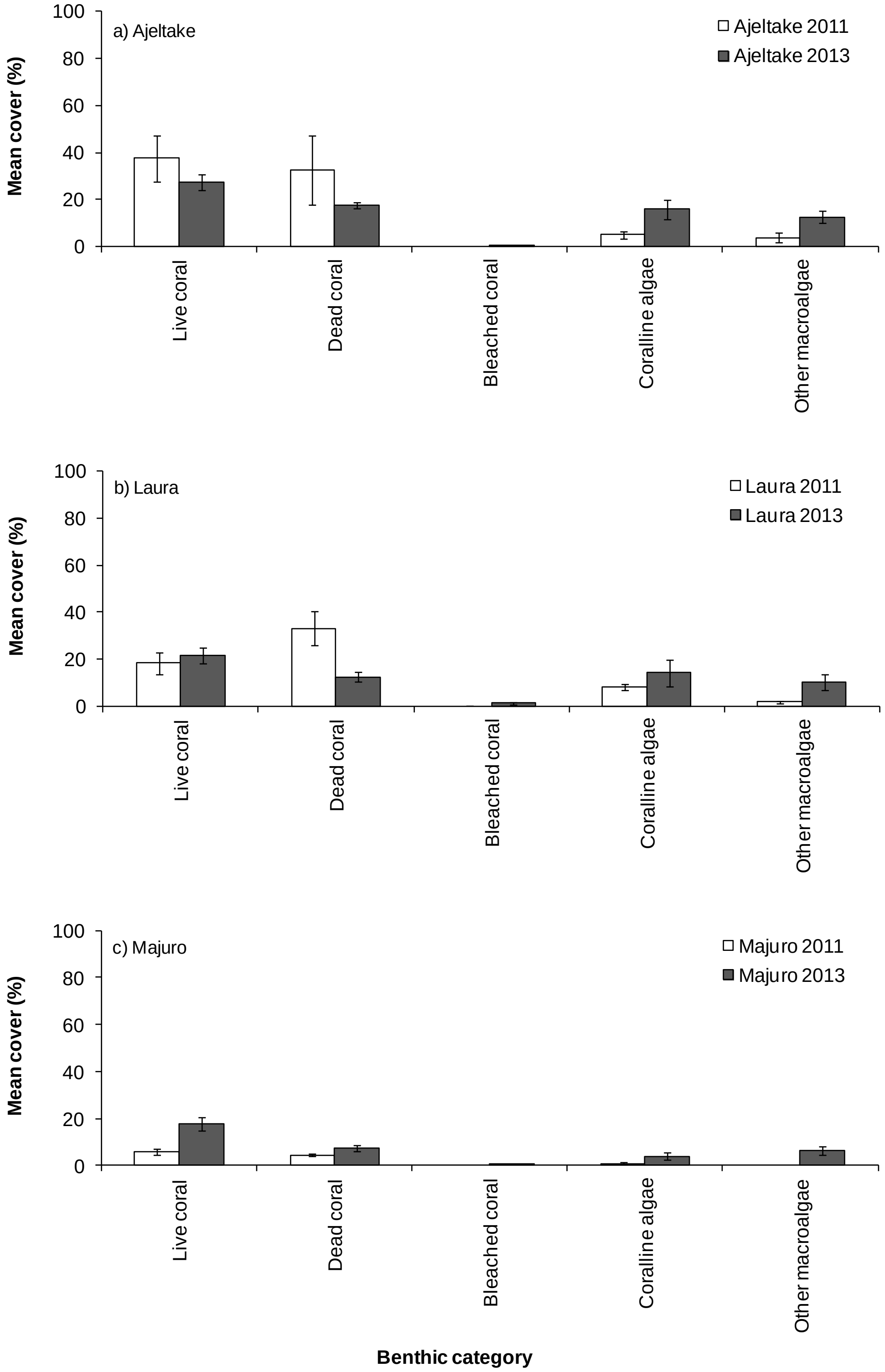


Figure 31 Percent cover of coral and algae observed during broad-scale habitat assessments via manta tow.

Fine-scale assessments

Drenmeo MPA site

Benthic habitat assessments within the Drenmeo MPA in both 2011 and 2013 covered three habitats, with three 50 m transects completed in each habitat (Table 19; Figure 9).

Table 19 Details of benthic habitat monitoring transects within the Drenmeo MPA monitoring site.

Habitat and transect	Latitude (N)	Longitude (E)	Years monitored
Back reef			
T10	7.120633	171.320583	2011, 2013
T11	7.120800	171.321383	2011, 2013
T12	7.120867	171.322117	2011, 2013
Lagoon reef			
T4	7.121267	171.316483	2011, 2013
T5	7.120517	171.316583	2011, 2013
T6	7.120233	171.317450	2011, 2013
Outer reef			
T31	7.126917	171.320333	2011, 2013
T32	7.127683	171.319333	2011, 2013
T33	7.128483	171.318250	2011, 2013

Back reef habitats of the Drenmeo MPA site showed little difference among surveys (Figure 32). Cover of turf algae decreased significantly from 9.33±1.71% in 2011 to 1.34±0.27% in 2013 ($P = 0.004$). In general, back reef habitats during both the 2011 and 2013 surveys were characterised by a relatively high percent cover of sand and rubble, and low percent cover of live hard corals (Figure 32).

Lagoon reefs of the Drenmeo MPA were dominated by live hard coral (Figure 32; Figure 33). A slight increase in percent cover of live hard coral (mainly due to an increase in cover of *Porites* and *Porites-rus*), and a slight decrease in cover of sand, was evident among the 2011 and 2013 surveys, however these changes were not significant.

Few differences in benthic habitat composition were evident on the outer reefs of the Drenmeo MPA site between the 2011 and 2013 surveys (Figure 32). Outer reefs during both surveys were characterised by a high cover of macroalgae (primarily *Halimeda* and *Microdictyon*), fleshy coralline algae (*Peyssonnelia*) and live hard coral (primarily *Acropora, Montipora* and *Pocillopora*) (Figure 32; Figure 34).

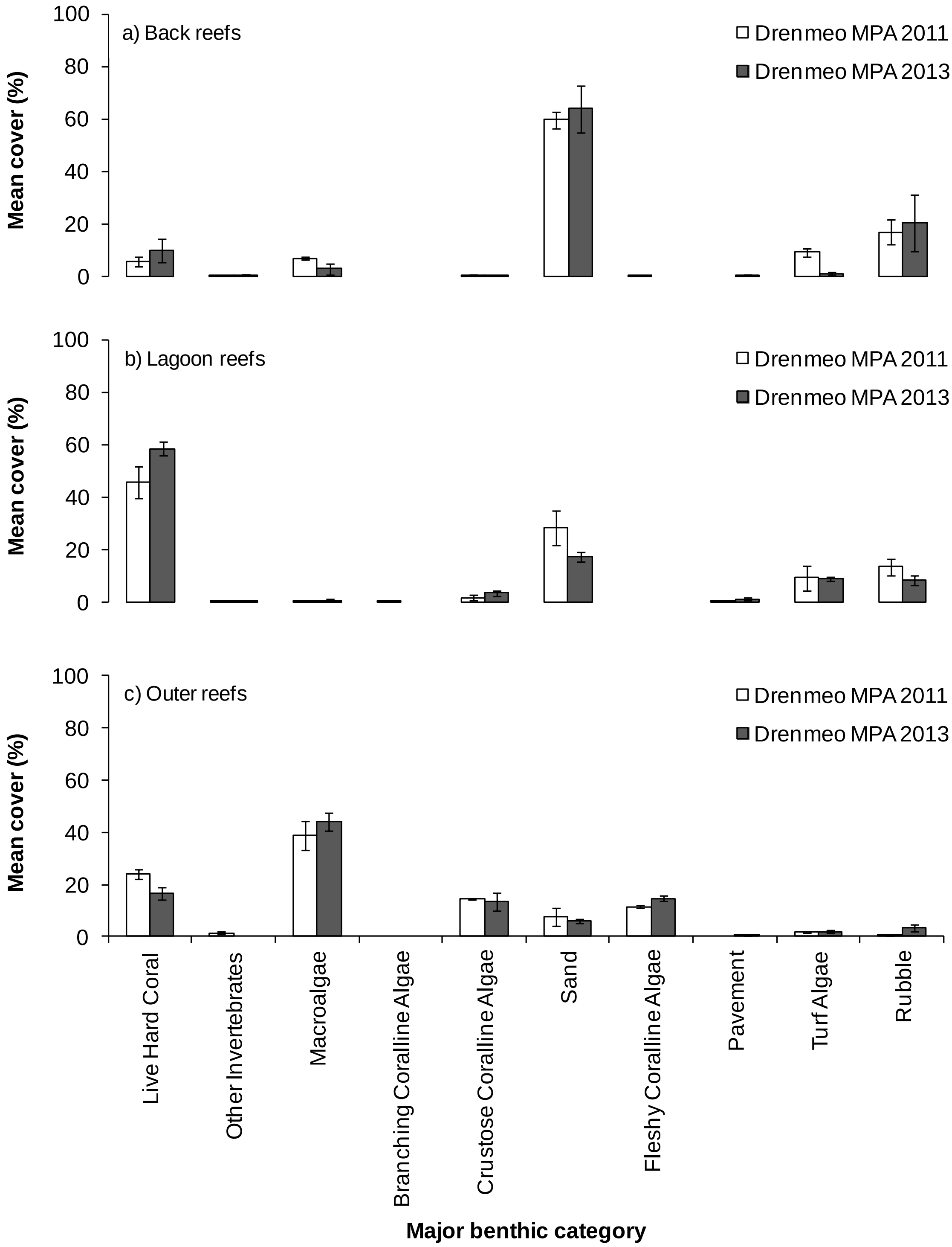


Figure 32 Percent cover of major benthic categories at a) back reef, b) lagoon reef and c) outer reef transects of the Drenmeo MPA monitoring site among 2011 and 2013 surveys.

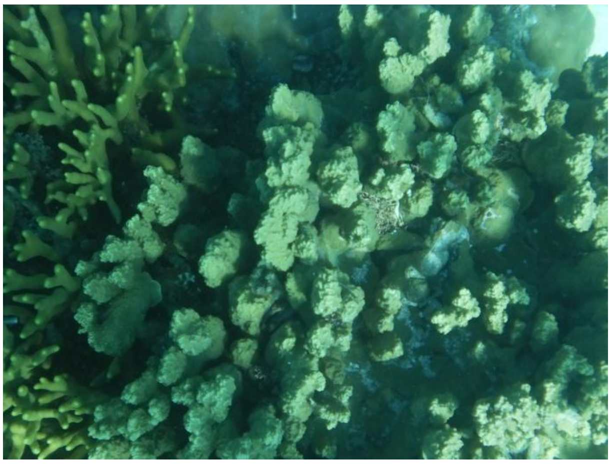


Figure 33 Lagoon reef transects of the Drenmeo MPA were characterised by a high cover of *Porites cylindrica* and *Porites-rus*.

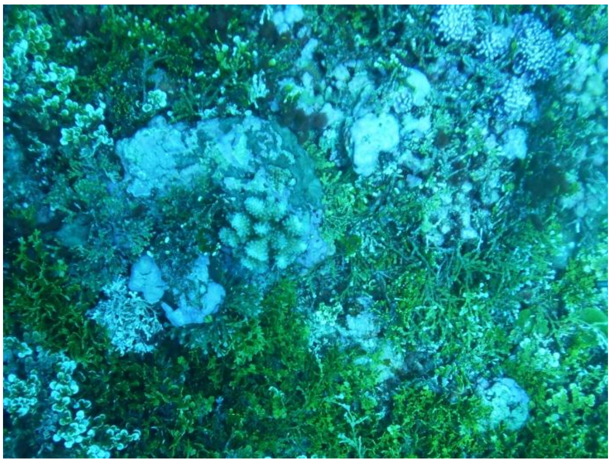


Figure 34 Benthic habitats of the outer reefs of the Drenmeo MPA was characterised by a high percent cover of macroalgae, in particular *Halimeda* spp.

Laura 1 site

Benthic habitats of the Laura 1 site have been monitored at four habitats during the project (Table 20; Figure 13). Reef flat, back reef and outer reef habitats were surveyed in both 2011 and 2013, while benthic habitats of lagoon reef habitats were surveyed in 2013 only.

Table 20 Details of benthic habitat monitoring transects within the Laura 1 monitoring site.

Habitat and transect	Latitude (N)	Longitude (E)	Years monitored
Reef flat			
T25	7.186417	171.046800	2011, 2013
T26	7.186033	171.046150	2011, 2013
T27	7.184917	171.046150	2011, 2013
Back reef			
T43	7.184933	171.050417	2011, 2013
T44	7.183833	171.050067	2011, 2013
T45	7.183133	171.049567	2011, 2013
Lagoon reef			
T13	7.194767	171.057183	2013
T14	7.194283	171.056067	2013
T15	7.193183	171.055233	2013
Outer reef			
T19	7.190083	171.042333	2011, 2013
T20	7.188200	171.041483	2011, 2013
T21	7.187050	171.041067	2011, 2013

Benthic composition of both reef flat and back reef habitats of the Laura 1 site appeared largely similar among the 2011 and 2013 surveys. On the reef flat, the cover of turf algae was slightly lower, and cover of rubble slightly higher, in 2013 relative to 2011, while slight increases in the cover of live hard coral and macroalgae, and decreases in cover of sand were observed for both habitats in 2013 compared to 2011 (however these were not statistically significant) (Figure 35).

Lagoon reef habitats at the Laura 1 site were surveyed for the first time in 2013. These habitats were characterised by a relatively high cover of live hard coral (primarily of the genera *Acropora*), and moderate cover of sand and macroalgae (predominately *Halimeda* spp.) (Figure 35).

