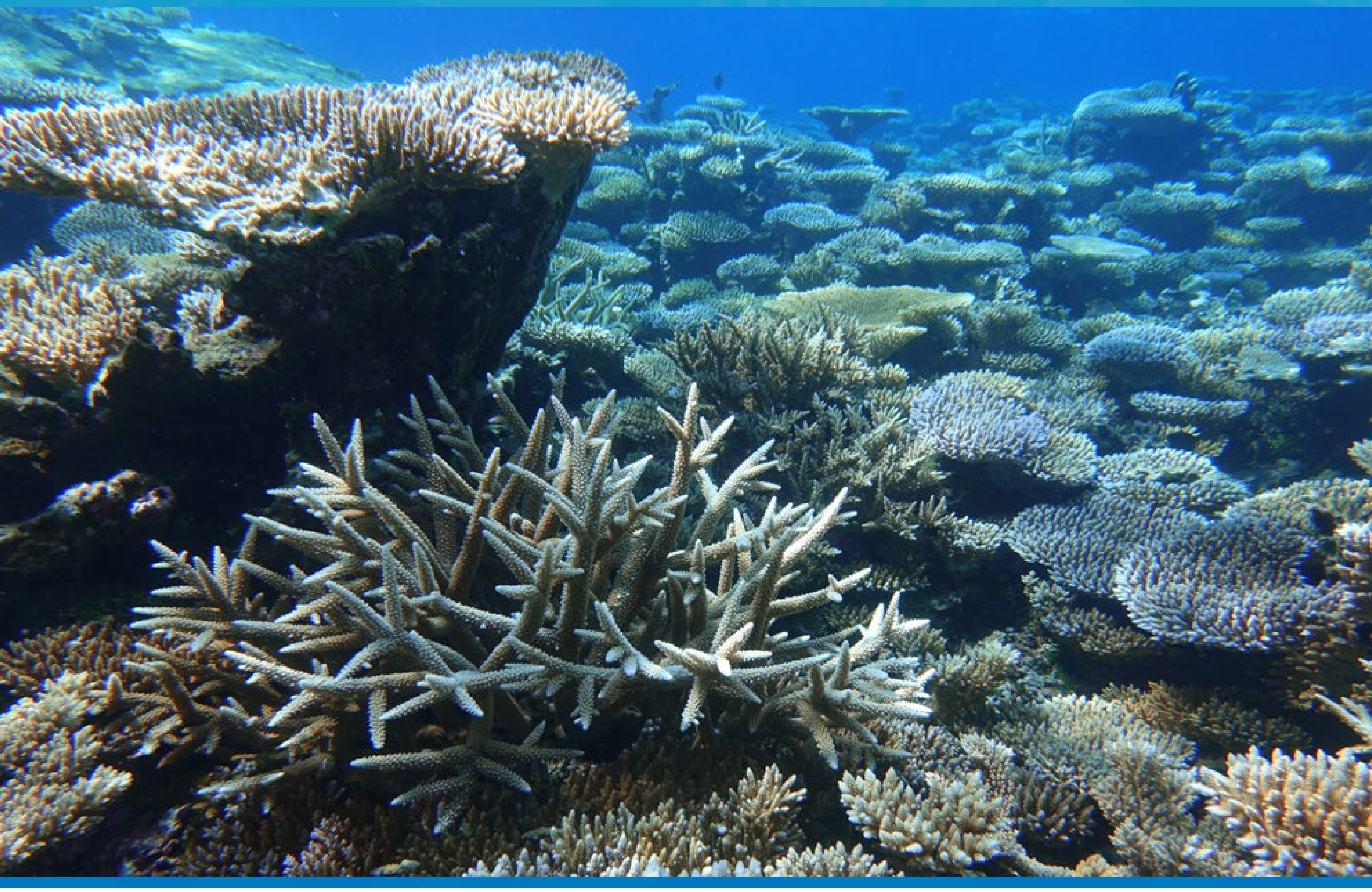
Monitoring the vulnerability and adaptation of coastal fisheries to climate change

Pauline Bosserelle, Andrew Halford, Lyla Lemari, Kyotak Ishiguro

Majuro Atoll
Republic of the Marshall Islands

Assessment report No. 3
July–August 2018



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Pacific Community
Communauté du Pacifique

Noumea, New Caledonia, January 2021

Original text: English

Pacific Community Cataloguing-in-publication data

Bosserelle, Pauline.

Monitoring the vulnerability and adaptation of coastal fisheries to climate change – Majuro Atoll, Republic of the Marshall Islands / Pauline Bosserelle, Andrew Halford, Lyla Lemari, Kyotak Ishiguro

(Assessment report no. 3 July-August 2018 / Pacific Community)

1. Fisheries – Marshall Islands - Climatic factors.

2. Fisheries – Monitoring – Marshall Islands.

2. Climatic change – Risk management – Marshall Islands.

3. Fishery management – Marshall Islands - Climatic factors.

I. Bosserelle, Pauline II. Halford, Andrew III. Lemari, Lyla IV. Ishiguro, Kyotak IV. Title V. Pacific Community VI. Series

639.22099683 ACCR2

ISBN: 978-982-00-1372-8

Cover picture: © Pauline Bosserelle

Prepared for publication and printed at SPC's headquarters,
B.P. D5, 98848 Noumea Cedex, New Caledonia, 2020

www.spc.int

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Acknowledgements

The Pacific Community (SPC) acknowledges with gratitude the funding support provided by the New Zealand Ministry of Foreign Affairs and Trade for third survey for the project Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change in Majuro Atoll, Republic of the Marshall Islands (RMI).

SPC also gratefully acknowledges the collaborative support of the Marshall Islands Marine Resource Authority (MIMRA). In particular, the authors are grateful to Glen Joseph (Director) and Florence Edwards (Chief, Coastal Fisheries) who showed much interest in the importance of this project and provided the needed support in moving it forward. In addition, the authors are greatly indebted to MIMRA (Coastal fisheries & MIMRA outer island fish market) staff and interns for helping in the field and for logistics: Fred Bukida, Benedict Yamamura, Emma Kabua-Tibon, Candice Guavis, Melba White, Jessie Capelle, Armer Ishoda, Rolandon Adde, Dua Rudolph and Alfred Alik. The authors are also grateful to Hulita Faanunu (Tonga Ministry of Fisheries) for the considerable help she provided during her attachment in Majuro. The authors are grateful to the publication team for organising editing, publishing and printing services; to Frances Pene for editing; to the information section for the layout work.

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Executive summary

This report discusses the results of the third survey at Majuro Atoll, Republic of the Marshall Islands (RMI), conducted in July and August 2018 under the project Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change. Details of the project's creation can be found in reports 1 and 2 from 2011 and 2013 respectively. The principal aim of the project is to better understand what role climate change is playing in influencing any observed changes in the health and productivity of coastal fisheries.

In-water assessments

Finfish surveys

The following key observations were made.

- Outer reef fish communities are very different from lagoon and back reef communities, while the lagoon and back reef communities are very similar to each other. This result will help to improve the survey design for future monitoring.
- Communities surveyed in 2011 were different from those surveyed in 2013 and 2018 and these differences were consistent across all three habitat types. The later years (2013 and 2018) being more similar provides confidence that the recent results are a true reflection of community structure.
- The main families represented in the 2018 survey are the same as those in the previous surveys. Observations were dominated by herbivores (grazers and scrapers) and micro-carnivores from the following families: Acanthuridae, Scaridae, Labridae and Pomacentridae.
- The introduction of timed-swim surveys in the last survey allowed for better assessment of larger fish in the community. Although the swim method revealed very low densities, communities observed were more consistent with locally harvested species than the standard underwater visual census (belt transect) survey method.

Benthic habitat surveys

- Similar to the fish surveys, the benthic communities at the outer reef habitats were different from those in the back reef and lagoon reef habitats.
- Additionally, habitats were also different between the locations on Majuro atoll.
- Minor differences were observed in benthic habitat composition at the study sites between years, including a slight decrease in coral cover since the last survey that may have resulted from a bleaching event.

Invertebrate surveys

- In general, densities of invertebrates observed were low during all surveys, irrespective of method used (manta tow, reef benthos transect RBt). Patterns of presence and abundance of invertebrate species tended to be site specific.
- The most abundant sea cucumber surveyed was *Holothuria atra (lollyfish),* irrespective of method. Abundance was, however, above a healthy reference density at one location only – Woja MPA (RBt).
- Giant clams (*T. Maxima* and *T.noae*) were observed regularly but remain at low densities across the atoll.
- Trochus (*R. nilotica*) was common at the Drenmeo MPA site during the RBt survey.

Creel surveys

In 2018, 11 creel surveys were completed (five bottom fishing and six spearfishing) and 1,583 individual fish belonging to 112 species and 17 families were identified, measured and weighed. All fishers taking part in the survey surveyed were men.

<u>Bottom fishing key results</u>

- On average these fishing trips involved 2.8±0.4 fishers and lasted on average 11.8±1.1 h. The average catch per trip corresponded to 51.7±8.9 kg and 151±34.2 individual fish. Catch per unit effort (CPUE) was 5.2±1.8 fish fisher^{-1} h^{-1} or 1.7±0.4 kg fisher^{-1} h^{-1}. Comparison with results from the 2013 survey suggest that, in 2018, bottom fishing trips involved fewer fishers, tended to last longer and targeted larger amounts of smaller fish.

- The catch was dominated by macro-carnivores/piscivores of the families Lutjanidae, Lethrinidae and Serranidae. The catch was more diverse than the 2013 survey and the proportion of catch represented by the Serranidae (notably *Epinephelus polyphekadion*) had largely decreased.

Spearfishing key results

- On average, trips involved 4.3±0.4 fishers, with a mean duration of 6±1.5 h. The average catch per trip was 51±10.1 kg, or 138±25.5 individual fish. The average CPUE was 8±2.7 fish $fisher^{-1}$ h^{-1} for abundance and 2.7±0.78 kg $fisher^{-1}$ h^{-1} for weight. In 2018 the overall catch per trip (fish number and weight) and number of fishers were slightly lower than in 2013 and the trip duration was slightly longer, but the CPUE remained comparable.
- The catch was dominated by grazers and to a lower extent by macro-carnivores/piscivores and lobsters. The main represented families were: Acanthuridae, Lutjanidae, Serranidae and Palinuridae (lobster).

Perceived resource condition by lead fishers

Only 50% of all respondents stated that their catches had decreased compared to five years ago, and 75% of all respondents stated that the size of fish had not changed compared to five years ago. This result was different from the 2013 survey, where the majority of fishers had seen a change in fisheries, both in quantity and size. Only a minor change in fishers' years of experience was recorded between surveys (fishers with less than 10 years' experience: 75 % in 2013, 50% in 2018).

Length distribution key result

Species that were caught in both 2013 and 2018 surveys tended to have similar size distributions. Using regional, size-at-maturity estimates, all *Naso lituratus* caught were found to be above their estimated size at maturity. However, only 20% to 30% of the individuals caught of the other two species seemed to have reached the size of maturity.

MANAGEMENT RECOMMENDATIONS

Several key management recommendations are outlined below to help improve the resilience of the coastal fisheries of Majuro Atoll by addressing both long-term (e.g. climate change) and short-term (e.g. overfishing) stressors. Some of these were described in the 2013 report and, when necessary, have been revised using the results of this survey. Recommendations on future survey improvements are also discussed in the report.