Few changes in benthic habitat composition were evident on the outer reefs of the Laura 1 monitoring site (Figure 35). The cover of turf algae decreased from 10.7±1.2% in 2011 to 2.1±0.3% in 2013, while the cover of live hard coral appeared slightly higher in 2013, largely due to an increase in the percent cover of the genera *Acropora* and *Porites* (Figure 35). Further surveys are required to assess whether these changes are consistent over time.

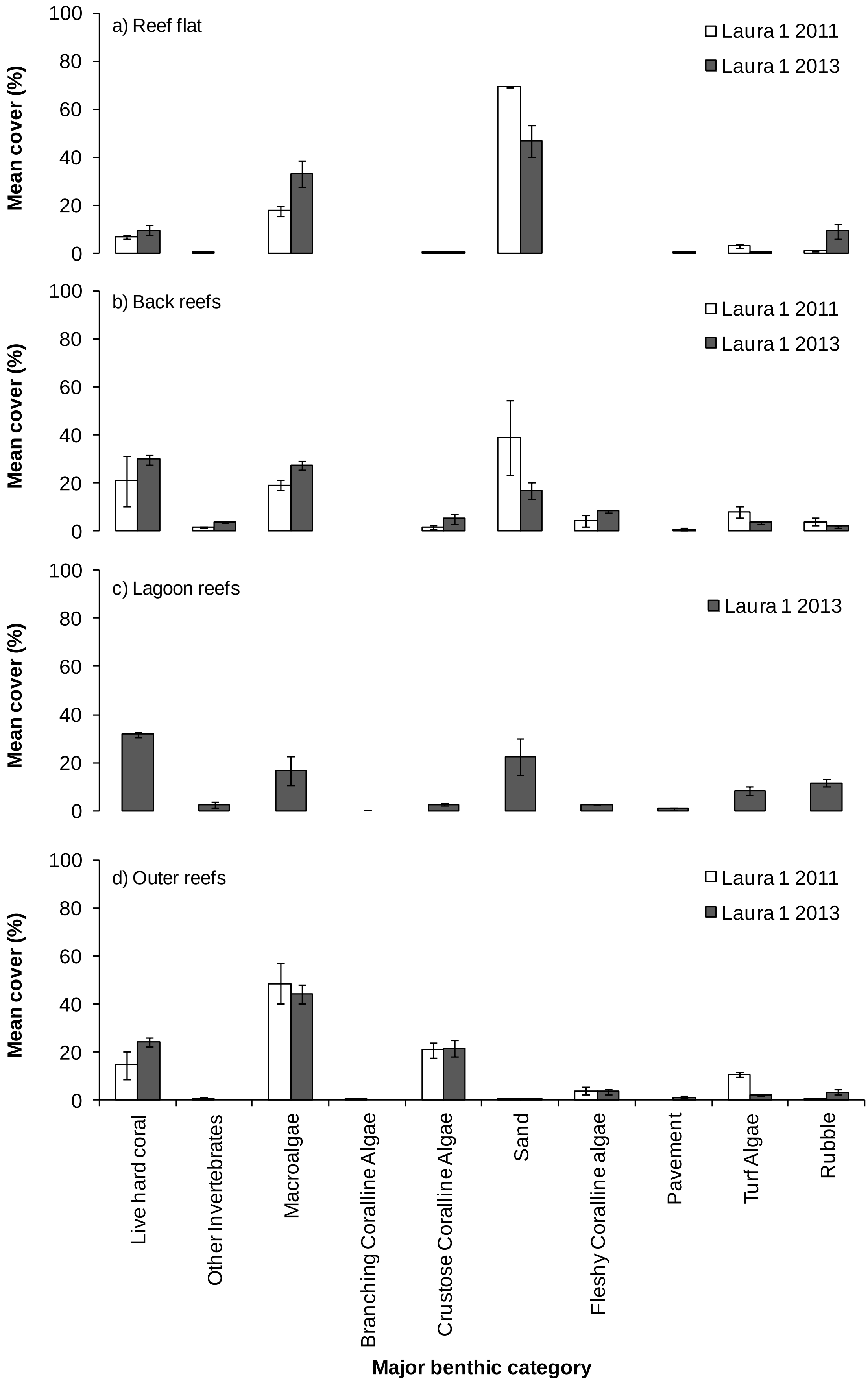


Figure 35 Percent cover of major benthic categories at a) reef flat, b) back reef, c) lagoon reef and d) outer reef transects of the Laura 1 monitoring site among 2011 and 2013 surveys.

Laura 2 site

Benthic habitats of the Laura 2 site have been monitored at three reef zones during the project (Table 21; Figure 17). Back reef and outer reef habitats were surveyed in 2011 and 2013, while benthic habitats of lagoon reef habitats were surveyed for the first time in 2013.

Table 21 Details of benthic habitat monitoring transects within the Laura 2 monitoring site.

Habitat and transect	Latitude (N)	Longitude (E)	Years monitored
Back reef			
T16	7.132083	171.050517	2011, 2013
T17	7.133600	171.050033	2011, 2013
T18	7.134783	171.049983	2011, 2013
Lagoon reef			
T28	7.139183	171.053083	2013
T29	7.138683	171.052383	2013
T30	7.139133	171.052067	2013
Outer reef			
T22	7.133017	171.040733	2011, 2013
T23	7.132033	171.041500	2011, 2013
T24	7.130833	171.042367	2011, 2013

No changes in mean live hard coral cover were evident on the back reef habitats of the Laura 2 site (Figure 36). The cover of crustose coralline algae and rubble appeared slightly higher in 2013 relative to 2011, while the cover of macroalgae and turf algae decreased slightly amongst surveys, however these differences were not statistically significant (Figure 36).

Lagoon reef habitats at the Laura 2 site were surveyed for the first time in 2013. These habitats were characterised by a relatively high cover of live hard coral (primarily *Porites*, *Porites-rus* and *Porites*-massive types), and moderate cover of sand (Figure 36).

Outer reef habitats of the Laura 2 site appeared largely similar amongst surveys. Slight decreases in cover of turf algae ($P = 0.045$) and ‘other invertebrates’ ($P = 0.013$) were observed, with the latter resulting from a decline in percent cover of soft coral from 7.0±0.5% in 2011 to 1.5±0.5% in 2013 (Figure 36).

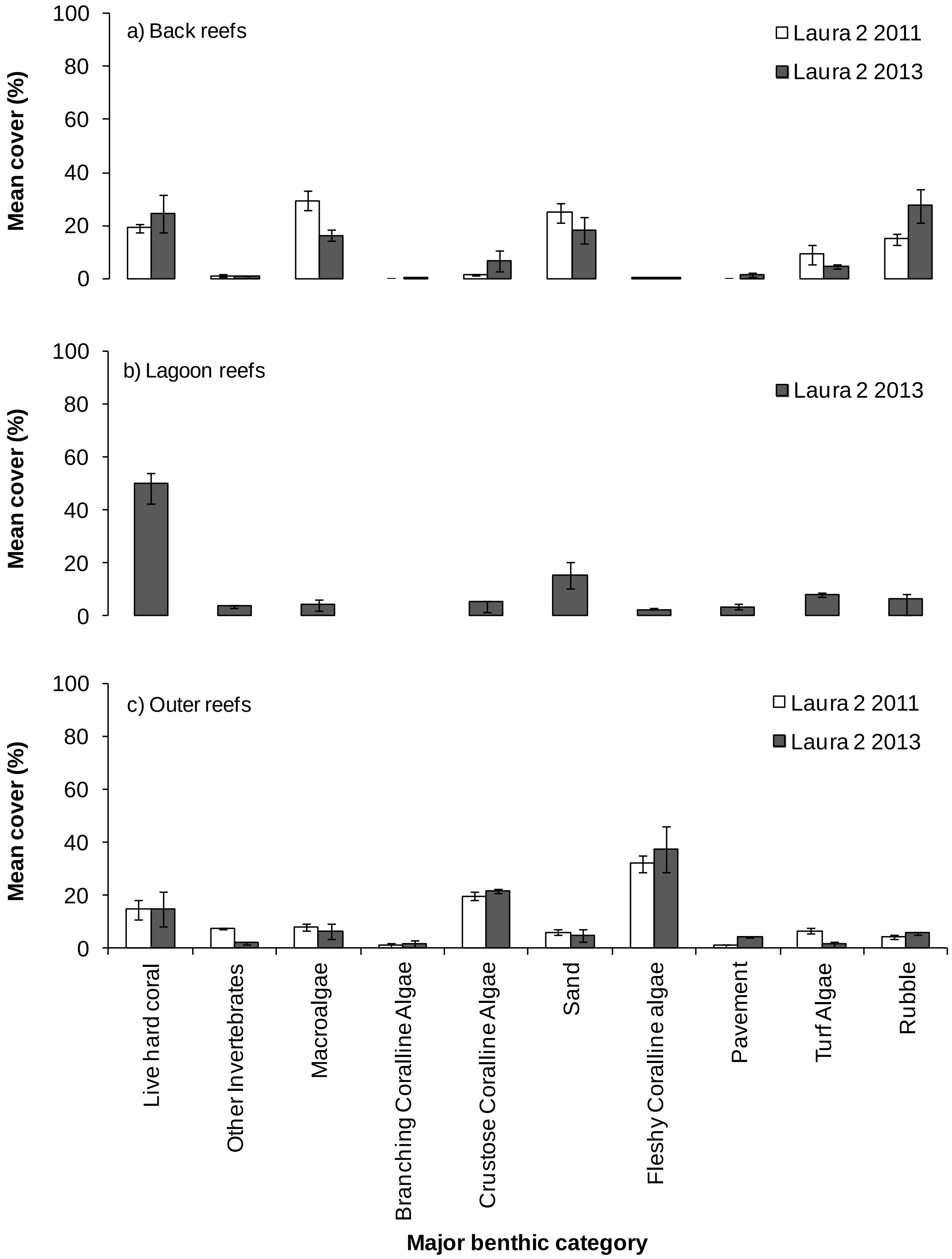


Figure 36 Percent cover of major benthic categories at a) back reef, b) lagoon reef and c) outer reef transects of the Laura 2 monitoring site among 2011 and 2013 surveys.

Majuro site

Benthic habitat assessments within the Majuro site in both 2011 and 2013 covered three habitats, with three 50 m transects completed in each habitat (Table 22; Figure 21).

Table 22 Details of benthic habitat monitoring transects within the Majuro monitoring site.

Habitat and transect	Latitude (N)	Longitude (E)	Years monitored
Back reef			
T7	7.155617	171.220450	2011, 2013
T8	7.156150	171.219700	2011, 2013
T9	7.156633	171.218983	2011, 2013
Lagoon reef			
T1	7.156600	171.213450	2011, 2013
T2	7.155850	171.212933	2011, 2013
T3	7.156433	171.215183	2011, 2013
Outer reef			
T34	7.163567	171.215917	2011, 2013
T35	7.163967	171.214633	2011, 2013
T36	7.164167	171.213250	2011, 2013

Few changes were evident in benthic composition of any habitat within the Majuro monitoring site (Figure 37). A slight decrease in turf algae and slight increase in cover of live hard coral were apparent for lagoon reef habitats between the 2011 and 2013 surveys (Figure 37). Increases in hard coral cover, while not statistically significant, were due to slightly higher covers of the genera *Pavona*, *Porites* and *Porites-rus* in 2013 relative to 2011 (Figure 37; Figure 38). For outer reef habitats, a slight decrease in macroalgae, and slight increase in crustose coralline algae, was evident between the 2011 and 2013 surveys (Figure 37), however these changes were not statistically significant. Outer reef transects of the Majuro site were dominated by live hard coral (in particular *Acropora* spp.), macroalgae (particularly *Halimeda* spp.), crustose coralline algae and fleshy coralline algae (*Peyssonnelia* sp.) (Figure 39).

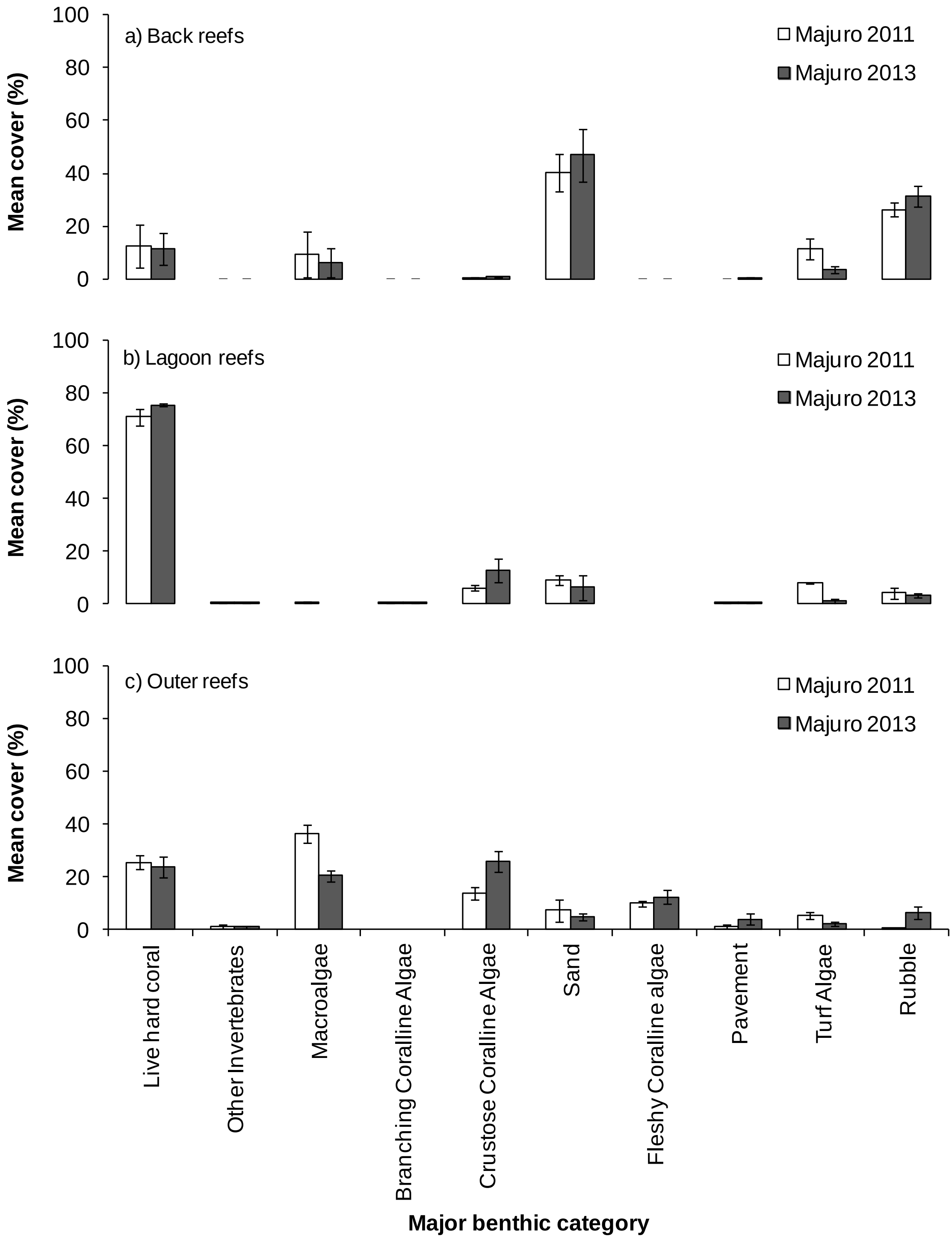


Figure 37 Percent cover of major benthic categories at a) back reef, b) lagoon reef and c) outer reef transects of the Majuro monitoring site among 2011 and 2013 surveys.