1. *Continue to expand the network of locally managed marine protected areas (MPAs)*. Even though no compelling evidence of significant MPA effects were found in Majuro, a high density of Trochus was recorded in the Drenmeo MPA, suggesting that there could be potential for invertebrate populations to recover here. The percentage of coral reef area under MPA management in Majuro is less than 2%, which is very low and much less than the proposed 30% suggested and supported through the Micronesia Challenge.
2. *Place restrictions on destructive or highly efficient fishing practices*, in particular night-time spearfishing. To maintain healthy reef communities, the pressure on browsing and scraping fish that have a crucial role in regulation of algal growth must be reduced.
3. *Assess and monitor grouper catches* in order to avoid overfishing. Consideration should be given to fishing bans during the spawning season for those grouper species that aggregate in large numbers to spawn.
4. *Monitor the export of reef fish to ensure their sustainability*. The commercial nature of fish exports, in particular *Lutjanus gibbus*, could be affecting the local resources. This species and any others showing signs of overfishing need to be studied and regulations implemented to avoid overfishing, severely reducing stocks.
5. *Manage the invertebrate fishery*. Invertebrates are found at low densities across the atoll. Sea-cucumber harvests need to be documented and regulated, as populations have not shown signs of recovery since the 2013 survey. The commercial harvest of other species is limited. Lobster population status can be assessed through dedicated catch monitoring.
6. *Develop and implement coastal fisheries management plans / regulations*. While coastal fish have gained critical recognition, finfish and invertebrate resources remain largely unregulated on the atoll. To ensure that fish and invertebrate stocks remain viable for future generations, a coastal fisheries management plan / regulations should be developed, addressing various fishing activities (gear and practice, size limits, seasonal closures, export regulation).
7. *Strengthen stakeholder awareness programmes and exchange of information on coastal fisheries, the marine environment and climate change*. Success of implementing management measures is highly dependent on development of awareness programmes and active engagement at community level.

Introduction

Project background

In 2011, with concerns over climate change and its effects on coastal fisheries resources, the Pacific Community (SPC) implemented the project Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change, with funding assistance from the Australian Government's International Climate Change Adaptation Initiative (ICCAI). This funding finished after the second survey in 2013, but SPC continued the funding, allowing for a third survey to be done on Majuro Atoll in 2018.

Five country sites were selected for monitoring climate change effects on coastal fisheries across the Pacific region: Federated States of Micronesia (Pohnpei), Kiribati (Abemama Atoll), Marshall Islands (Majuro Atoll), Papua New Guinea (Manus Province) and Tuvalu (Funafuti Atoll). Details on the origins of the project are summarised here; more detail can be obtained from the 2011 and 2013 CC reports.

The objectives of the project are:

a) to collect appropriate data to facilitate understanding of what role climate change is having in any observed changes to the productivity of coastal fisheries, independent of more local pressures such as overfishing and habitat degradation;

b) to build technical capacity and awareness through training and collaborative work so that coastal fisheries agencies will recognise and understand the need for long-term monitoring of their coastal fisheries and commit to allocating the resources to undertake such programmes on a continual basis; and

c) to assess the effects of any adaptive management programmes that may be implemented to mediate climate change impacts, improve resilience and maintain the productivity of coastal fisheries.

This report presents the results of the third round of field surveys for the project conducted on Majuro Atoll, Republic of the Marshall Islands (RMI), in July–August 2018, by a team from SPC's Coastal Fisheries Science and Management Section and staff from the Marshall Islands Marine Resource Authority (MIMRA) (Table 1). Collected data are compared to the previous surveys conducted at Majuro in 2013 (Moore et al. 2014) and 2011 (Moore et al. 2012).

Table 1: Summary of activities and variables measured during the monitoring programme on Majuro Atoll, Republic of the Marshall Islands, 2018

Task	Description	Variables measured
Monitoring of water temperature	Fine-scale monitoring of local water temperature within and outside lagoon	Water temperature (°C)
Benthic habitat assessments	Photoquadrat transects across outer, back and lagoon reef habitats at selected sites	Percentage cover of benthic organisms and substrate types (with emphasis on hard corals and algae)
Finfish surveys	Underwater visual census surveys of finfish communities across outer, back and lagoon reef habitats at selected sites. Belt transects at all sites and timed swims on selected outer reef sites	Counts and sizes of most non-cryptic fish species & habitat videos
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

General background

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 Federated States of Micronesia, on the south by Nauru and Kiribati, and on the north by the United States territory of Wake Island (Figure 1). The total land area of RMI is approximately 181 km2, while the exclusive economic zone (EEZ) totals approximately 2.13 million km2 (Gillett 2009). In 2011, the estimated population of RMI (Marshall Islands et al. 2012) was 53,158, with half of the population living in the capital, Majuro Atoll. In RMI, in 2011, 40% of the population was under the age of 15. 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.

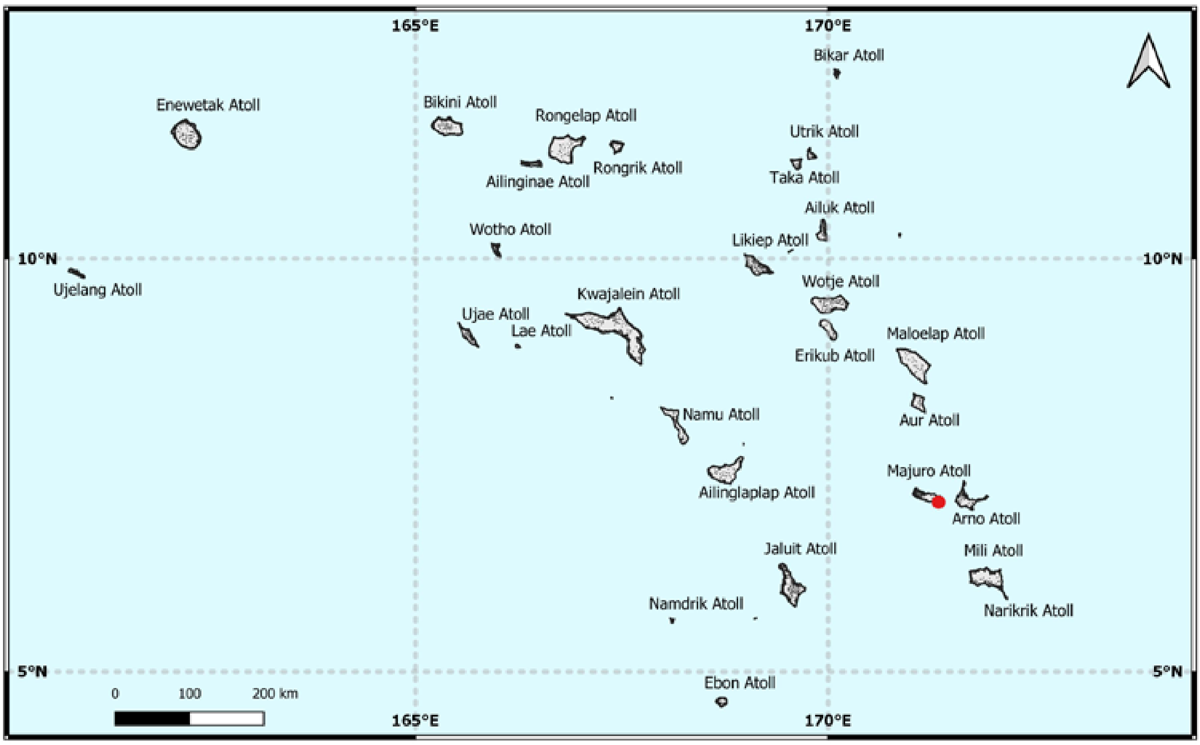


Figure 1: Republic of the Marshall Islands

Fisheries

National oceanic fisheries

Tuna fishing in the EEZ makes up the bulk of marine-derived income for RMI, with average catches by their purse seine fleet of > 47,000 tonnes, worth USD 56.7 million per year and contributing (Bell et al. 2011) approximately 14% to the gross domestic product (GDP) of RMI (Gillett 2016). In addition to the local fleet, RMI also licenses foreign fishing vessels to fish for tuna and associated species within its EEZ, with average annual catches of approximately 22,500 tonnes, worth USD 20 million per year (Bell et al. 2011).

National coastal fisheries

Coastal fisheries of RMI are summarised under 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 2014, the total annual catch of this sector was estimated to be 4500 tonnes, worth > USD 10.3 million (Gillett 2016) (Table 2). The commercial component of this catch was an estimated 1500 tonnes, while the subsistence catch was 3000 tonnes (Gillett 2016) (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 RMI, 2014 (Gillett 2016)

Harvest sector	Quantity (tonnes)	Value (USD million)
Offshore locally-based	85,918	135,530,000
Offshore foreign-based	29,754	38,700,638
Coastal commercial	1500	4,350,000
Coastal subsistence	3000	6,000,000
Freshwater	0	0
Aquaculture	10,000 pieces	50,000
Total	**120,172 t plus 10,000 pieces**	**182,630,638**

The Marshallese harvest, market and consume a wide range of coastal finfish and invertebrates (Table 3). Nationally, fresh fish consumption averages well in excess of the regional average of 35 kg per person per year (Pinca et al. 2009). Such reliance on coastal fisheries to support the daily protein needs of the Marshallese indicates that climate change-induced changes to this environment could have very strong flow-on effects, especially if there are significant changes to habitat.

Table 3: Estimated catch 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

Surface air temperature and sea-surface temperature

Historical air temperature data records for Majuro Atoll show an increase in annual temperatures of approximately 0.12°C per decade since recording began in 1955 (Figure 2) (Australian Bureau of Meteorology and CSIRO 2014). Mean air temperatures are projected to continue to rise, with increases of 0.4, 1.1°C (relative to 1990 values) projected for 2030, under the different emissions scenarios for both southern RMI and northern RMI (Australian Bureau of Meteorology and CSIRO 2014) (Table 4).

Sea-surface temperatures are closely linked to surface air temperatures, so trends presented for the latter (Table 4, Figure 2) can be used for the former (Australian Bureau of Meteorology and CSIRO 2014).

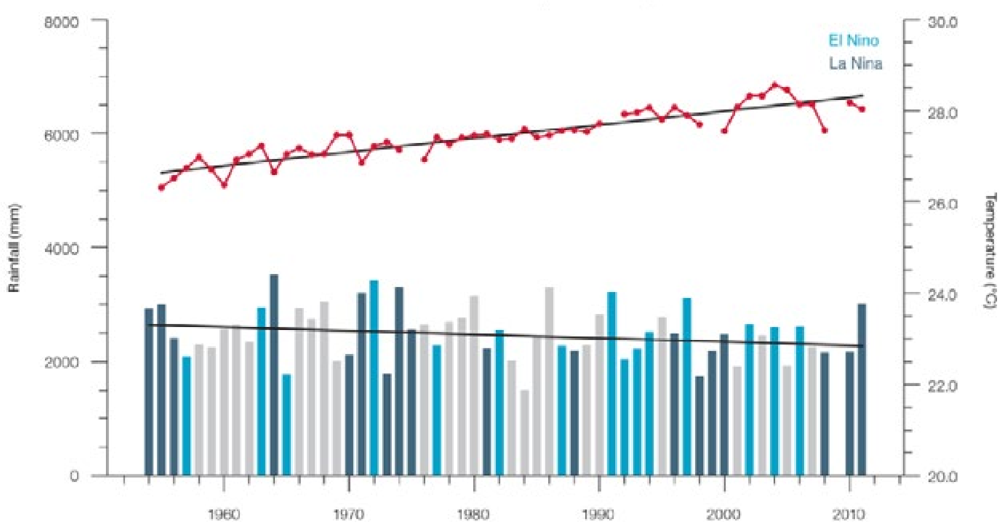


Figure 2: Mean annual air temperature (red dots and line) and total rainfall (bars) at Majuro (1955–2011) (Australian Bureau of Meteorology and CSIRO, 2014)

Table 4: Projected air temperature increases (in °C) for a) northern and b) southern Republic of the Marshall Islands under various IPCC emission scenarios (Australian Bureau of Meteorology and CSIRO, 2014)

Region	Emission scenario	2030	2050	2070	2090
a) northern RMI	RCP2.6	0.5–1.0	0.6–1.2	0.5–1.2	0.5–1.2
	RCP4.5	0.4–1.0	0.7–1.4	0.9–1.9	1.0–2.1
	RCP6.0	0.4–0.9	0.7–1.4	1.1–2.0	1.4–2.6
	RCP8.5	0.5–1.1	1.0–1.9	1.6–3.2	2.2–4.2
b) southern RMI	RCP2.6	0.4–0.9	0.6–1.2	0.5–1.2	0.5–1.2
	RCP4.5	0.5–1.0	0.7–1.4	1.0–1.8	1.0–2.1
	RCP6.0	0.4–0.9	0.7–1.4	1.0–2.0	1.3–2.6
	RCP8.5	0.6–1.1	1.0–1.9	1.7–3.1	2.1–4.0

Sea-level rise

As part of the AusAID-sponsored South Pacific Sea Level and Climate Monitoring Project ('Pacific Project') a SEA-FRAME (Sea Level Fine Resolution Acoustic Measuring Equipment) gauge was installed at Majuro Atoll in May 1993 (Figure 3). According to the 2014 PACCSAP country report (Australian Bureau of Meteorology and CSIRO 2014), update of the sea-level rise at Majuro Atoll was calculated at +7 mm per year, although the El Niño Southern Oscillation may have been influential in this unusually high rate (global average 2.8–3.6 mm per year).

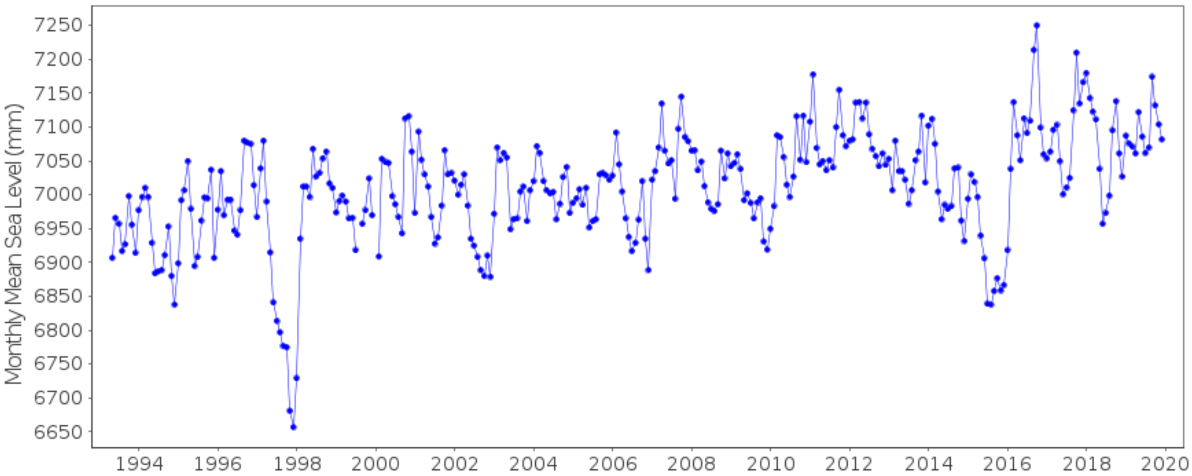


Figure 3: Evolution of monthly mean sea level from 1993 to 2019 in Majuro (https://www.psmsl.org/data/obtaining/stations/1838.php)

Based on empirical modeling, the mean sea-level is projected to continue to rise during the 21st century, with increases of 8 to 19 cm projected for 2030 and 23 to 92 cm projected for 2090 (Australian Bureau of Meteorology and CSIRO 2014). Such rises may potentially create severe problems for low-lying coastal areas, with increases in coastal erosion and saltwater intrusion (Mimura 1999). Saltwater inundation will severely degrade food crops and result in increased fishing pressure on coastal habitats, further exacerbating the effects of climate change on coastal fisheries.

Table 5: Projected sea-level rise (in cm) for Republic of the Marshall Islands under various IPCC emission scenarios (Australian Bureau of Meteorology and CSIRO, 2014)

Emission scenario	2030	2050	2070	2090
RCP2.6	7– 8	13–30	19–45	23–60
RCP4.5	7–18	14–32	21–49	28–69
RCP6.0	7–17	14–31	21–49	30–70
RCP8.5	8–19	16–35	27–60	41–92

Ocean acidification

In the RMI region, the aragonite saturation state declined from ~4.5 in the late 18th century to ~ 3.9 ± 0.1 by 2000 (Kuchinke et al. 2014). As ocean acidification is projected to increase, thus aragonite saturation states are projected to decrease during the 21st century (Australian Bureau of Meteorology and CSIRO 2014). 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 under higher emission scenarios (Australian Bureau of Meteorology and CSIRO 2014). These projections suggest that coral reefs of RMI will be vulnerable to actual dissolution as they will have trouble producing the calcium carbonate needed to build their skeletons. This will affect 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 effects on ocean life other than corals, including calcifying invertebrates, non-calcifying invertebrates and fish. High levels of CO_2 in the water are expected to negatively affect 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, 2009b). The effect 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 (Australian Bureau of Meteorology and CSIRO 2014).

Projected effects of climate change on coastal fisheries of RMI

Climate change is expected to add to existing local threats to coral reef, mangrove and seagrass habitats of RMI, resulting in declines in the quality and area of all habitats (Table 6). Accordingly, all coastal fisheries categories in RMI are projected to show progressive declines in productivity due to both the direct (e.g. increased sea-surface temperature) 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 RMI under various IPCC emission scenarios (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 RMI under various IPCC emission scenarios (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.

In-water assessments

Methods

Detailed descriptions of the methodologies employed have been given in previous reports from 2011 and 2013 and will only be briefly summarised here.

Monitoring of water temperature

To monitor sea-surface temperatures at a local scale, two 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 ±0.002°C and programmed to record temperature every five minutes. Due to battery life flaws in the original loggers (RBR TR1060), a third logger (Sea-Bird SBE 56) was installed in the lagoon in August 2012. This logger was retrieved, and a second Sea-Bird SBE 56 was deployed in July 2013. In August 2018, the Sea-Bird SBE 56 lagoon logger was replaced by another one (same model). Another concrete housing was deployed with a logger on the outer reef (east of the main pass in the north of the atoll).

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

Sites	Majuro 1	Majuro 2	Majuro 3	Majuro 4
1st Deployment date	17/05/2011	17/05/2011	27/8/2012	08/08/2018
Logger type	RBR TR1060	RBR TR1060	Seabird SBE 56	Seabird SBE 56
Recording interval	5 min	5 min	10 min	10 min
Location	Laura, Majuro Atoll	Laura, Majuro Atoll	Laura, Majuro Atoll	Majuro, Majuro Atoll
Habitat	Lagoon	Outer	Lagoon	Outer
Longitude	171.054299E	171.045127E	171.054144E	171.213047E
Latitude	7.192523N	7.198610N	7.192525N	7.164125N
Depth	10 m	19 m	10 m	11 m
Status	Removed	Removed	Active	Active

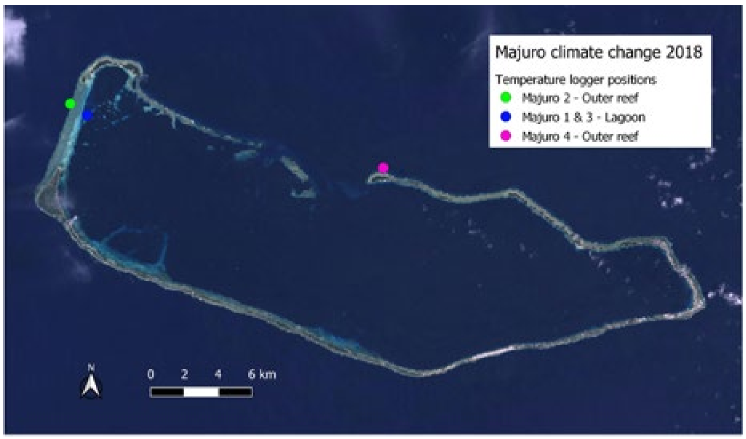


Figure 4: Location of water temperature loggers deployed in Majuro Atoll

Finfish and benthos methodology

Due to the limited sampling of reef flat locations done during previous surveys and the minimal communities surveyed there (one station only), it was decided to remove this habitat strata from further surveys.

Finfish

Reef fish communities were surveyed using underwater visual census (UVC) allied to two distance methods.

1. Belt transects

Finfish assessments were conducted at five sites around Majuro Atoll: Drenmeo MPA, Laura 1, Laura 2, Majuro and

Woja MPA (Figure 5). Within each site, assessments were conducted in three habitat types, where present (back reef, lagoon reefs and outer reefs). Three replicate 50 m transects were surveyed in each habitat at each of the five sites. Individual transects were laid consecutively and parallel to the reef crest with a gap of ~10 m between transects. This design was a slight change from previous surveys where the three individual transects were separated by hundreds of metres. Transects were brought closer together to provide a safer and more efficient dive programme without compromising the quality of the data.

The designated fish surveyor swam down each transect, recording the species identity, abundance and size (fork length in 5 cm bin sizes) of all targeted fish encountered (see Appendix 2 for a list) within a five-metre band. Upon reaching the end of the third transect, the fish counter returned along the same transects, this time counting only species from the Pomacentrid family within a two-metre band. This family is many times more abundant than the other species counted, so the two-metre band width enables a more accurate visual assessment of this family. The distance sampling methodology previously used is no longer the preferred method and hence will no longer be used. While effective with highly trained fish surveyors, this technique was not easily learnt and resulted in imprecise counts. Reducing the distance surveyed to a maximum of five metres reduces the error associated (Figure 6). For comparisons with the revised method, only counts from the distance method out to five metres were compared. An effort was made to ensure that the survey took place during the same period of the year as the previous surveys. Regular cross-checks between divers ensured that accurate and consistent data were collected.

2. Timed swims

At Woja and Laura (Figure 5), a timed swim method was introduced to complement the transect based finfish surveys on the outer reef habitat. This method allows divers to observe larger and often more wary fish that are not properly captured on transect surveys. More importantly, these species are usually the ones most common in the local market, yet they were not usually seen during the belt transect surveys. At each site, three consecutive timed swims of 10 min were made using SCUBA. The diver was located at a depth of approximately 10 m and counted all target fish within a 20 m band – 10 m either side of the diver following the reef contour until the end of the swims. All fish over 35 cm in length were identified, enumerated and sized. In addition to large individual fish, schools of fish (even of smaller size) within the band were also recorded. A GPS attached to a buoy with a rope was towed by one of the divers to evaluate the distance covered during the swims. the length of each replicate was estimated by dividing the total length of a swim station by three.