Figure 38 Lagoon reef habitats of the Majuro monitoring site had a high cover of live coral, in particular *Porites-rus*.

Figure 39 Outer reef habitats of the Majuro monitoring site had a high cover of live coral (in particular *Acropora* spp.), *Halimeda* spp. and crustose coralline algae.

Woja MPA site

The benthic habitats of the Woja MPA were surveyed for the first time in 2013. Three 50 m transects were completed along each of the back reef and outer reefs within the MPA (Table 23; Figure 25). No lagoon reef habitats were available for survey at this site.

Table 23 Details of benthic habitat monitoring transects within the Woja MPA monitoring site.

Habitat and transect	Latitude (N)	Longitude (E)	Years monitored
Back reef			
T37	7.094867	171.129783	2011, 2013
T38	7.094533	171.131333	2011, 2013
T39	7.093683	171.132767	2011, 2013
Outer reef			
T40	7.087817	171.120267	2011, 2013
T41	7.087350	171.131633	2011, 2013
T42	7.086733	171.132783	2011, 2013

Back reefs of the Woja MPA were characterised by relatively high cover of macroalgae and live coral (Figure 40). The dominant coral genera were *Acropora*, *Porites* and *Porites-rus*, while the dominant algae genera were *Dictyota* and *Halimeda* (Figure 41). Mean cover of both live hard coral and macroalgae were slightly higher on the back reefs of the Woja MPA than those of the comparably-situated Laura 2 site (Figure 40).

Outer reef habitats of the Woja MPA were characterised by a relatively high percent cover of fleshy coralline algae (*Peyssonnelia*) and macroalgae (*Halimeda* spp.) (Figure 40). In contrast to back-reef habitats, no differences in broadscale benthic habitat composition were evident for outer reefs among the Woja MPA and Laura 2 monitoring sites (Figure 40). Slight differences in coral community composition were evident, with outer reef habitats of the Woja MPA having a slightly higher percent cover of *Isopora* and *Porites*-massive corals, and a lower percent cover of *Acropora* spp. relative to the outer reef of the Laura 2 monitoring site.

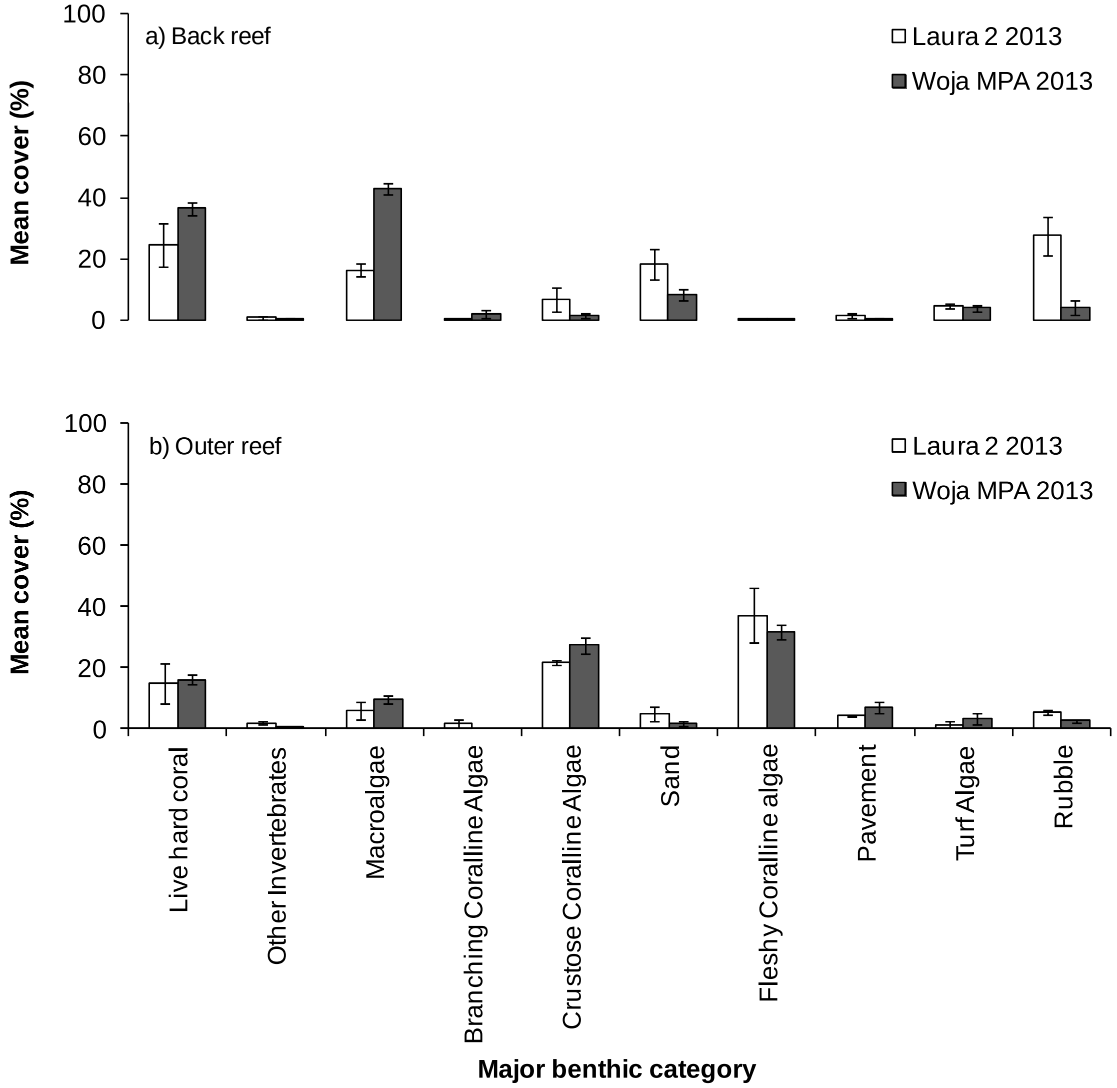
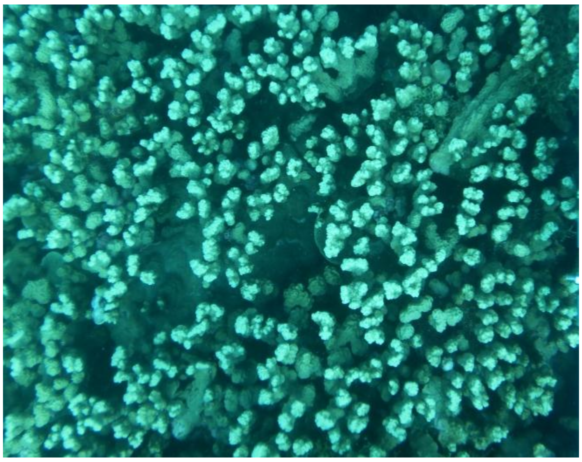


Figure 40 Percent cover of major benthic categories at a) back reef and b) outer reef transects of the Laura 2 and Woja MPA sites, 2013.

Figure 41 Benthic habitats of the Woja MPA were characterized by relatively high cover of macroalgae and live hard coral, in particular *Halimeda* spp. and *Acropora* spp.

Figure 42 A stand of *Porites-rus* within the back-reef of the Woja MPA.



6. Invertebrate Surveys

Methods and Materials

Data collection

Broad-scale assessments

Invertebrate resources of Majuro Atoll were surveyed using two complementary techniques: 1) manta tows, and 2) reef-benthos transects (RBt). Broad-scale assessments were conducted by manta tow in three sites of Majuro Atoll: Laura, Majuro and Ajeltake (Figure 29). In these assessments, a snorkeler was towed behind a boat with a manta board for recording the abundance of large sedentary invertebrates (e.g. sea cucumbers) at an average speed of approximately 4km/hour (Figure 43; Table 24). Hand tally counters were also mounted on the manta board to assist with enumerating the common species on site. The snorkeller'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 Etrex 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.

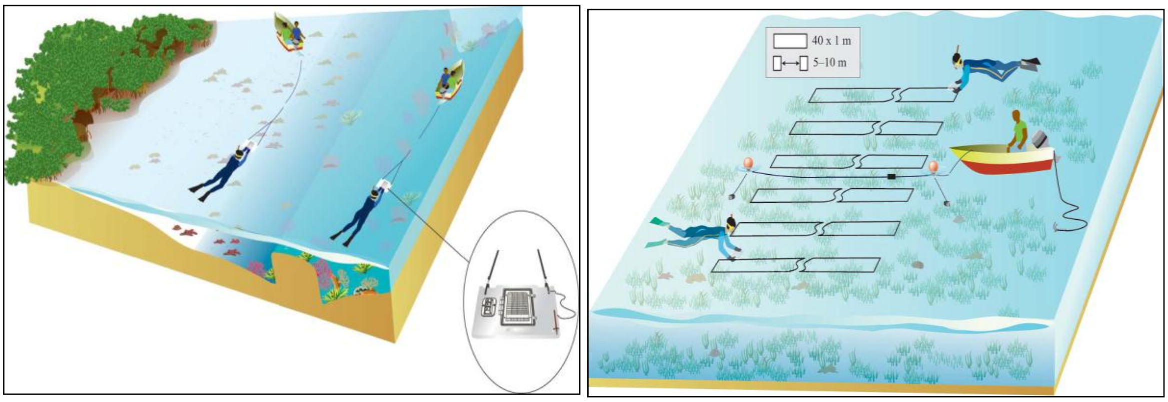


Figure 43 Diagrammatic representation of the two invertebrate survey methods used at Majuro Atoll during the 2011 and 2013 surveys: manta tow (left) and reef benthos transects (right).

Fine-scale assessments

Reef-benthos transects (RBt) were conducted to assess the abundance, size and condition of invertebrate resources and their habitat at finer-spatial scales. Eighteen RBt stations were established within Majuro Atoll, with stations established at the Laura (n = 6), Woja MPA (n = 3), Majuro (n = 6) and Drenmeo MPA (n = 3) regions (Figure 44). Reef-benthos transects were conducted by two snorkellers equipped with measuring instruments attached to their record boards (slates) for recording the abundance and size of invertebrate species. For some species, such as sea urchins, only abundance was recorded due to difficulty in measuring the size of these organisms. Each transect was 40 m long with a 1 m 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 43). The GPS position of each station was recorded in the centre of the station.

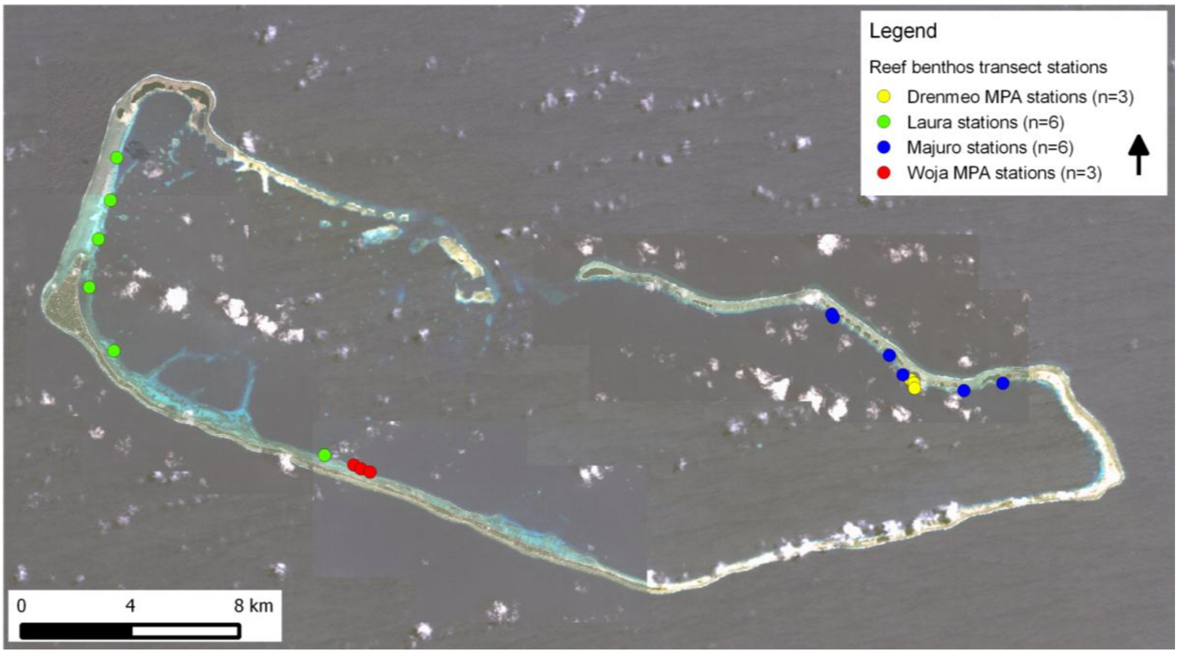


Figure 44 Location of reef-benthos transect (RBt) monitoring stations at Majuro Atoll.

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 site divided by the number of stations at that site;
3) mean density per station (individuals/ha); and
4) mean size (mm).

Additionally, mean densities of invertebrate species at the Laura stations in both 2011 and 2013 were compared against those collected during the PROCFish surveys in this region in 2007 (Pinca et al. 2009) for manta tow assessments.

Table 24 Species analysed in manta tow assessments (where present).

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

To explore differences in invertebrate densities observed during manta tows and RBts amongst surveys and sites, density data within each station were ln(x+1) transformed to reduce heterogeneity of variances and analysed by two way ANOVA at P = 0.05, using Statistica 7. Data was analysed on an individual species level except for gastropods, which were pooled at a genus level. 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 $P = 0.025$ was used.

Results

Manta tow

In general, densities of invertebrates observed during manta tows were low during all surveys, with only *H. atra* observed in densities greater than 150 individuals/ha (Figure 45). The following differences were observed amongst surveys:

- Densities of the sea cucumber *Thelenota anax* at the Majuro site appeared significantly lower in the 2013 survey than in 2011, decreasing from 122±32.79 to 9.72±4.90 (P < 0.001)
- Densities of the giant clam *Tridacna maxima* at the Laura site appeared significantly lower in 2013 relative to the PROCFish surveys of the region in 2007, decreasing from 25.35±11.29 to 0.46±0.46 (P = 0.015)
- Densities of the giant clam *Tridacna squamosa* at the Laura site appeared significantly lower in both 2011 and 2013 relative to the PROCFish surveys in 2007, decreasing from 2.31±0.89 to zero in both 2011 and 2013 (P = 0.015)

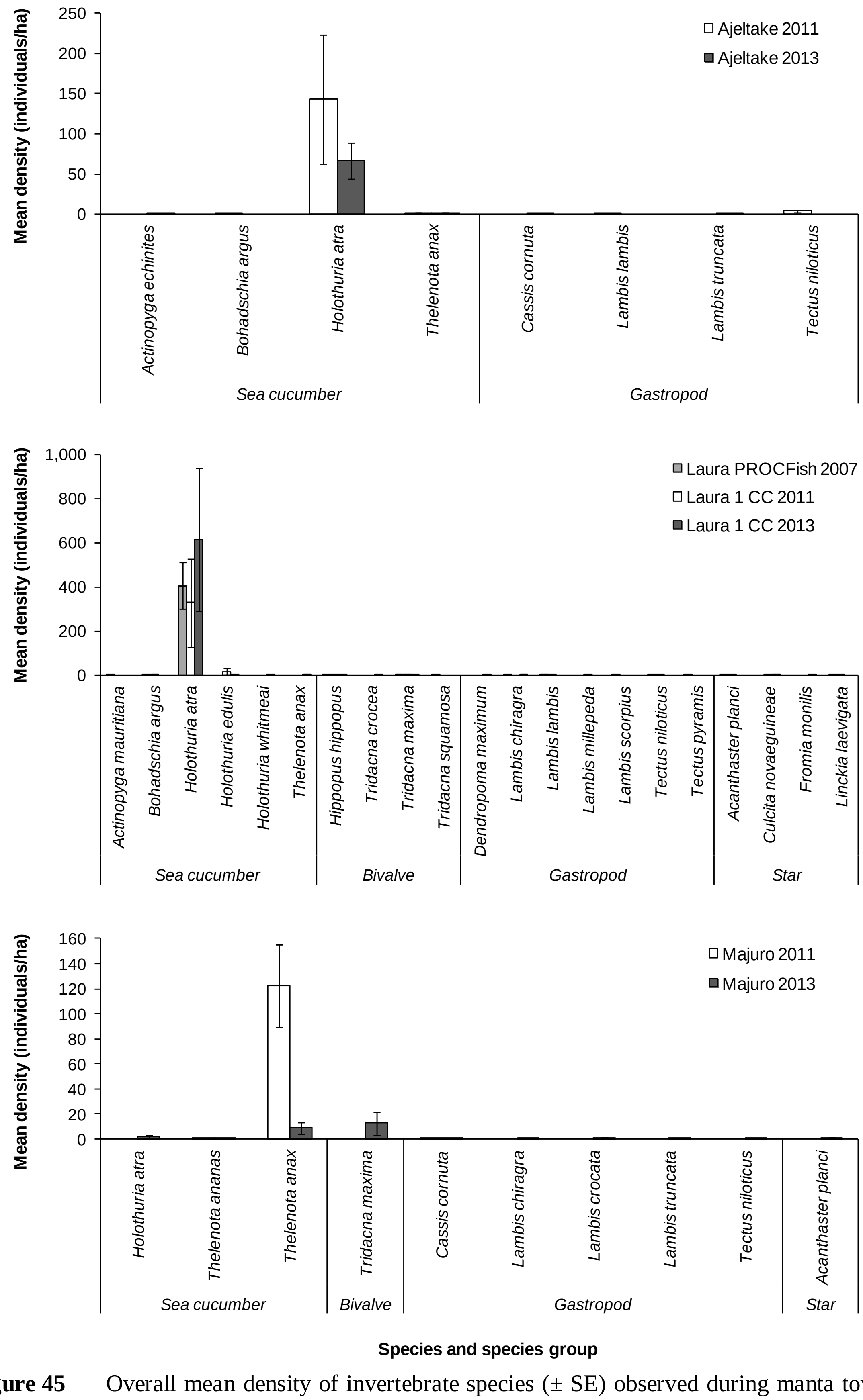


Figure 45 Overall mean density of invertebrate species (± SE) observed during manta tows at a) Ajeltake (top), Laura (middle) and Majuro stations, 2007, 2011 and 2013.

Reef-benthos transects

Invertebrate diversity at RBt stations was higher in 2013 than 2011 for all monitoring sites (Table 25). In terms of mean densities, the following differences were observed amongst surveys:

- Densities of the sea cucumber *Bohadschia argus* at the Drenmeo MPA site appeared significantly lower in the 2013 survey than in 2011, decreasing from 291.67 to 13.89±13.89 ($P < 0.001$)
- Densities of the sea cucumber *Holothuria atra* were significantly higher within the Woja MPA site than all other sites ($P < 0.001$)
- Densities of members of the gastropod genus *Turbo* were significantly higher within the Woja MPA site than the Laura site in both 2011 and 2013 ($P \leq 0.035$)

While densities of *Conomurex luhuanus* appeared lower at the Majuro and Drenmeo MPA sites in 2013 relative to 2011 (Figure 46), these were not significantly different at $P = 0.05$.

Table 25 Total number of genera and species, and diversity of invertebrates observed during reef-benthos transects at the Drenmeo MPA, Majuro, Laura and Woja MPA monitoring sites, 2011 and 2013.

Parameter	**Drenmeo MPA**		**Majuro**		**Laura**		**Woja MPA**	
	2011	**2013**	**2011**	**2013**	**2011**	**2013**	**2011**	**2013**
No. stations completed	1	3	4	6	5	6	0	3
No. of genera	3	14	7	17	10	15	-	9
No. of species	3	15	7	23	11	18	-	11
Diversity	3.0	5.0	1.8	3.8	2.2	3.0	-	3.7

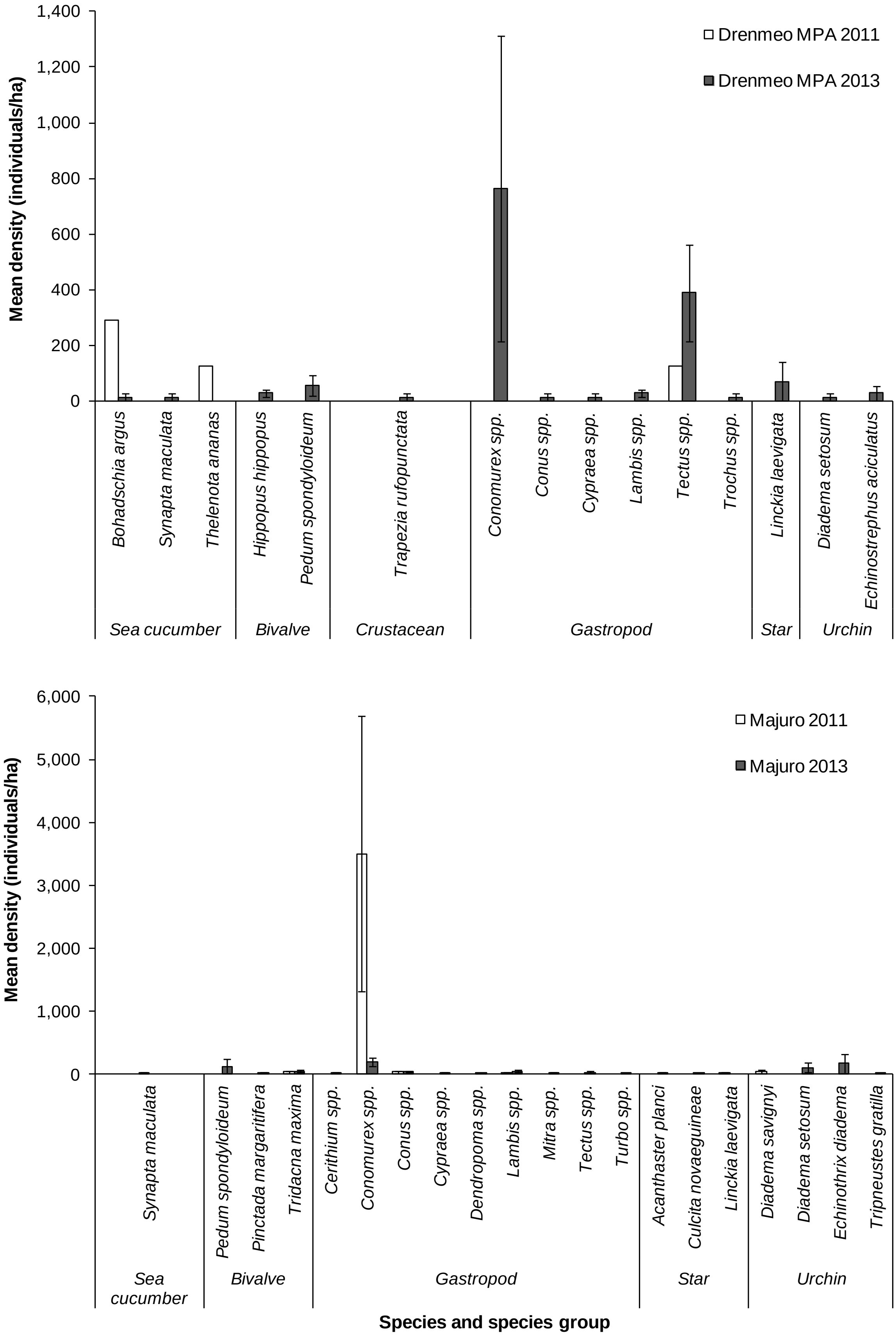


Figure 46 Overall mean density of invertebrate species (± SE) observed during reef-benthos transects at Drenmeo MPA (top) and Majuro monitoring stations, 2011 and 2013.

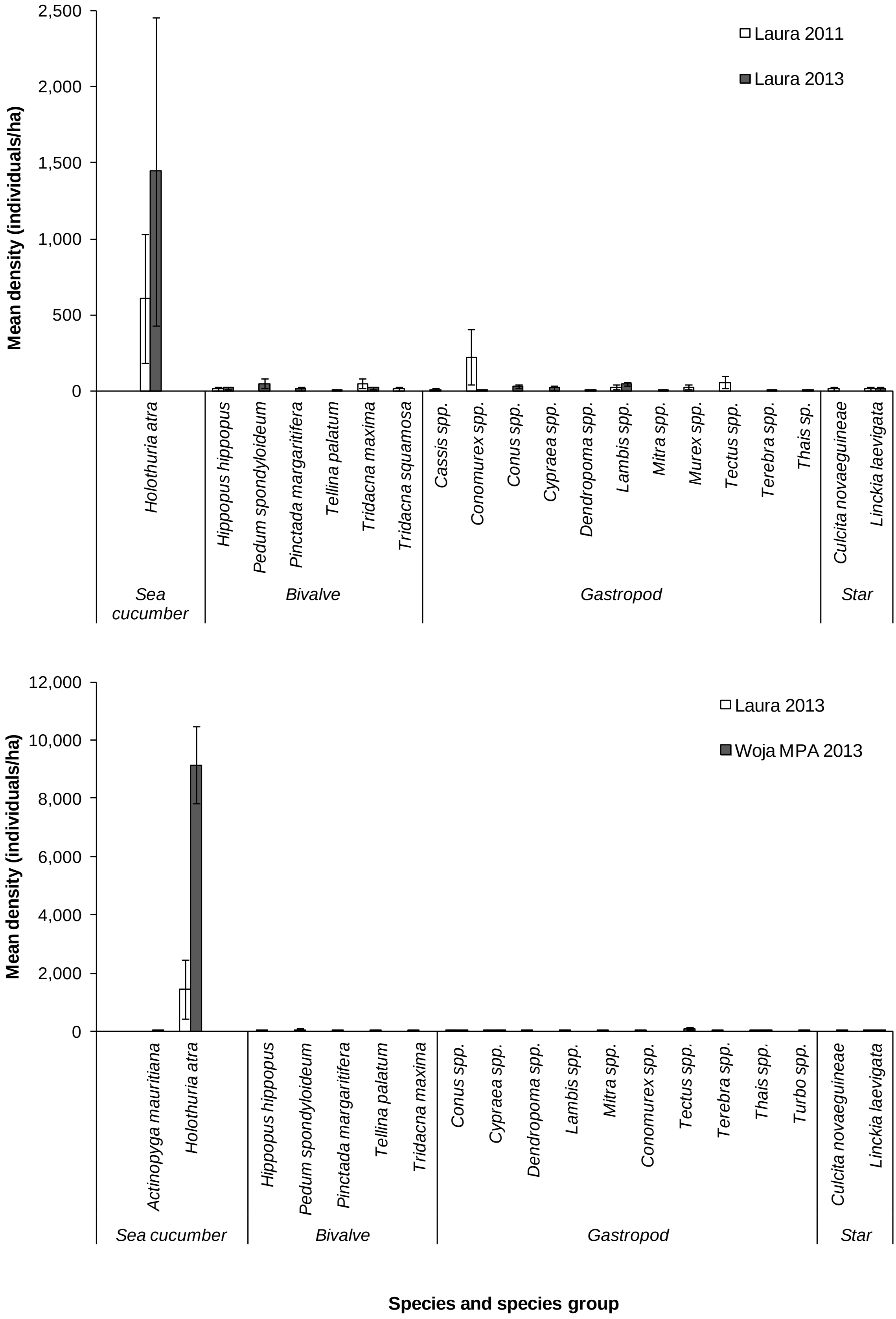


Figure 47 Overall mean density of invertebrate species (± SE) observed during reef-benthos transects at Laura stations, 2011 and 2013 (top), and Laura and Woja MPA stations, 2013.