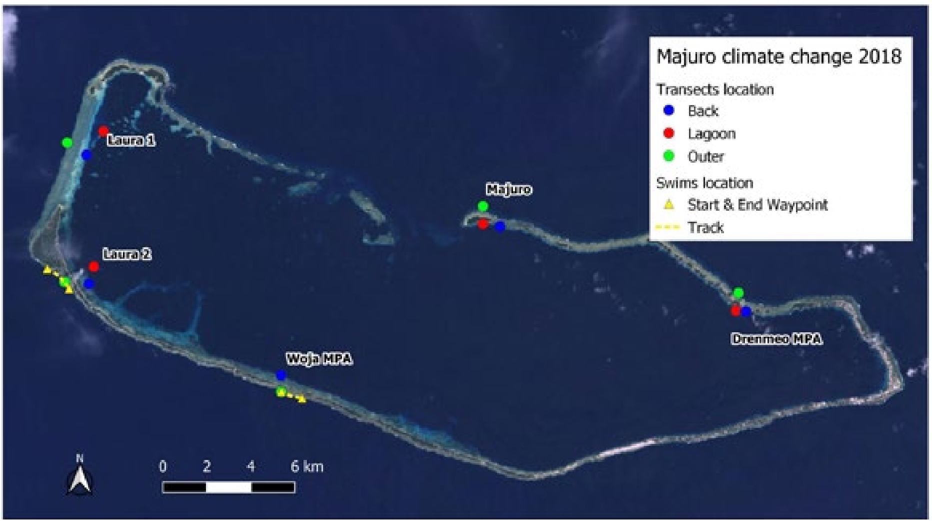


Figure 5: Location of finfish and fine-scale benthic habitat monitoring sites at Majuro Atoll

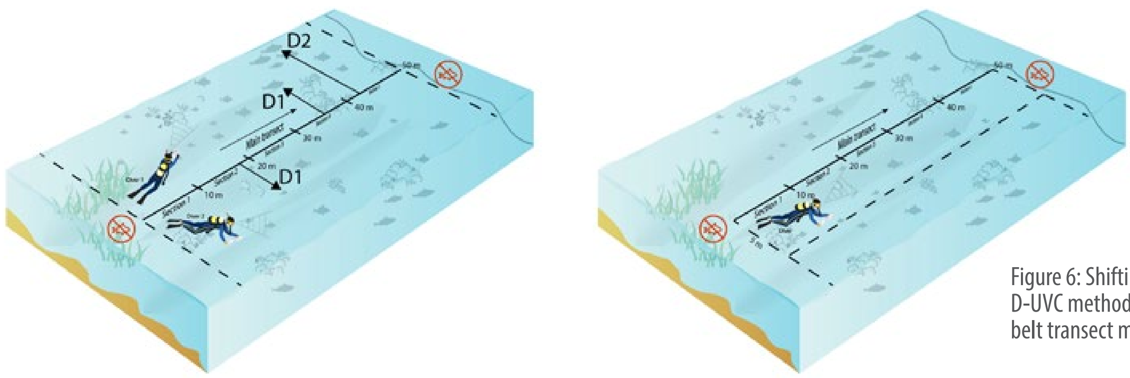


Figure 6: Shifting from the D-UVC method (left) to the belt transect method (right)

Benthos

The methodology used was the same as for the 2011 and 2013 climate change surveys with the exception that no broad scale assessments were made. While sites were not changed between surveys, the exact locations of the transects were adjusted in 2018 to reduce the number of dives and increase efficiency of the limited number of diving staff available for the survey. The methodology is presented in Appendix 4.

Invertebrate methodology

The methodology used in 2018 was the same as that used for the 2011 and 2013 climate change surveys. Although GPS reference waypoints of the 2013 survey were used to locate survey stations or transects, the location of transects may have been slightly different in 2018. The methodology is presented in Appendix 6.

Data analysis and reporting

Fish and benthos community-level assessments

Multivariate analyses were performed on both the fish and benthic communities to explore spatial and temporal patterns in whole community structure. Multivariate regression trees were used in conjunction with PCA biplots to provide a visually easy way to understand major patterns in communities and the influence of environmental parameters. All analyses were run using the open-source R software.

Fish

The status of finfish resources has been characterised using the parameters described below.

1) Relative richness – Due to a slight change in methodology and in order to make adequate comparison, this variable is presented as the number of species in families having a strong interaction with the benthos for feeding or sheltering (Acanthuridae, Chaetodontidae, Scaridae and Siganidae) and per number of functional groups counted on UVC transects.

   Functional groups – For the analysis of functional health, each species identified during the UVC surveys was classified into one of eight broad functional groups (Appendix 1), adapted from (Bellwood et al. 2004; Green and Bellwood 2009; Pratchett 2005). Details can be obtained from the CC reports of 2011 and 2013. The functional categories are:

   - macro-carnivores, e.g. some species of Lethrinidae, Lutjanidae and Serranidae;
   - micro-carnivores, e.g. some members of the Labridae;
   - corallivores e.g. Chaetodontidae;
   - planktivores, e.g. some members of the families Acanthuridae, Apogonidae, Chaetodontidae, Holocentridae, Pomacentridae and Serranidae;
   - scrapers/excavators, e.g. members of the Scaridae;
   - grazers/detritivores e.g. some members of the families Acanthuridae, all Siganidae except *Siganus canaliculatus*;
   - browsers, e.g. some members of the Acanthuridae, *Siganus canaliculatus*; and
   - territorial / farming herbivores, e.g. some members of the Pomacentridae.

2) Mean densities (fish 100 m^2) – calculated at a total, functional group, family and individual species level.

3) Community structure in time and space – Multivariate ordination and regression trees were used to examine community patterns within and between years to better understand the main influences on the observed structure in the surveyed fish communities.

Barplots of mean density (± SE) were plotted for each site to compare and contrast patterns in the mean density of the 16 indicator families and eight functional groups by habitat and survey year. Data for the Pomacentridae family are reported separately, as they were counted using a narrower transect. In these plots, highlighting differences between the years of survey was done using error bars; when the error bars overlapped between years, it was considered that there were no differences, and when the error bars did not overlap it was considered that there was a difference, which may or may not be statistically relevant.

To further explore patterns among surveys and habitat type and densities, the different data types (total, family-specific [with pomacentridae separated from the other families], and functional group-specific density data) were tested using different statistical tools, outlined in Appendix 2.

Due to multiple obvious differences in surrounding land use, oceanic influence and tidal flushing among sites both open or closed (MPA) to fishing, it was not possible to make an assessment of the effectiveness of MPAs.

Table 9: List of families used for data analysis

* Pomacentrids are analysed separately from the other families as they were recorded along a different width transect

Families used for data comparisons
Acanthuridae
Balistidae
Chaetodontidae
Ephippidae
Kyphosidae
Labridae
Lethrinidae
Lutjanidae
Monacanthidae
Nemipteridae
Pomacentridae*
Pomacanthidae
Scaridae
Serranidae
Siganidae
Zanclidae

Benthos

Summary graphs of the mean percentage cover (± SE) of the main benthic categories are presented for each site by habitat and survey year. Specific categories summarised were:

- live coral
- macroalgae
- halimeda algae
- rubble
- sand.

In these cover plots, highlighting differences between years of survey was done using error bars.

Invertebrates

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

- richness and relative diversity – the number of genera and species observed for each survey method across surveys – the total number of observed species per site divided by the number of stations at that site
- mean density per station (individuals ha-1) (± SE)
- mean size per species (mm).

In the density plots, differences between years of survey were highlighted using error bars.

The species analysed for the manta tow method and reef benthos transects can be quite different. For the former, only the large species (Table 1) are considered, whereas a greater range of species of various size is considered for the latter.

Additionally, mean densities of invertebrate species at the Laura stations in 2011, 2013 and 2018 were compared with those collected during the PROCFish surveys in this region in 2007 (Pinca et al. 2009) only on species observed between 2011 and 2018.

Due to the complex nature of invertebrate populations (difficulties to report at community level and highly variable densities) no statistical analyses were conducted on comparisons between the 2011, 2013 and 2018 surveys.

Table 10: 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, *Rochia nilotica* (previously known as *Tectus niloticus*), Tectus pyramis, Trochus maculatus, Turbo marmoratus
Starfish	*Acanthaster planci*, *Anchitosia queenslandensis*, *Choriaster granulatus*, *Cornaster nobilis*, *Culcita novaeguineae*, *Fromia monilis*, all *Linckia* species, *Protoreaster nodosus*, *Tropiometra afra*, *Valvaster striatus*

Results

Temperature

Both RBR TR1060 loggers collected temperature data for approximately four months before failing. These loggers were subsequently removed from the water and data were presented in Majuro Atoll coastal fisheries monitoring report # 2 (Moore et al. 2014).

Since the first Seabird SBE 56 temperature logger deployment in August 2012, the water temperature in the lagoon has been continuously recorded (Figure 7). A maximum average daily water temperature of 30.67°C was observed in September 2014, while a minimum average daily temperature of 27.73°C was observed in February 2013 (Figure 7). The maximum recorded temperature was 31.09°C, reached in September 2014, while the minimum recorded temperature was 27.40°C, reached in February 2012. If logistics allows, the logger in place will be continuously retrieved and re-deployed to maintain water temperature monitoring in the atoll. Since the last climate change survey, bleaching observations were reported (Mathiesen 2014). The NOAA bleaching alert programme, through the degree heating week[1] (DHW) variable, was identified as a good coral bleaching index (Kayanne 2017). The past DHW indicated very high bleaching risk (DHW > 8°C-weeks) in Majuro (Figure 7) for both 2014 and 2016.

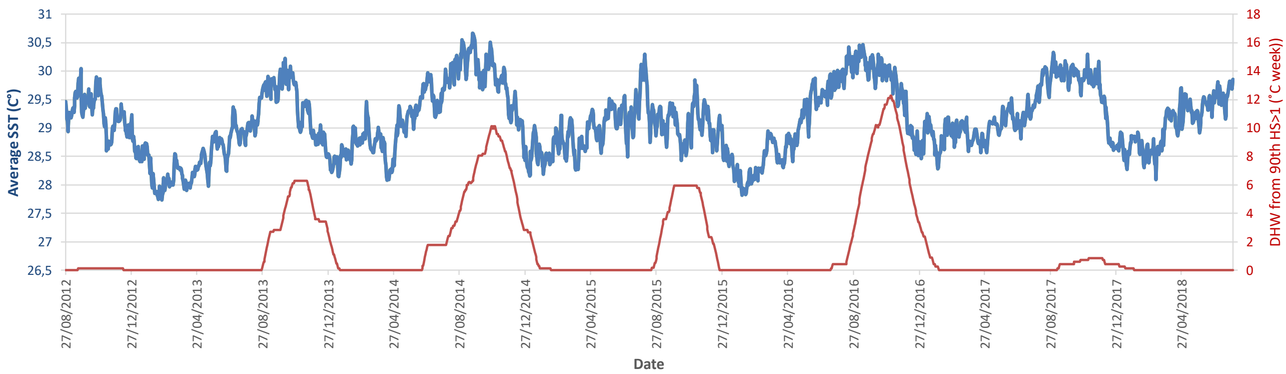


Figure 7: Mean sea-surface temperate (SST) recorded in the lagoon at Majuro Atoll using SBE 56 temperature loggers, 27 August 2012 to 31 July 2018 associated with degree heating week (NOAA Coral Reef Watch 2019)

1 The daily degree heating week value calculated by accumulating daily 90th percentile HotSpot values (greater than 1) for pixels contained in a Regional Virtual Station (https://coralreefwatch.noaa.gov/vs/description.php).