7. Creel Surveys

Methods

Creel surveys at Majuro Atoll focused on commercial spear and bottom (handline) fishers. The creel surveys had the following objectives:

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

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

During the survey the lead fisher was asked questions relating to the fishing trip, including the number of fishers, fishing methods used, locations fished, distance travelled, and costs involved (Figure 48). Their historical fishing patterns, and perceptions of the state of resources, were also documented. Perceptions were documented once only for each lead fisher, regardless of how many times that fisher was surveyed. All finfish caught were identified to species, measured to the nearest mm and weighed to the nearest 10 g unless damaged. Shells were measured to the nearest mm, and octopus measured to the nearest mm and weighed the nearest 10 g, following methods of Pakoa et al. (2014). A copy of the survey form used in the creel surveys is included as Appendix 6.

Data analysis

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

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

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

Figure 48 Melba White of the Marshall Islands Marine Resources Authority interviewing a handline fisher

Figure 49 Lyla Lemari of the Marshall Islands Marine Resources Authority weighing individuals during a bottom fishing survey.

Results

A total of 13 creel surveys were completed, with 1,745 individual fish belonging to 72 species and 14 families identified, measured and weighed. All fishers surveyed were male.

Bottom fishing

Five surveys where bottom fishing was the main fishing activity were completed. On average, bottom fishing trips involved 3.4±0.2 fishers and lasted on average 6.8±0.5 hours (Table 26). The average catch per trip was 29.18±4.68 kg, or 51.2±7.9 individual fish. CPUE was 2.24±0.34 fish/fisher/hour, or 1.27±0.19 kg/fisher/hour (Table 26). Bottom fishing took place mainly in the main pass near Irooj Islet, around the back and patch reefs near Rongrong Islet and along the back reefs of Woja.

The catch was dominated by macro-carnivores/piscivores of the families Serranidae, Lethrinidae and Lutjanidae (Figure 50;Appendix 7). A total of 247 individual fishes from twenty species were observed in the bottom fishing catch (Appendix 7), the most common of which were *Epinephelus polyphekadion* (representing 51% of total catch by number and 47% of the total catch by weight), *Epinephelus maculatus* (9% of total catch by number and 14% of the total catch by weight), *Lutjanus gibbus* (9% of total catch by number and 5% of the total catch by weight) and *Lethrinus erythropterus* (6% of the total catch by both number and weight) (Appendix 7).

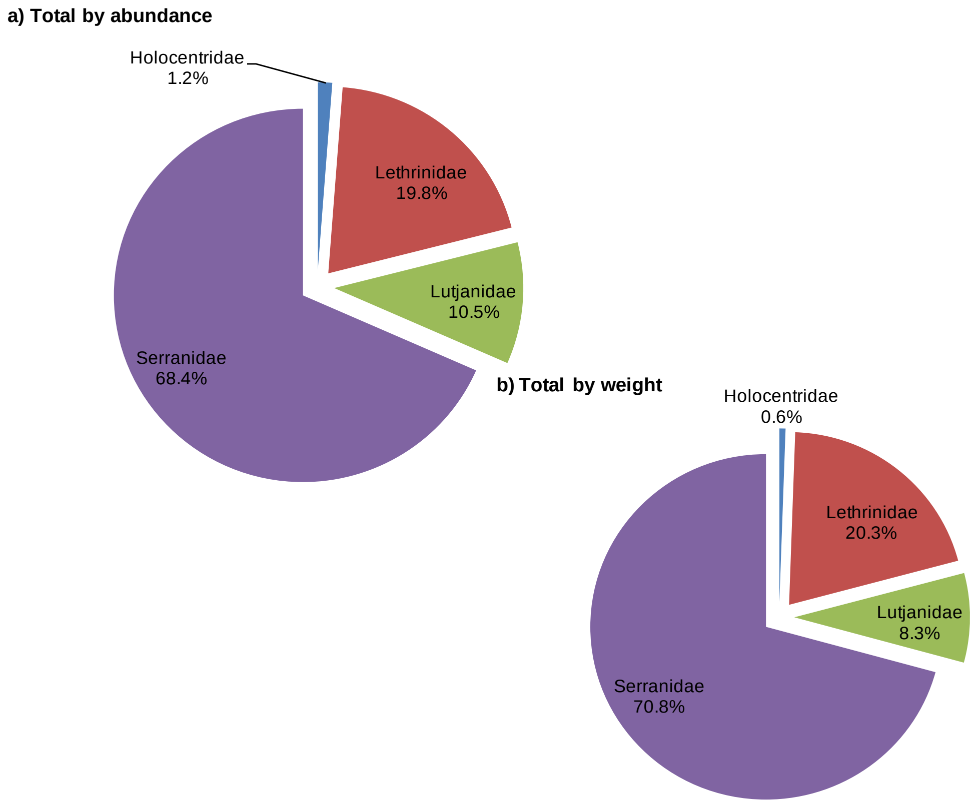


Figure 50 Percent contribution by a) total number and b) total weight of families caught by bottom fishing, Majuro Atoll, August 2013.

Table 26 Data summary of creel surveys conducted at Majuro Atoll, 2013.

Predominant fishing method used	**Handline**	**Spear**
No. surveys	5	8
Total number of fishers surveyed	17	41
Mean time spent fishing (hrs)	6.8±0.5	4.4±0.5
Mean no. of fishers per trip	3.4±0.2	5.1±0.6
Average catch (number of fish) per trip	51.2±7.9	186.1.5±31.2
Average catch (kg) per trip	29.18±4.68	55.9±10.0
Average CPUE by abundance (no. fish / fisher / hour)	2.24±0.34	8.7±1.1
Average CPUE by weight (kg / fisher / hour)	1.27±0.19	2.59±0.37
No. of landings needed to survey to detect change in CPUE by abundance at precision of 0.2 (to 1 sig. fig.)	3	3
No. of landings needed to survey to detect change in CPUE by weight at precision of 0.2 (to 1 sig. fig.)	3	4

Spearfishing

Eight surveys where spearfishing was the main fishing activity were completed. With the exception of a single trip, all spear-fishing trips were conducted at night. On average, spearfishing trips involved 5.1±0.6 fishers, with a mean duration of 4.4±0.5 hours (Table 26). The average catch per trip was 55.86±9.99 kg, or 186.1±31.2 individual fish. Catch-per-unit effort (CPUE) was 8.73±1.11 fish/fisher/hour, or 2.59±0.37 kg/fisher/hour (Table 26). As with bottom fishing, spearfishing trips mainly took place around the back and patch reefs of the north-west of the atoll near Rongrong Islet, the main pass near Irooj Islet and along the back reefs of Woja and Ajeltake.

Fourteen families were observed in the spearfishing catch, with members of the Acanthuridae, Siganidae, Holocentridae and Serranidae dominating the total catch by both abundance and weight (Figure 51; Appendix 7). A total of 1,498 individual fishes from 62 species were observed in the spearfishing catch (Appendix 7). The most common finfish species caught were *Siganus argenteus* (representing 24% of total catch by abundance and 17% by weight), *Acanthurus lineatus* (18% of total catch by abundance and 11% by weight), *Naso lituratus* (7% of the total catch by both abundance and weight) and *Myripristis berndti* (5% of total catch by abundance and 3% by weight) (Appendix 7).

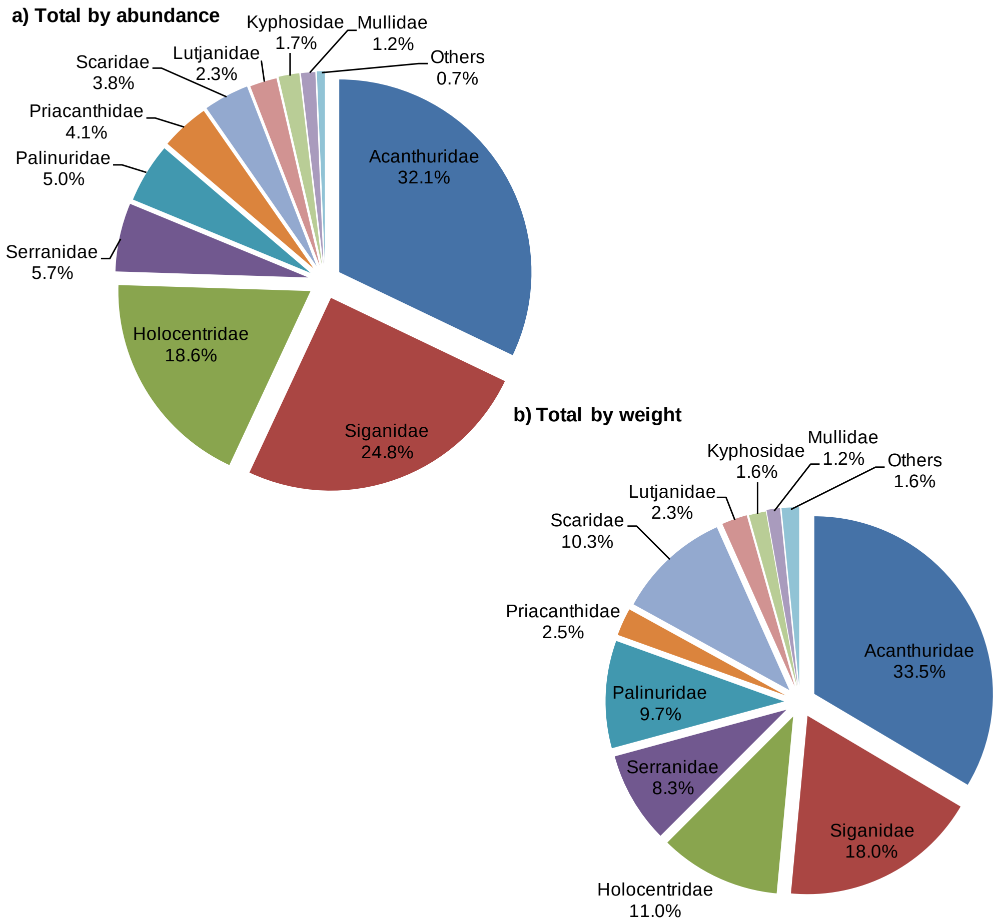


Figure 51 Percent contribution by a) total number and b) total weight of families caught by spearfishing, Majuro Atoll, August 2013.

Length frequencies

Length frequency plots for eight of the most commonly observed species for bottom fishing and spearfishing catches are presented as Figure 53. For *Epinephelus polyphekadion* and *Lutjanus gibbus*, few differences were observed in size of individuals caught by the different fishing methods (Figure 53). Approximately 73% of the *E. polyphekadion* caught by bottom fishing and 81% caught by spearfishing were under the median length at maturity of 352 mm proposed by Rhodes et al. (2011) for populations in Pohnpei. Similarly, 53% of the *L. gibbus* caught by bottom fishing, and 52% caught by spearfishing, were under the regional estimated median length of maturity of 25 cm FL (SPC unpublished data) (Figure 53). All *N. lituratus* and were larger than the median lengths of maturity estimated for populations in Micronesia (Taylor et al. 2014).

Fisher Perceptions

Fisher perceptions were collected during six surveys[2]. The majority of fishers surveyed indicated that they had seen changes in the fishery in the last few years, with 67% of all respondents stating they considered their catches had decreased compared to five years ago, and 83% of all respondents stating the sizes of fish had decrease compared to five years ago (Figure 52).

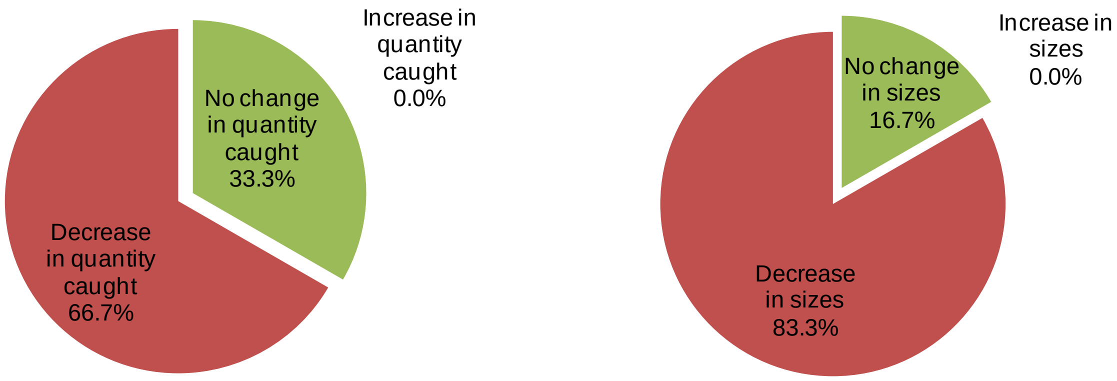


Figure 52 Responses of lead fishers to questions on perceptions on whether catch quantities (left) or fish sizes (right) have changed over the last five years.

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

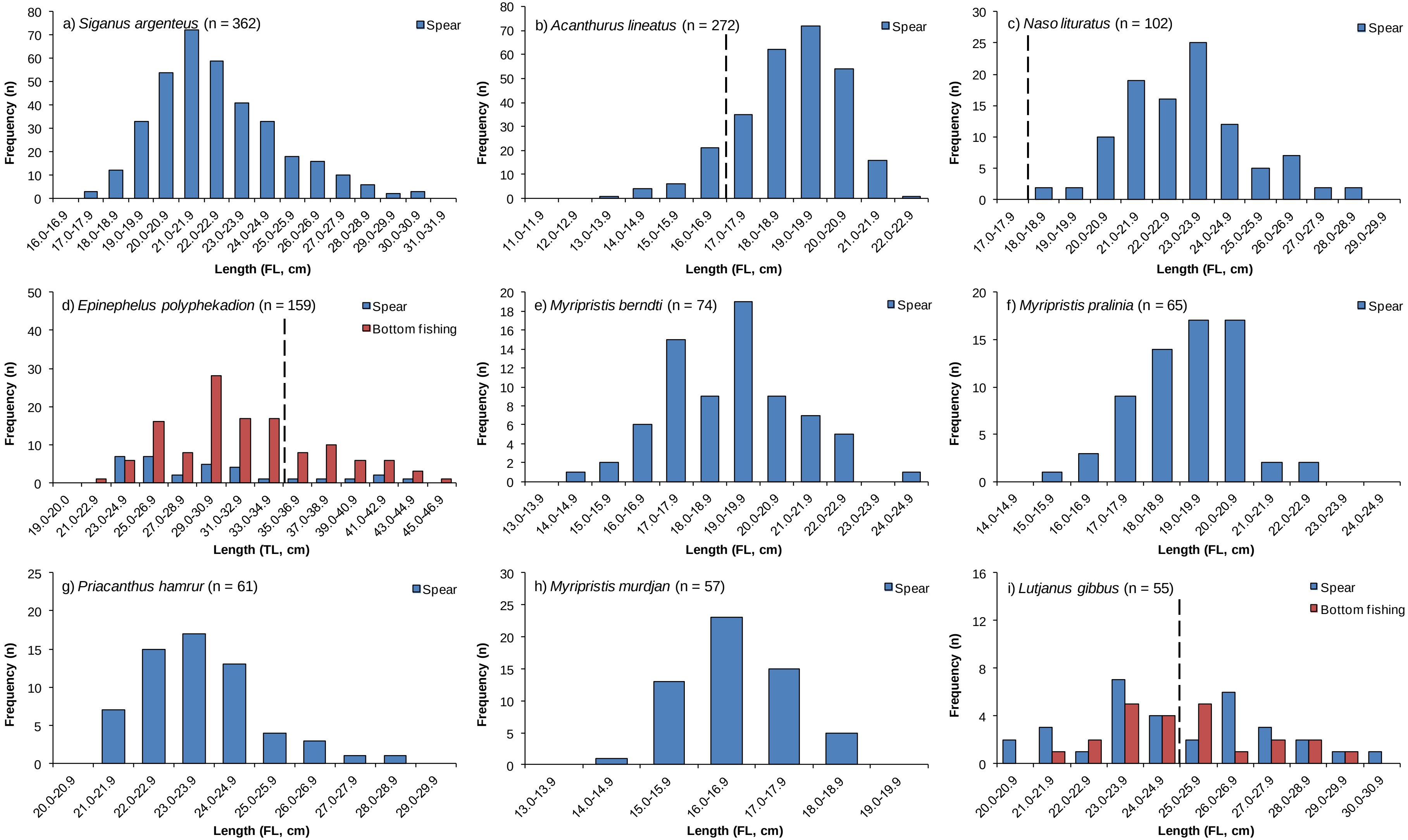


Figure 53 Length frequency of most commonly observed finfish species during creel surveys at Majuro Atoll, 2013.Dashed lines indicate estimated lengths at 50% maturity from: c) Taylor et al. (2014); d) Rhodes et al. (2011); i) SPC unpublished data.

8. Biological Monitoring of Selected Reef Fish Species

Methods

Sample collection

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

Sample processing

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

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

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

Data analysis

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

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

where L_t is the length of fish at age t, L_∞ is the hypothetical asymptotic length, K is the growth coefficient or rate at which L_∞ is approached, and t_0 is the hypothetical age at which fish would have a length of zero. Due to a lack of smaller, younger fish in the samples, t_0 was constrained to zero. Sex-specific VBGFs were initially fitted for each species. Preliminary results indicated little significant difference in growth of males and females of *C. lunulatus* and *C. striatus*; hence a combined growth curve was fitted for males and females of each of these species.

Age-based catch curves (Ricker 1975) were used to estimate the instantaneous rate of total mortality (Z) for each species with samples sizes ≥ 40. Catch curves were generated by fitting a linear regression to the natural log-transformed number of fish in each age class against fish age. The slope of this regression is an estimate of the rate of annual mortality. Regressions were fitted from the first modal age class, presumed to be the first age class fully selected by the sampling gear, to the oldest age class that was preceded by no more than two consecutive zero frequencies. Instantaneous natural mortality rates (M) were derived using the general regression equation of Hoenig (1983) for fish:

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

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

Results

Thirty-seven redfin butterflyfish (*C. lunulatus*) were collected by fisheries-independent spearfishing at Majuro Atoll, with 31 of these aged to date. Estimated ages ranged from 1–4 years, with a modal age of 2 years (Figure 54; Table 27). Growth was similar amongst sexes, and was rapid early in life, conistsent with descriptions of growth elsewhere across the species range (Figure 54) (Berumen et al. 2012). Age structures were relatively truncated compared to those of Berumen et al. (2012), who estimated a maximum age of 17+ years for this species on the Great Barrier Reef, Australia. Such differences likely reflect the low samples sizes of the present study. Due to low sample sizes, no mortality estimates were calculated for this species. Accordingly, greater sampling of this species at Majuro Atoll should be undertaken.

Forty-eight striated surgeonfish (*C. striatus*) were collected by fisheries-independent spearfishing at Majuro Atoll, with 46 of these aged to date. Estimated ages ranged from 1–17 years, with a modal age of 3 years (Figure 54; Table 27). Little difference in growth was evident among sexes

(Figure 54). As with *C. lunulatus*, age structures were relatively truncated compared to those from previous studies (e.g. Choat and Axe 1996, Trip et al. 2008), which again may reflect the low samples sizes of the present study. Accordingly, further sampling of this species at Majuro Atoll should be undertaken.

Fifty-five humpback red snapper (*L. gibbus*) were collected from the commercial catch from Majuro Atoll, with 52 of these having been aged to date. Estimated ages for this species at Majuro ranged from 2–21 years, with a modal age of 5 years (Figure 54; Table 27). Growth differed markedly among sexes, with males reaching a greater length at a given age than females (Figure 54). Total (Z) and natural (M) rates of mortality were estimated as 0.288 and 0.199, respectively (Table 28). Fishing mortality was estimated as 0.090, slightly under the recommended maximum fishing mortality rate of 0.099 (Table 28).

Fifty-five orangespine unicornfish (*N. lituratus*) were collected from the spearfishing catch from Majuro Atoll, with 47 of these aged to date. Estimated ages ranged from 1–20 years, with a modal age of 2 years (Figure 54; Table 27). As with *L. gibbus*, growth differed among sexes, with males reaching a greater length at a given age than females (Figure 54). Total (Z) and natural (M) rates of mortality were estimated as 0.245 and 0.209, respectively (Table 28). Fishing mortality was estimated as 0.036, under the recommended optimal fishing mortality rate of 0.104 (Table 28).

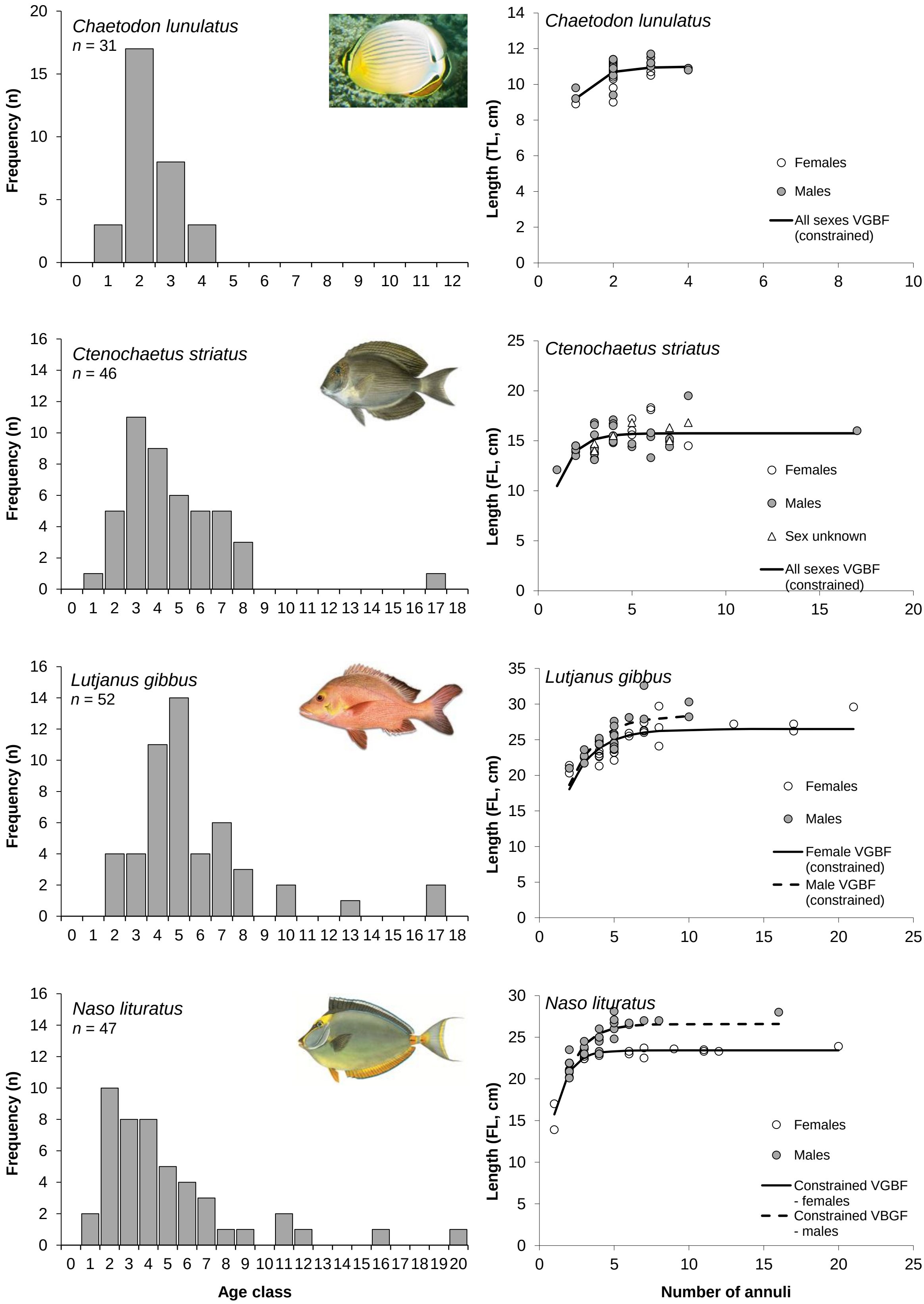


Figure 54 Age frequency distributions (left) and von Bertalanffy growth function curves (right) for the four monitored finfish species at Majuro Atoll, July–August 2013.

Table 27 Demographic parameter estimates for selected reef fish species from Majuro Atoll, Marshall Islands, July–August 2013. VBGF parameters are based on constrained (t_0=0) estimates.

Species	No. collected	No. aged to date	Size range (cm)	Age range	L_∞ (males / females)[3]	K (males / females)
Chaetodon lunulatus	37	30	8.9–11.7 (TL)	1–4	10.99	1.82
Ctenochaetus striatus	48	46	12.1–19.5 (FL)	1–17	15.75	1.09
Lutjanus gibbus	60	52	20.3–32.6 (FL)	2–21	28.47 / 26.50	0.53 / 0.57
Naso lituratus	55	52	13.9–28.1 (FL)	1–20	26.59 / 23.43	0.79 / 1.11

Table 28 Estimates of mortality for exploited species using catch curve and Hoenig (1983) estimators. Maximum ages used in the equation of Hoenig (1983) and age ranges used for total mortality (Z) calculations are indicated. Green faces indicate F < 0.5M.

Species	Maximum age (yr)	Age range	Catch curve (Z)	Hoenig (1983)	Fishing mortality (F)	Fopt
Lutjanus gibbus	21 (this study)	5–13	0.289	0.199	0.090	0.099 ☺
Naso lituratus	20 (this study)	3–12	0.265	0.209	0.056	0.104 ☺

[3] Figures for *Chaetodon lunulatus* and *Ctenochaetus striatus* are based on data for males and females combined.