Finfish

Community-level patterns

Two major patterns were observed in the fish community structure over the three survey periods (Figure 8, Figure 9).

- Outer reef fish communities are very different from lagoon and back reef communities, while lagoon and back reef communities are very similar to each other. This result will help to improve the survey design for the future as the lagoon and back reef habitats can be considered the same in terms of locating survey sites for continuing monitoring.
- Communities surveyed in 2011 are different from those surveyed in 2013 and 2018 and these differences were consistent across all three habitat types. The reasons for this result are less clear, as there have been changes in survey methodology and personnel which could lead to different results. However, the later years (2013 and 2018) being more similar provides confidence that the recent results are a true reflection of community structure.

The major differences between fish communities in the different habitat types and between years was in the structure of the damselfish communities. Groups of species had strong preferences for either the outer reef environment or the lagoonal/back reef. This difference in pomacentrid species was also the main reason for the observed differences between the 2011 surveys and the 2013/18 surveys.

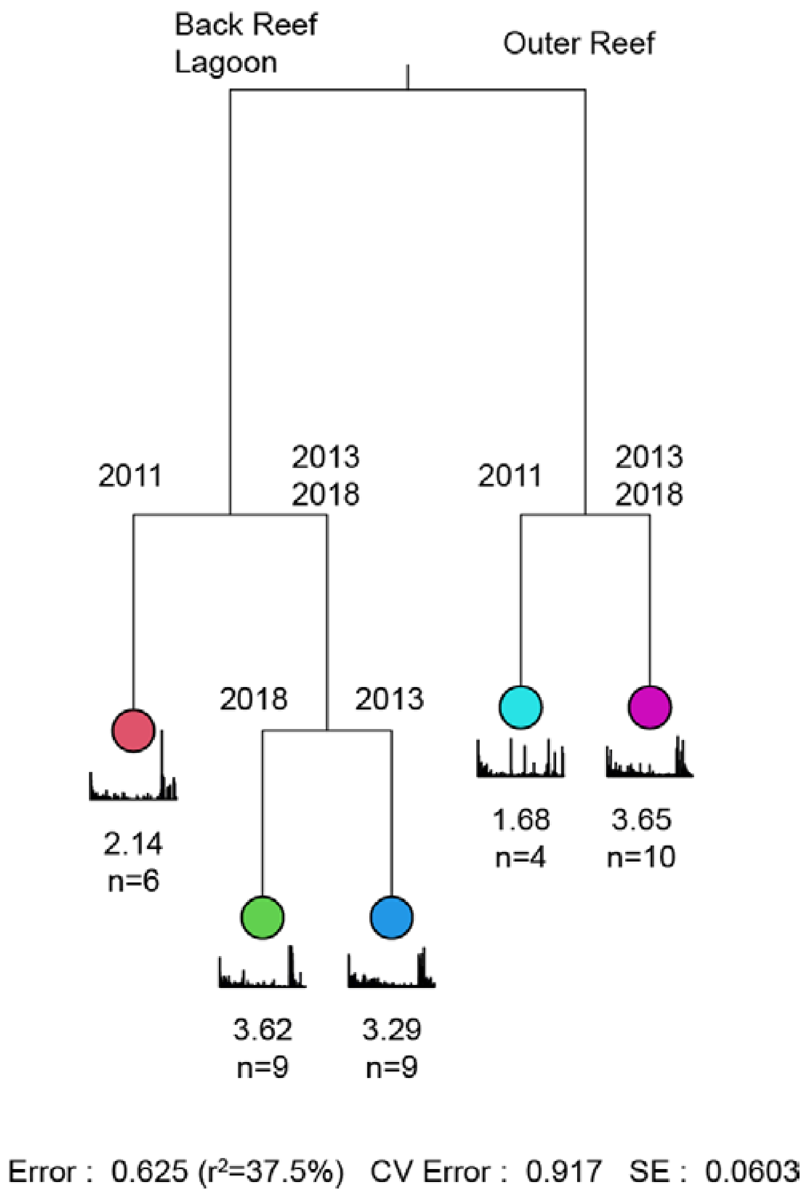


Figure 8: Multivariate regression tree displaying the main patterns in the structure of the fish communities across 2011, 2013 and 20

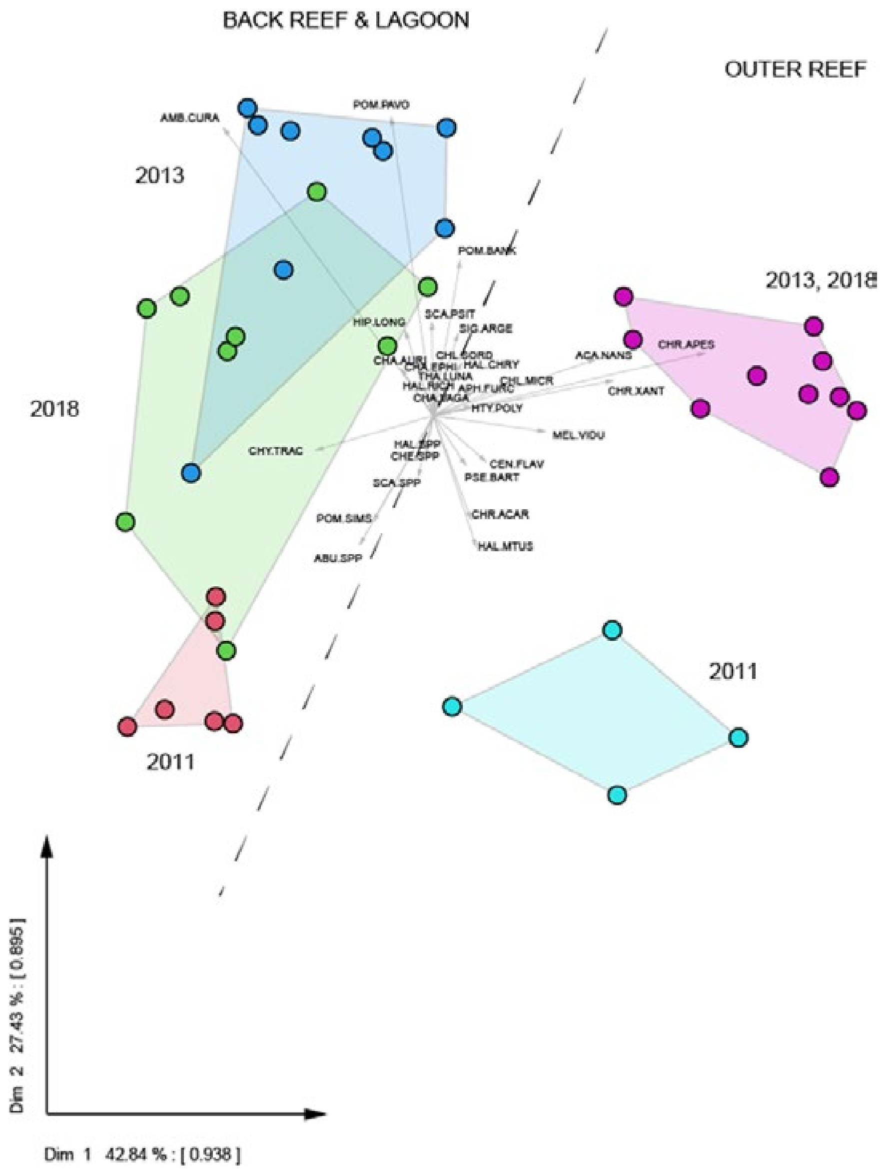


Figure 9: PCA biplot ordination with colours corresponding to the regression tree in Figure 8. Grey arrows represent the relationship of all species to the observed community patterns. Only those species with the strongest relationships (longest arrows) are named in the plot.

Site summaries

Drenmeo MPA

Finfish diversity of the selected family within the Drenmeo MPA tended to be lower during the 2018 survey relative to 2013 for all three habitats examined (Table 11), in particular for Chaetodontidae. In terms of functional groups, browsers were absent from back reef transects in 2011 and 2018, and were absent from outer reef transects in 2018, while corallivores were absent from this habitat in 2011. In 2013 all functional groups were represented in each habitat (Table 11).

Table 11: Total number of species in four key families (Acanthuridae, Chaetodontidae, Scaridae and Siganidae) and the number of functional groups at back, lagoon and outer reef habitats of the Drenmeo MPA monitoring site, 2011, 2013 and 2018

	Back reef			Lagoon reef			Outer reef			Overall site		
DRENMEO MPA	2011	2013	2018	2011	2013	2018	2011	2013	2018	2011	2013	2018
Acanthuridae	3	7	7	7	9	6	7	9	6	12	12	11
Chaetodontidae	3	10	8	10	9	5		9	3	10	15	10
Scaridae	2	5	4	6	13	11	3	9	2	6	15	13
Siganidae	0	1	0	1	2	1	0	1	0	1	3	1
Functional group	7/8	8/8	7/8	8/8	8/8	8/8	7/8	8/8	7/8		8/8	

There was important variability observed in each habitat for the different surveys for family specific densities and functional group densities (Figure 10, Figure 12). In contrast, no important differences were observed for the Pomacentridae family (Figure 11).

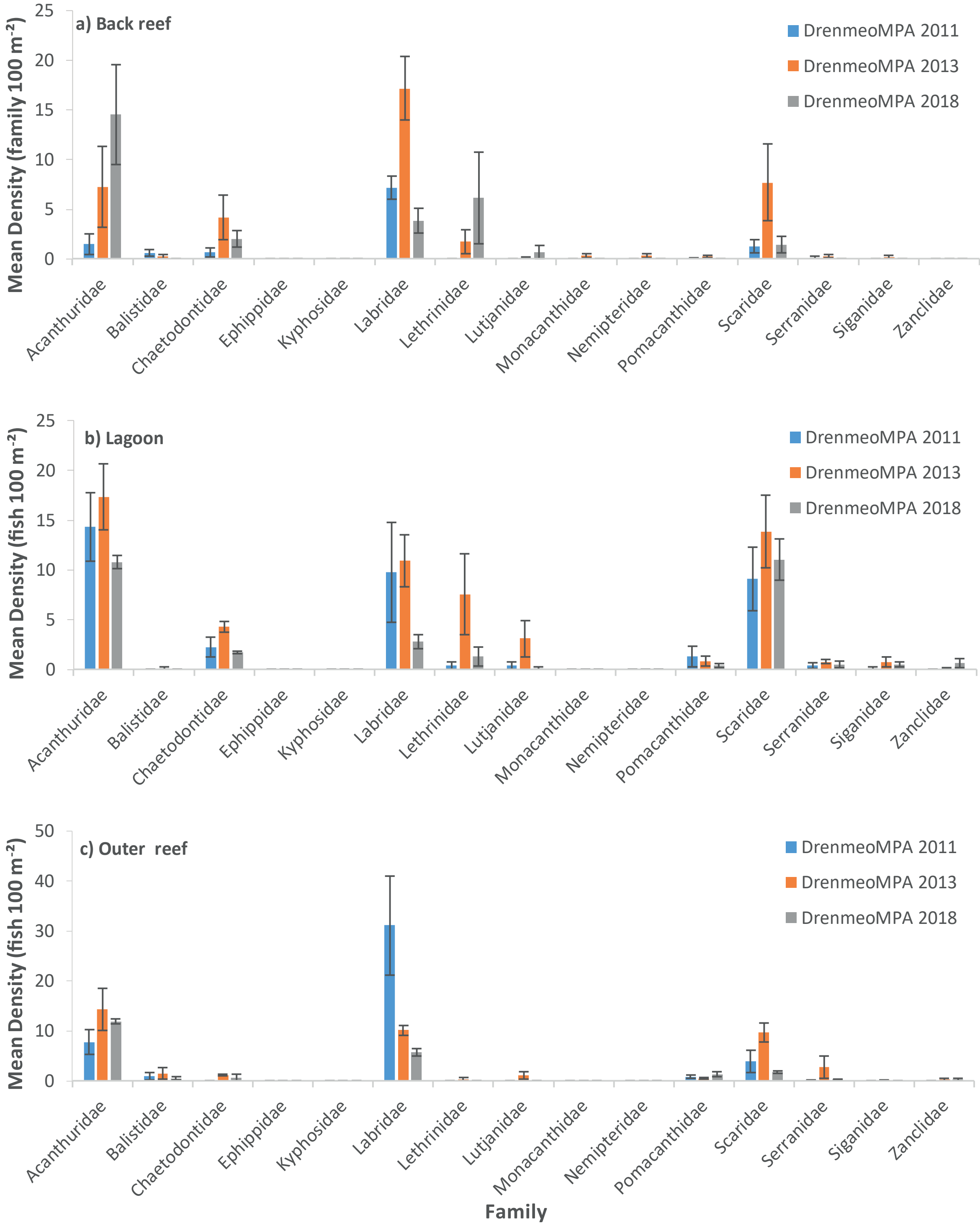


Figure 10: Mean densities (± SE) of common finfish families (excluding Pomacentridae) among a) back reef, b) lagoon reef and c) outer reef habitats of the Drenmeo MPA monitoring site during the 2011, 2013 and 2018 surveys