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

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

1. **Expand the network of locally managed Marine Protected Areas.** To maintain biodiversity, ecosystem functioning and resilience, and confer benefits to adjacent fisheries, in accordance with the objectives of the Micronesia Challenge, it is highly recommended that the reserve network within Majuro Atoll be expanded. Combined, no-take areas make up < 2% of the reef area of Majuro Atoll. The expansion of the MPA network in Majuro Atoll could be conducted in two ways: 1) creation of new protected areas, and/or 2) expanding the existing protected areas. That both the Drenmeo and Woja MPAs showed little differences in finfish density or biomass relative comparably-situated areas that are open to fishing suggests that the current design is ineffective for protecting fish populations. Ultimately, the design of the MPA network should take into account conservation targets, socio-ecological and economic interests, and the home ranges of species the MPA is intended to protect (Green et al. 2013). Green et al. (2013) provide a guide to designing marine protected areas to achieve conservation objectives in tropical ecosystems. As a general rule of thumb, they recommend the following:
    - that MPAs represent 20–40% of the available area of each habitat;
    - that protected areas are established across widely separated areas, to minimise the risk that all areas will be adversely impacted by the same disturbance; and
    - that MPAs be twice the size of the minimum home range of the species they are implemented to protect. For example, most species of browsing or scraping herbivores, considered to be key for reducing overgrowth of coral by macroalgae (and thus preventing coral-algae regime shifts) have home ranges in the order of 500 m to 2 km (Green et al. 2013).

2. **Place restrictions on destructive or highly efficient fishing practices, in particular night-time spearfishing.** While coral communities in the northern regions of Majuro Atoll are relatively healthy, considerable overgrowth of corals by macroalgae is apparent along the back-reef of the more densely populated south of the Atoll, spanning from Laura in the west to Delap in the east (encompassing the Laura and Ajeltake broad-scale habitat assessment sites). This finding is suggestive of a widespread historical coral-algae regime shift in this region, likely resulting from heavy fishing pressure on herbivorous fishes, higher levels of eutrophication and relatively poor tidal flushing. While few browsing herbivores were observed during the in-water assessments, the group comprised a significant proportion of the spearfishing catch

observed during the creel surveys. In addition to expanding the MPA network, any possible methods to reduce fishing effort on browsing and scraping herbivorous fishes should be undertaken to minimise the risk of a widespread coral-algae regime shift in the Atoll. In particular, moves to restrict or prohibit the destructive and highly efficient fishing practices that target these groups, in particular night-time spearfishing, should be put in place. In conjunction, incentives should be offered to move fishing effort away from reef resources and onto small pelagics.

3. **Assess and monitor grouper catches.** The relatively large numbers of serranids, in particular *Epinephelus polyphekadion*, observed during creels surveys is cause for concern and needs greater investigation. The over-dominance of *E. polyphekadion* and other grouper species in the bottom fishing catch suggests that fishers may be targeting a spawning aggregation. Both *E. polyphekadion* and *E. fuscoguttatus* are listed as 'Near Threatened' on the IUCN Red list due to their susceptibility to over-fishing, particularly of spawning aggregations. Should a spawning aggregation be identified management measures, such as seasonal closures, need to be put in place to ensure its protection. Many Pacific Island countries and territories have implemented or are in the process of implementing seasonal restrictions of the harvest of groupers. For example, in Palau it is illegal to fish for, sell, receive, export, process or buy any *E. fuscoguttatus*, *E. polyphekadion*, *Plectropomus areolatus*, *P. laevis* or *P. leopardus*, from April 1 to October 1 regardless of where such species may have originated. Such restrictions could be embedded within a larger coastal fisheries management plan or set of domestic fishing regulations (see Item 6 below).

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

5. **Maintain the national closure of sea cucumber fisheries.** A total ban was placed on the export of sea cucumbers in 2011 to allow stocks to recover until new sea cucumber fishery regulations could be developed. Due to low observed densities, sea cucumber fisheries within Majuro Atoll should remain closed to allow recovery of stocks and the ecological functioning they perform. Similarly, there is no potential for commercial fishing of trochus at this time, and stocks are in need of on-going protection to build until recommended minimum harvest densities of 500–600 individuals/ha are achieved.

6. **Develop and implement coastal fisheries management plan / regulations.** Finfish fishing in Majuro Atoll and elsewhere in the Marshall Islands is at present highly unregulated, with little rules or restrictions on harvests. To ensure fish for futire generations is strongly recommended that a coastal fisheries management plan / regulations be developed that addresses various fishing activities (e.g. fishing gears and practices), restrictions on species' harvests (e.g. size limits, seasonal closures during spawning season), export of coastal resources and community management practices.

7. **Strengthen stakeholder awareness programs and exchange of information on coastal fisheries, the marine environment and climate change.** Further to maintaining the existing and establishing additional no-take areas, education or awareness programs should be offered to the general public of Majuro Atoll regarding the benefits of marine reserves or herbivorous fish stocks, lengths at maturity etc. A better-informed public would assist in the co-management of coastal fisheries resources.

Recommendations for Future Monitoring

To be able to assess the success of management interventions and well as monitor the status and trends in productivity of the region's coastal fisheries and supporting habitats in the face of climate change and other anthropogenic stressors, continual monitoring is needed. Finfish communities in particular typically show high inter-annual variation (e.g. Sweatman et al. 2008), meaning a long time-series of data is required to detect prevailing trends. In addition to continuing the monitoring program established here, the following recommendations are proposed for future monitoring events:

- It is highly recommended that a 'core' coastal fisheries monitoring team be established within MIMRA, as well as other relevant organizations (e.g. College of the Marshall Islands, Marshall Islands Conservation Society and Republic of the Marshall Islands Environmental Protection Authority). Developing a core team of monitoring staff will help maintain and build monitoring capacity within the team, and help reduce surveyor biases that may otherwise preclude the detection of 'real' trends.

- Despite several apparent differences in benthic habitat composition and finfish densities among surveys, few statistically significant differences were observed. To improve the power of the benthic habitat and finfish surveys to detect change, and thus reduce the potential for type II errors (i.e. failing to detect difference where differences exist) it is strongly recommended that additional benthic habitat and finfish transects ($\geq$ 2) be established at each site, where space permits. Unfortunately, while this issue was anticipated during the fieldwork, further additional transects (that is, in addition to the 14 added in 2013 from the 2011 survey) could not be completed due to time constraints. These additional transects should be established with immediate effect so as to allow for reliable detection of future changes in benthic habitat and finfish assemblages.

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

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

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

- Monitoring of additional pinnacle reefs within the lagoon of the atoll is highly recommended, however due to the small sizes of many of these reefs modified designs of the present survey methods or alternate monitoring approaches may be required for these habitats (e.g. smaller transects, stationary points counts for monitoring finfish).

- It is advised that the logger housing be shifted to the outer reef near the Majuro and Drenmeo MPA monitoring sites. Here the topography is less steep and better suited to the long-term deployment of the logger housing.

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

- It is highly recommended that the biological monitoring program be expanded, through both an increase in the sample sizes of species collected here and inclusion of other exploited species in this component. Monitoring of the age structure of exploited species is likely to be a more sensitive indicator of the effects of exploitation than monitoring of catch and effortand length frequency data in isolation, due to the likelihood of catch rates for reef-associated species being affected by hyperstability (whereby stable CPUE may persist long after declines in overall population abundance have occurred, due to their high habitat dependencies and aggregative nature) and density-dependence issues (Newman and Dunk 2000).

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Appendix 1 Finfish distance-sampling underwater visual census (D-UVC) survey form

Fish form UVC PAGE /

Campaign |__________| Site |____________________| Diver |__|__| Transect |__|__|__|

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

ST	SCIENTIFIC NAME	NBER	LGT	D1	D2	COMMENTS

Appendix 2 Form used to assess habitats supporting finfish

Habitat Form UVC (new)

Campaign |_______________| **Site** |_______________________| **Diver** |__|__| **Transect** |__|__|__|

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

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

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

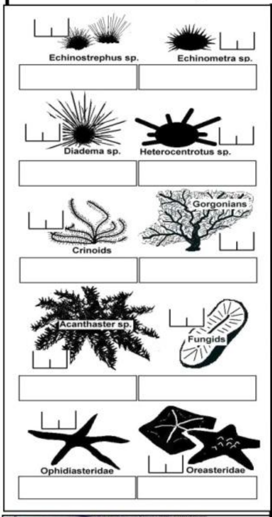
	current	oceanic influence	terrigenous influence
none	☐	☐	☐
medium	☐	☐	☐
strong	☐	☐	☐

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

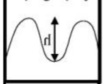
Remarks:

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

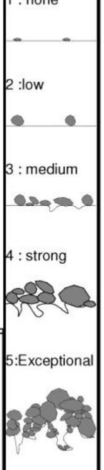
Branching : has secondary branching
Digitate : no secondary branching
Hard coral (dead & live) : Coral attached to substrate with an identifiable shape (otherwise it's abiotic)
Rubble : any piece or whole coral colony of any size that is not attached to substrate
Topography (regardless of surface orientation):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

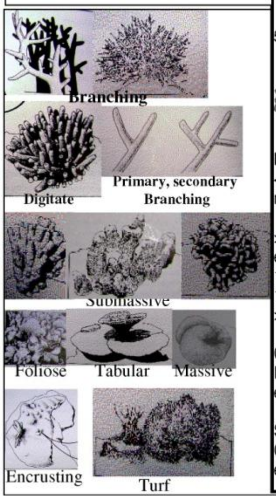


Topography



Complexity





Depth :
<10m : measure it ;

>10 m : estimate as
10-15m
15-20m
>20m

Crest side : Floor=transect depth

Slope side : Crest=transect depth

Appendix 3 Invertebrate survey form

SPC INVERTEBRATE SURVEYS

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

DATE		RECORDER		Pg No	

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

Appendix 4 GPS positions of manta tow surveys conducted at the Ajeltake, Laura and Majuro monitoring sites

Site	Station ID	Replicate	Start Latitude (N)	Start Longitude (E)	End Latitude (N)	End Longitude (E)
Ajeltake	Manta_5	1	7.072183	171.182333	7.072083	171.185183
Ajeltake	Manta_5	2	7.072133	171.185817	7.071167	171.188467
Ajeltake	Manta_5	3	7.071150	171.188767	7.070183	171.191583
Ajeltake	Manta_5	4	7.070233	171.191883	7.069650	171.194767
Ajeltake	Manta_5	5	7.069700	171.195350	7.068567	171.197967
Ajeltake	Manta_5	6	7.068267	171.198550	7.066917	171.200933
Ajeltake	Manta_6	1	7.064200	171.210083	7.062500	171.211767
Ajeltake	Manta_6	2	7.062033	171.212433	7.060850	171.215000
Ajeltake	Manta_6	3	7.060500	171.215717	7.059467	171.218650
Ajeltake	Manta_6	4	7.059250	171.218917	7.057933	171.222133
Ajeltake	Manta_6	5	7.057733	171.222850	7.057117	171.225517
Ajeltake	Manta_6	6	7.056783	171.225817	7.056917	171.225417
Ajeltake	Manta_7	1	7.056083	171.237083	7.056350	171.240017
Ajeltake	Manta_7	2	7.056450	171.240433	7.056983	171.243267
Ajeltake	Manta_7	3	7.057217	171.243933	7.058017	171.246750
Ajeltake	Manta_7	4	7.058233	171.247467	7.059417	171.249833
Ajeltake	Manta_7	5	7.059917	171.250450	7.061133	171.253283
Ajeltake	Manta_7	6	7.061283	171.253417	7.062283	171.256117
Ajeltake	Manta_8	1	7.062283	171.259383	7.063917	171.261450
Ajeltake	Manta_8	2	7.064150	171.262483	7.065150	171.265283
Ajeltake	Manta_8	3	7.065367	171.265667	7.066300	171.268383
Ajeltake	Manta_8	4	7.066400	171.268950	7.067033	171.271683
Ajeltake	Manta_8	5	7.067067	171.272217	7.067917	171.274900
Ajeltake	Manta_8	6	7.067833	171.275233	7.068417	171.278000
Laura	Manta_1	1	7.163617	171.043650	7.165933	171.044383
Laura	Manta_1	2	7.165933	171.044617	7.167383	171.044900
Laura	Manta_1	3	7.167383	171.044900	7.169833	171.045100
Laura	Manta_1	4	7.169983	171.045267	7.171833	171.047367
Laura	Manta_1	5	7.171950	171.047450	7.174583	171.046133
Laura	Manta_1	6	7.175417	171.046417	7.177833	171.047817
Laura	Manta_16	1	7.114767	171.077950	7.114233	171.080500
Laura	Manta_16	2	7.114217	171.081033	7.113367	171.083533
Laura	Manta_16	3	7.113083	171.083833	7.112300	171.086133
Laura	Manta_16	4	7.112250	171.086250	7.111083	171.088183
Laura	Manta_16	5	7.111033	171.088383	7.110067	171.090567
Laura	Manta_16	6	7.111200	171.092000	7.111067	171.094467
Laura	Manta_2	1	7.183400	171.049633	7.185883	171.049833
Laura	Manta_2	2	7.186333	171.049650	7.188967	171.050333
Laura	Manta_2	3	7.189300	171.050217	7.192367	171.050933
Laura	Manta_2	4	7.192733	171.050850	7.196583	171.051583
Laura	Manta_2	5	7.197083	171.051400	7.199650	171.052267
Laura	Manta_2	6	7.199850	171.052333	7.202583	171.053050