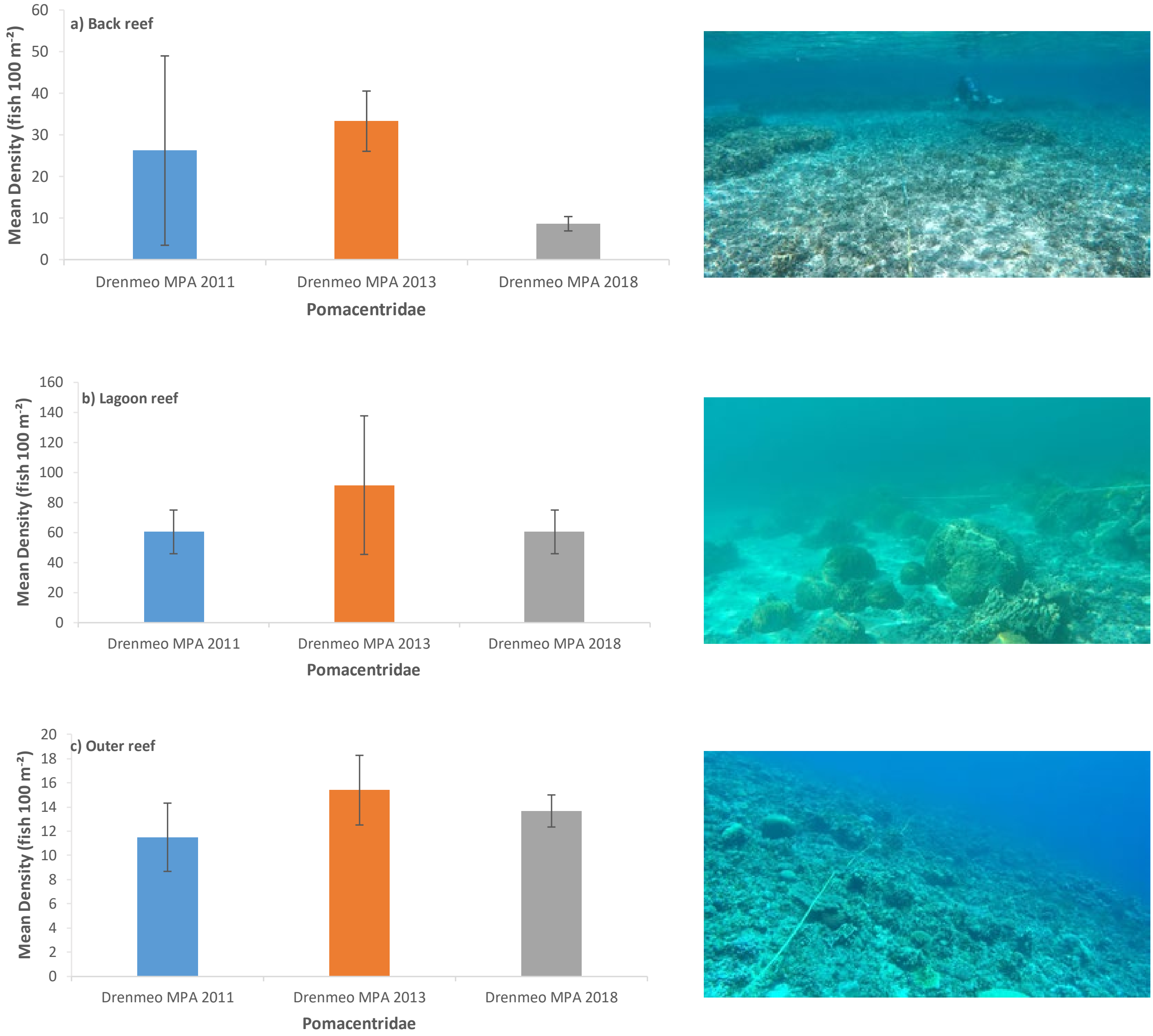


Figure 11: Mean densities (± SE) of Pomacentridae among a) back reef, b) lagoon reef and c) outer reef habitats of the Drenmeo MPA monitoring site during the 2011, 2013 and 2018 surveys

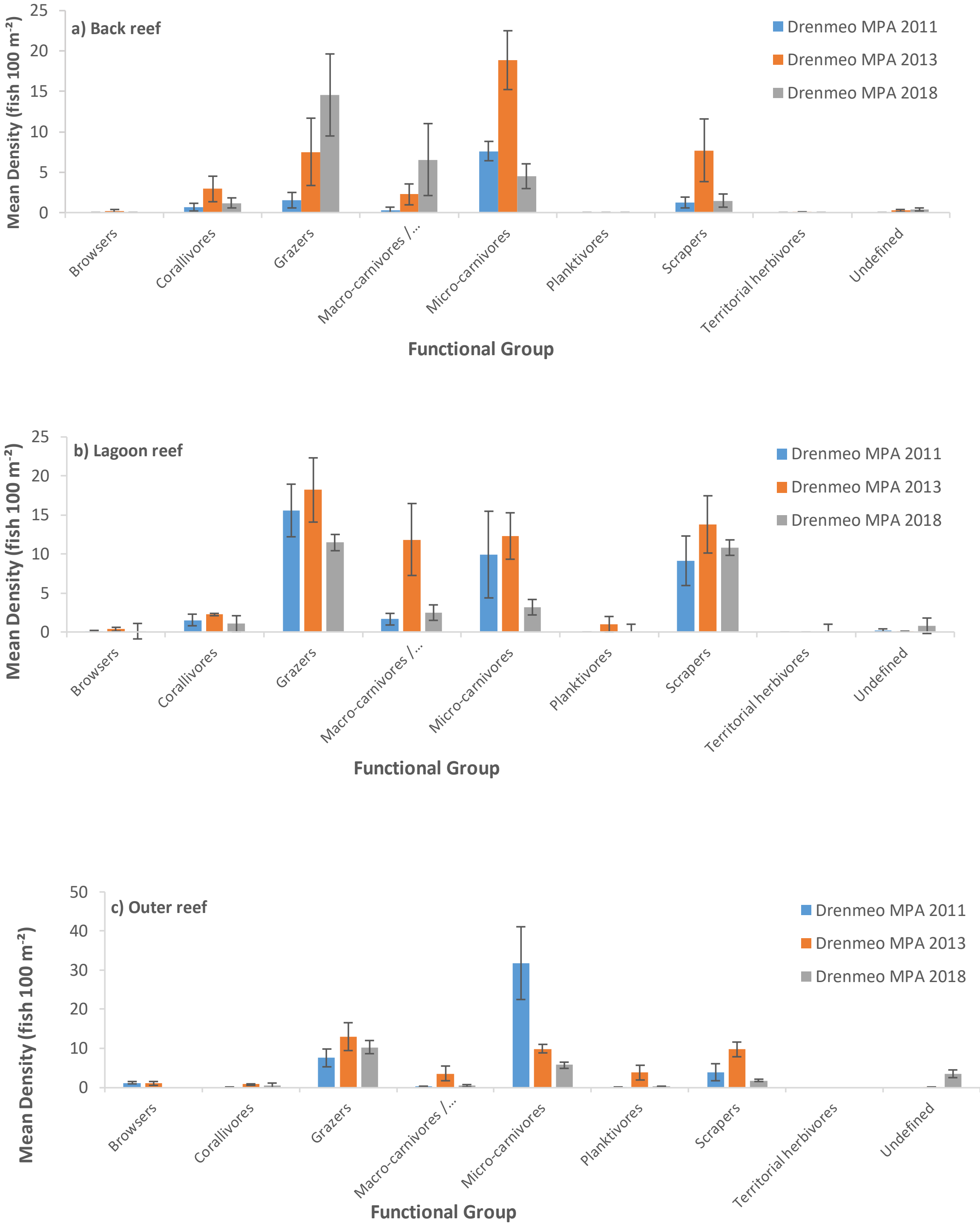


Figure 12: Mean densities (± SE) of key functional groups (excluding Pomacentridae) among a) back reef, b) lagoon reef and c) outer reef habitats of the Drenmeo MPA monitoring site during the 2011, 2013 and 2018 surveys

Laura 1

The relative diversity of selected families in the Laura 1 site was lower during the 2018 survey relative to 2013 for all habitats examined (Table 12). In 2018, browsers were absent in all habitats, while in previous surveys they were absent only from lagoon reefs in 2013 (Table 12, Figure 15).

Table 12: Total number of species in four key families (Acanthuridae, Chaetodontidae, Scaridae and Siganidae) and the number of functional groups at back, lagoon and outer reef habitats of the Laura 1 monitoring site during the 2011, 2013 and 2018 surveys

	Back reef			Lagoon reef			Outer reef			Overall site		
LAURA 1	2011	2013	2018	2011	2013	2018	2011	2013	2018	2011	2013	2018
Acanthuridae	6	11	7	4	12	4	7	7	6	12	17	10
Chaetodontidae	1	11	6	7	11	5	11	13	6	15	21	11
Scaridae	2	11	6	5	9	7	9	8	6	10	14	10
Siganidae	0	1	0	0	2	1	0	1	0	0	2	1
Functional group	7/8	8/8	7/8	8/8	8/8	8/8	7/8	8/8	7/8	8/8		

During the last survey, the densities of Scaridae, Chaetodontidae and Scaridae appeared lower in all habitats than in the 2013 survey (Figure 13) and some associated functional group densities, such as grazers and scrapers, also appeared lower (Figure 15). In contrast, the Pomacentridae family density seemed higher in 2018 for the back reef and lagoon habitats (Figure 14).

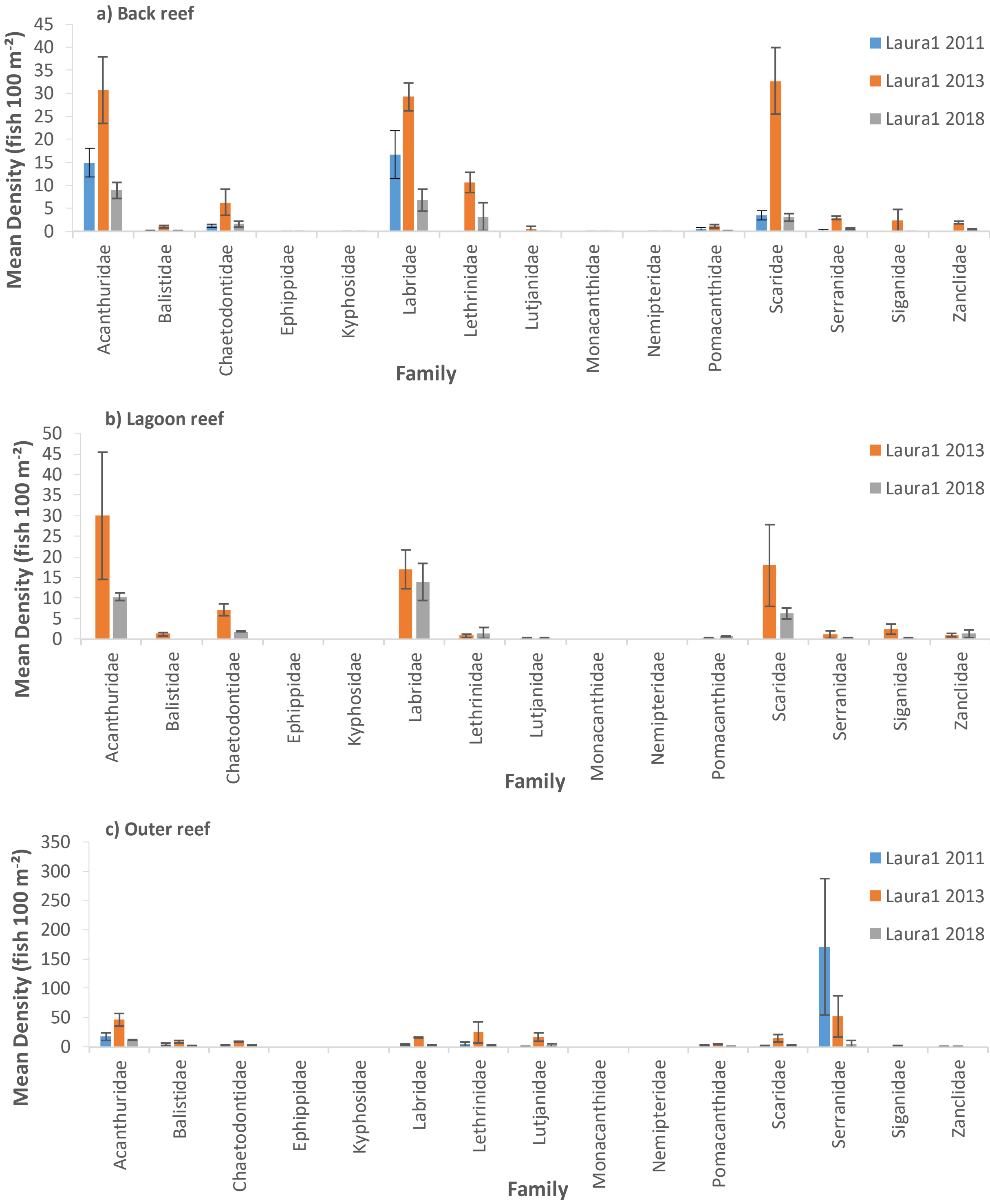


Figure 13: Mean densities (± SE) of common finfish families (excluding Pomacentridae) among a) back reef, b) lagoon reef and c) outer reef habitats of the Laura 1 monitoring site during the 2011, 2013 and 2018 surveys

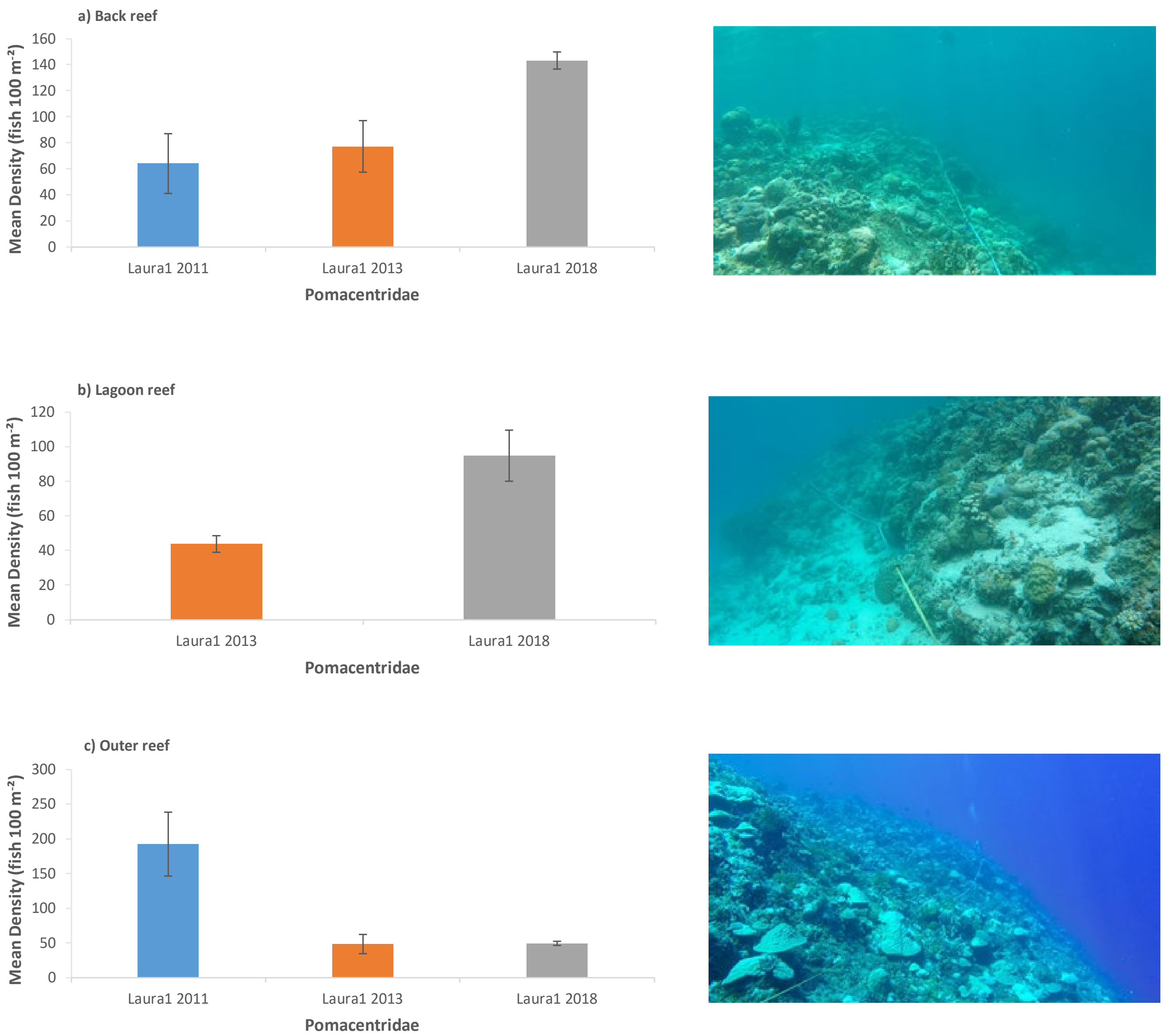


Figure 14: Mean densities (± SE) of Pomacentridae among a) back reef, b) lagoon reef and c) outer reef habitats of the Laura 1 monitoring site during the 2011, 2013 and 2018 surveys

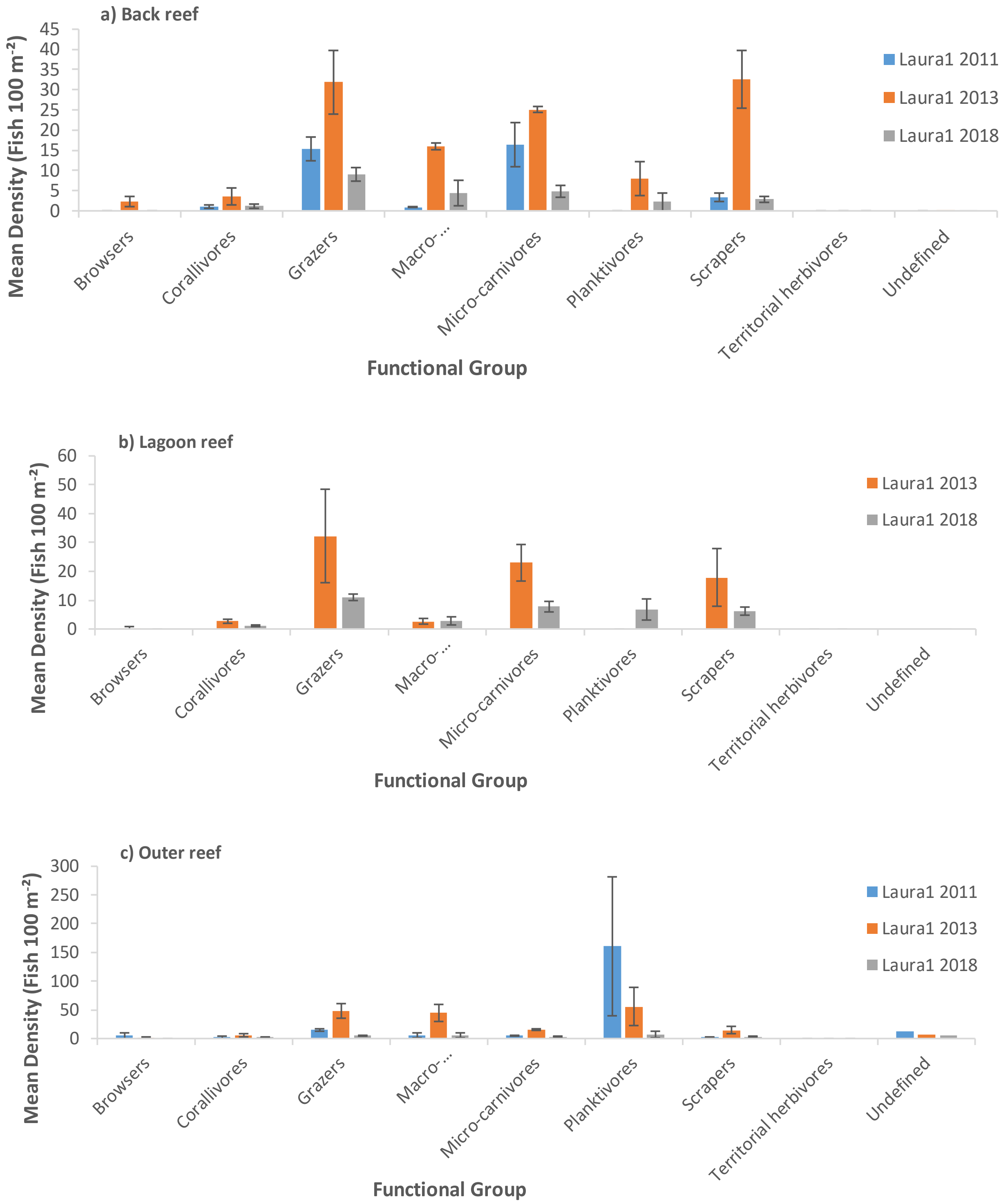


Figure 15: Mean densities (± SE) of key functional groups (excluding Pomacentridae) among a) back reef, b) lagoon reef and c) outer reef habitats of the Laura 1 monitoring site during the 2011, 2013 and 2018 surveys

Laura 2

Consistent with other monitoring sites, reef fish relative diversity of key families in the Laura 2 site tended to be slightly lower during the 2018 survey compared to 2013 for all habitats examined (Table 13). The number of functional groups present was similar among surveys, with only browsers absent from the back reef in 2013 and 2018 and from the back reef and the lagoon reef in 2018 (Table 13, Figure 18).