Site	Station ID	Replicate	Start Latitude (N)	Start Longitude (E)	End Latitude (N)	End Longitude (E)
Laura	Manta_3	1	7.136100	171.049867	7.133250	171.050300
Laura	Manta_3	2	7.132617	171.050550	7.130217	171.051467
Laura	Manta_3	3	7.130517	171.051700	7.127733	171.053350
Laura	Manta_3	4	7.127167	171.053683	7.125567	171.055917
Laura	Manta_3	5	7.125167	171.056167	7.123850	171.059433
Laura	Manta_3	6	7.122983	171.060167	7.121300	171.062217
Laura	Manta_4	1	7.121183	171.062417	7.119767	171.064800
Laura	Manta_4	2	7.119383	171.065217	7.119167	171.067567
Laura	Manta_4	3	7.118667	171.067617	7.118017	171.069967
Laura	Manta_4	4	7.117467	171.070117	7.115950	171.072233
Laura	Manta_4	5	7.116200	171.072533	7.115200	171.074283
Laura	Manta_4	6	7.114683	171.074667	7.113850	171.077133
Majuro	Manta_10	1	7.157300	171.214550	7.156750	171.216850
Majuro	Manta_10	2	7.156833	171.217067	7.156033	171.219550
Majuro	Manta_10	3	7.156000	171.219500	7.155217	171.222033
Majuro	Manta_10	4	7.155150	171.222083	7.154333	171.224850
Majuro	Manta_10	5	7.154450	171.224950	7.154450	171.227700
Majuro	Manta_10	6	7.154367	171.227700	7.153667	171.229883
Majuro	Manta_11	1	7.153817	171.230167	7.152417	171.232583
Majuro	Manta_11	2	7.152450	171.232633	7.151250	171.235083
Majuro	Manta_11	3	7.151133	171.235050	7.149567	171.237250
Majuro	Manta_11	4	7.149450	171.237233	7.148550	171.239650
Majuro	Manta_11	5	7.148250	171.239533	7.148250	171.242117
Majuro	Manta_11	6	7.148050	171.242083	7.146900	171.244467
Majuro	Manta_12	1	7.146650	171.244300	7.146350	171.246933
Majuro	Manta_12	2	7.146283	171.247083	7.145733	171.249583
Majuro	Manta_12	3	7.145750	171.250083	7.145400	171.252750
Majuro	Manta_12	4	7.145350	171.252967	7.145467	171.255633
Majuro	Manta_12	5	7.145483	171.255683	7.145517	171.258500
Majuro	Manta_12	6	7.145417	171.258883	7.146317	171.261617
Majuro	Manta_13	1	7.146600	171.264800	7.147017	171.267517
Majuro	Manta_13	2	7.146900	171.267567	7.147567	171.270167
Majuro	Manta_13	3	7.147383	171.270200	7.147750	171.272883
Majuro	Manta_13	4	7.147667	171.272967	7.148250	171.275683
Majuro	Manta_13	5	7.148250	171.275717	7.148000	171.278483
Majuro	Manta_13	6	7.148050	171.278517	7.148550	171.281100
Majuro	Manta_14	1	7.148333	171.281367	7.147700	171.284133
Majuro	Manta_14	2	7.147617	171.284183	7.146233	171.286083
Majuro	Manta_14	3	7.146233	171.286183	7.145100	171.288700
Majuro	Manta_14	4	7.144967	171.288833	7.143150	171.290700
Majuro	Manta_14	5	7.142967	171.290733	7.141417	171.292667
Majuro	Manta_14	6	7.141567	171.292767	7.139700	171.294567
Majuro	Manta_15	1	7.139217	171.295333	7.137933	171.297567
Majuro	Manta_15	2	7.138500	171.297767	7.136650	171.299817
Majuro	Manta_15	3	7.136683	171.299617	7.134700	171.301817

Site	Station ID	Replicate	Start Latitude (N)	Start Longitude (E)	End Latitude (N)	End Longitude (E)
Majuro	Manta_15	4	7.132317	171.304267	7.132750	171.303800
Majuro	Manta_15	5	7.131667	171.306867	7.131550	171.306300
Majuro	Manta_15	6	7.130067	171.308950	7.130083	171.308700
Ajeltake	Manta_5	1	7.072183	171.182333	7.072083	171.185183
Ajeltake	Manta_5	2	7.072133	171.185817	7.071167	171.188467
Ajeltake	Manta_5	3	7.071150	171.188767	7.070183	171.191583
Ajeltake	Manta_5	4	7.070233	171.191883	7.069650	171.194767
Ajeltake	Manta_5	5	7.069700	171.195350	7.068567	171.197967
Ajeltake	Manta_5	6	7.068267	171.198550	7.066917	171.200933
Ajeltake	Manta_6	1	7.064200	171.210083	7.062500	171.211767
Ajeltake	Manta_6	2	7.062033	171.212433	7.060850	171.215000
Ajeltake	Manta_6	3	7.060500	171.215717	7.059467	171.218650
Ajeltake	Manta_6	4	7.059250	171.218917	7.057933	171.222133
Ajeltake	Manta_6	5	7.057733	171.222850	7.057117	171.225517
Ajeltake	Manta_6	6	7.056783	171.225817	7.056917	171.225417
Ajeltake	Manta_7	1	7.056083	171.237083	7.056350	171.240017
Ajeltake	Manta_7	2	7.056450	171.240433	7.056983	171.243267
Ajeltake	Manta_7	3	7.057217	171.243933	7.058017	171.246750
Ajeltake	Manta_7	4	7.058233	171.247467	7.059417	171.249833
Ajeltake	Manta_7	5	7.059917	171.250450	7.061133	171.253283
Ajeltake	Manta_7	6	7.061283	171.253417	7.062283	171.256117
Ajeltake	Manta_8	1	7.062283	171.259383	7.063917	171.261450
Ajeltake	Manta_8	2	7.064150	171.262483	7.065150	171.265283
Ajeltake	Manta_8	3	7.065367	171.265667	7.066300	171.268383
Ajeltake	Manta_8	4	7.066400	171.268950	7.067033	171.271683
Ajeltake	Manta_8	5	7.067067	171.272217	7.067917	171.274900
Ajeltake	Manta_8	6	7.067833	171.275233	7.068417	171.278000
Laura	Manta_1	1	7.163617	171.043650	7.165933	171.044383
Laura	Manta_1	2	7.165933	171.044617	7.167383	171.044900
Laura	Manta_1	3	7.167383	171.044900	7.169833	171.045100
Laura	Manta_1	4	7.169983	171.045267	7.171833	171.047367
Laura	Manta_1	5	7.171950	171.047450	7.174583	171.046133
Laura	Manta_1	6	7.175417	171.046417	7.177833	171.047817
Laura	Manta_16	1	7.114767	171.077950	7.114233	171.080500
Laura	Manta_16	2	7.114217	171.081033	7.113367	171.083533
Laura	Manta_16	3	7.113083	171.083833	7.112300	171.086133
Laura	Manta_16	4	7.112250	171.086250	7.111083	171.088183
Laura	Manta_16	5	7.111033	171.088383	7.110067	171.090567
Laura	Manta_16	6	7.111200	171.092000	7.111067	171.094467
Laura	Manta_2	1	7.183400	171.049633	7.185883	171.049833
Laura	Manta_2	2	7.186333	171.049650	7.188967	171.050333
Laura	Manta_2	3	7.189300	171.050217	7.192367	171.050933
Laura	Manta_2	4	7.192733	171.050850	7.196583	171.051583
Laura	Manta_2	5	7.197083	171.051400	7.199650	171.052267
Laura	Manta_2	6	7.199850	171.052333	7.202583	171.053050

Appendix 5 GPS positions of reef-benthos transects established at Majuro Atoll

Site	Station ID	Latitude (N)	Longitude (E)
Drenmeo MPA	RBt_12	7.123	171.3154
Drenmeo MPA	RBt_19	7.121833	171.3164
Drenmeo MPA	RBt_9	7.120183	171.3167
Laura	RBt_1	7.1538	171.042
Laura	RBt_15	7.098033	171.1203
Laura	RBt_2	7.1698	171.0451
Laura	RBt_3	7.1827	171.0491
Laura	RBt_4	7.196867	171.0512
Laura	RBt_5	7.132683	171.0502
Majuro	RBt_8	7.1246	171.3128
Majuro	RBt_10	7.11935	171.3331
Majuro	RBt_11	7.121783	171.3461
Majuro	RBt_13	7.143683	171.2897
Majuro	RBt_14	7.14475	171.2892
Majuro	RBt_7	7.131083	171.3083
Woja MPA	RBt_16	7.09475	171.1301
Woja MPA	RBt_17	7.09345	171.1324
Woja MPA	RBt_18	7.092383	171.1354

Appendix 6 Form used for creel surveys at Majuro Atoll

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

Slice C1 basic information on fishers

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

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

C3 Species sizes and C4 Species weights

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

C5 Effort data for CPUE

How many hours spent fishing today?	hrs

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

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

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

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

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

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

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

Site	**Location** (on map, lat/long, or distance to each fishing ground) and **reef type (back, lagoon patch, outer etc)**
1.	
2.	
3.	
4.	

What kind of boat used today?

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

If "Other", What kind of boat?

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

C6 Catch prices

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

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

Item / group	Unit of sale	No. Per unit	Price / unit of sale	Price / item
1. Crabs	*String*	*5*	*$25 / string*	*$5/crab*
1.				
2.				
3.				
4.				

C7 Perceptions of fishers

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

Appendix 7 Number of individuals observed from various methods during creel surveys, August 2013 and relative percent contribution to overall catch by method

Fishing method	Species	Number observed	% contribution by abundance	% contribution by weight
Bottom fishing	*Epinephelus cyanopodus*	2	0.81	0.65
	Epinephelus fuscoguttatus	6	2.43	4.17
	Epinephelus maculatus	22	8.91	13.53
	Epinephelus polyphekadion	127	51.42	46.54
	Lethrinus erythropterus	16	6.48	6.40
	Lethrinus miniatus	3	1.21	2.45
	Lethrinus obsoletus	7	2.83	1.63
	Lethrinus olivaceus	7	2.83	4.61
	Lethrinus ornatus	7	2.83	1.80
	Lethrinus rubrioperculatus	5	2.02	1.59
	Lethrinus xanthochilus	3	1.21	1.23
	Lutjanus bohar	2	0.81	3.24
	Lutjanus gibbus	23	9.31	4.83
	Lutjanus vitta	1	0.40	0.25
	Monotaxis grandoculis	1	0.40	0.62
	Plectropomus leopardus	2	0.81	0.62
	Plectropomus maculatus	4	1.62	2.47
	Plectropomus oligacanthus	1	0.40	0.66
	Sargocentron spiniferum	3	1.21	0.56
	Variola louti	5	2.02	2.15
Spearfishing	*Acanthurus auranticavus*	1	0.07	0.02
	Acanthurus guttatus	1	0.07	0.03
	Acanthurus lineatus	273	18.22	10.84
	Acanthurus mata	44	2.94	5.19
	Acanthurus nigricauda	3	0.20	0.22
	Acanthurus nubilus	1	0.07	0.08
	Anyperodon leucogrammicus	1	0.07	0.05
	Caranx melampygus	3	0.20	0.41
	Cephalopholis argus	11	0.73	1.13
	Cetoscarus bicolor	1	0.07	0.30
	Cheilinus undulatus	1	0.07	0.27
	Chlorurus frontalis	2	0.13	0.35
	Chlorurus microrhinos	34	2.27	6.20
	Chlorurus sordidus	1	0.07	0.11
	Epinephelus cyanopodus	1	0.07	0.11
	Epinephelus fuscoguttatus	2	0.13	0.23
	Epinephelus hexagonatus	10	0.67	0.59
	Epinephelus howlandi	2	0.13	0.10
	Epinephelus macrospilos	4	0.27	0.36
	Epinephelus maculatus	6	0.40	0.85
	Epinephelus melanostigma	4	0.27	0.42
	Epinephelus merra	1	0.07	0.05

Fishing method	**Species**	**Number observed**	**% contribution by abundance**	**% contribution by weight**
	Epinephelus polyphekadion	32	2.14	3.13
	Epinephelus socialis	1	0.07	0.08
	Epinephelus spilotoceps	4	0.27	0.22
	Hipposcarus longiceps	11	0.73	1.33
	Kyphosus vaigiensis	26	1.74	1.55
	Lethrinus harak	1	0.07	0.04
	Lethrinus laticaudis	1	0.07	0.15
	Lethrinus obsoletus	2	0.13	0.18
	Lutjanus fulvus	1	0.07	0.05
	Lutjanus gibbus	32	2.14	2.18
	Lutjanus semicinctus	1	0.07	0.08
	Monotaxis grandoculis	1	0.07	0.15
	Mulloidichthys flavolineatus	1	0.07	0.05
	Mulloidichthys vanicolensis	3	0.20	0.14
	Myripristis adusta	5	0.33	0.23
	Myripristis berndti	74	4.94	2.92
	Myripristis murdjan	57	3.81	1.75
	Myripristis pralinia	65	4.34	3.10
	Myripristis violacea	53	3.54	1.69
	Naso brachycentron	1	0.07	0.10
	Naso brevirostris	2	0.13	0.14
	Naso caesius	16	1.07	1.92
	Naso hexacanthus	1	0.07	0.09
	Naso lituratus	102	6.81	6.71
	Naso unicornis	36	2.40	8.18
	Panulirus sp.	75	5.01	9.74
	Parupeneus barberinus	9	0.60	0.70
	Parupeneus cyclostomus	4	0.27	0.25
	Parupeneus trifasciatus	1	0.07	0.08
	Plectropomus maculatus	4	0.27	0.58
	Priacanthus hamrur	61	4.07	2.50
	Pseudobalistes flavimarginatus	1	0.07	0.37
	Sargocentron spiniferum	23	1.54	1.28
	Sargocentron tiere	1	0.07	0.04
	Scarus oviceps	1	0.07	0.13
	Scarus rubroviolaceus	7	0.47	1.90
	Siganus argenteus	362	24.17	17.32
	Siganus puellus	9	0.60	0.53
	Siganus punctatus	1	0.07	0.11
	Variola louti	3	0.20	0.39