Table 13: Total number of species in four key families (Acanthuridae, Chaetodontidae, Scaridae and Siganidae) and the number of functional groups at back, lagoon and outer reef habitats of the Laura 2 monitoring site, 2011, 2013 and 2018

	Back reef			Lagoon reef			Outer reef			Overall site		
LAURA 2	2011	2013	2018	2011	2013	2018	2011	2013	2018	2011	2013	2018
Acanthuridae	4	9	7		9	5	7	11	9	8	15	11
Chaetodontidae	4	6	5		8	3	8	12	8	8	14	11
Scaridae	3	12	7		10	4	4	8	8	5	16	16
Siganidae	0	2	1		4	1	0	0	0	0	5	1
Functional group	7/8	8/8	7/8	8/8	8/8	8/8	7/8	8/8	7/8		8/8	

At the family-specific density scale, a lot of variability was observed among surveys with a scaridae density that appeared lower for the lagoon reef in 2018 (Figure 16). The pomacentridae density also seemed lower in this habitat compared to the 2013 data (Figure 17). In the lagoon reef habitat, most functional group densities seemed lower in 2018, with the exception of corallivores and undefined functional groups (Figure 18).

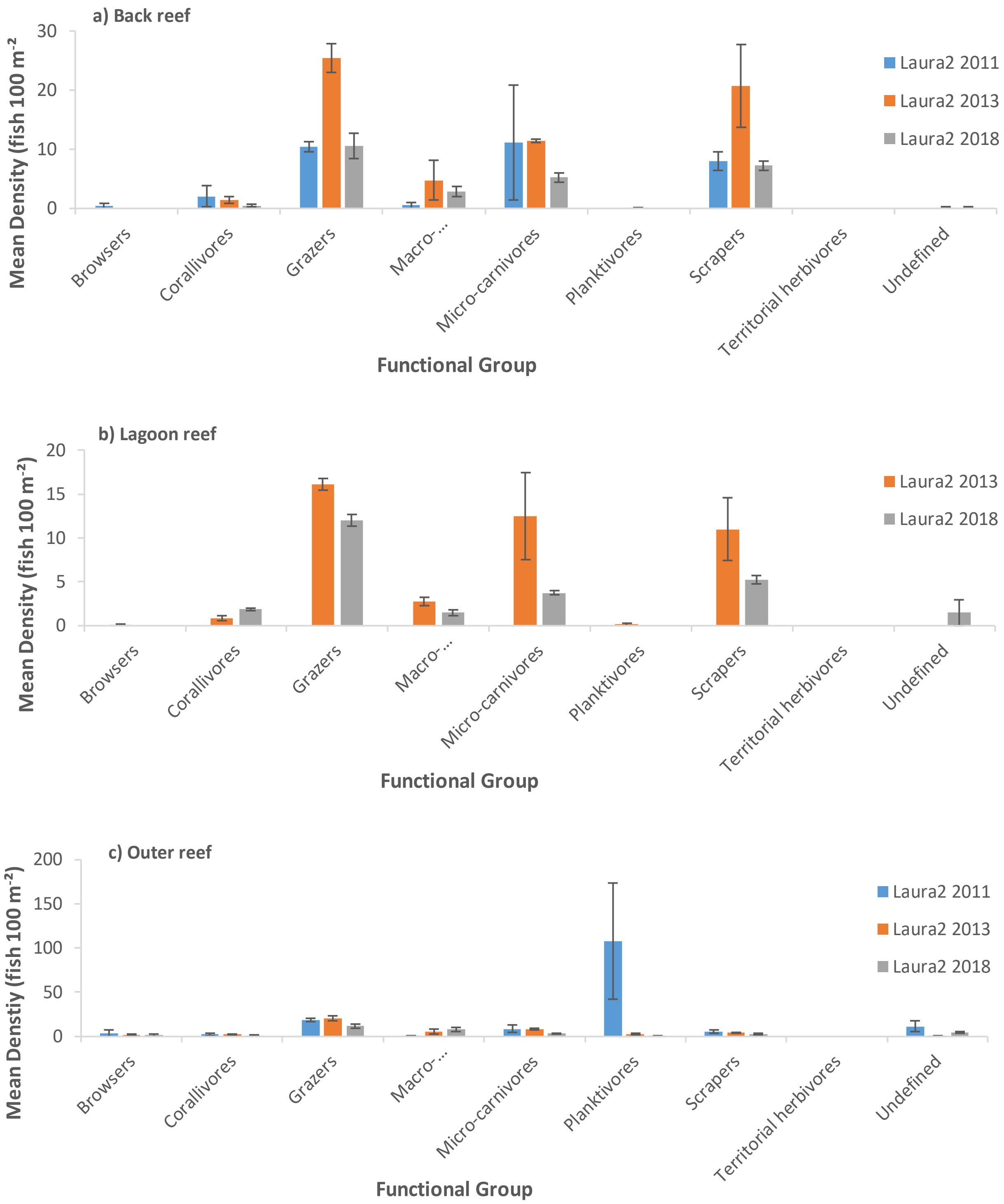


Figure 16: Mean densities (± SE) of common finfish families (excluding Pomacentridae) among a) back reef, b) lagoon reef and c) outer reef habitats of the Laura 2 monitoring site during the 2011, 2013 and 2018 surveys

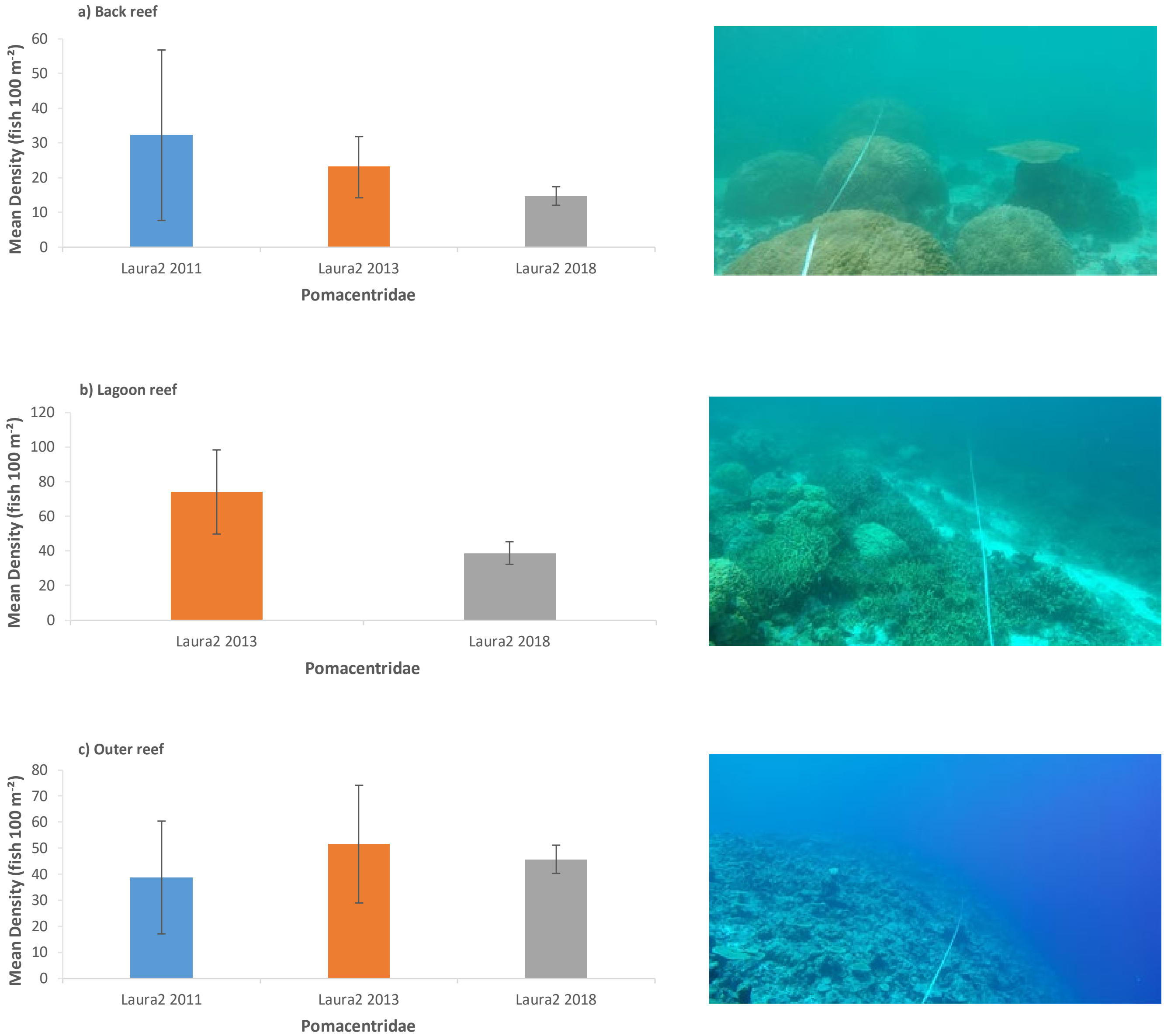
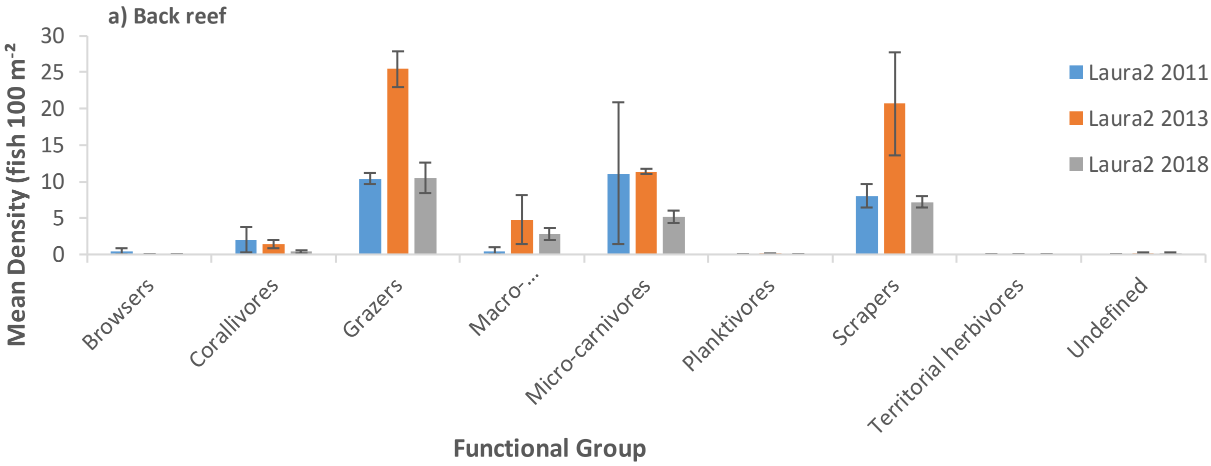
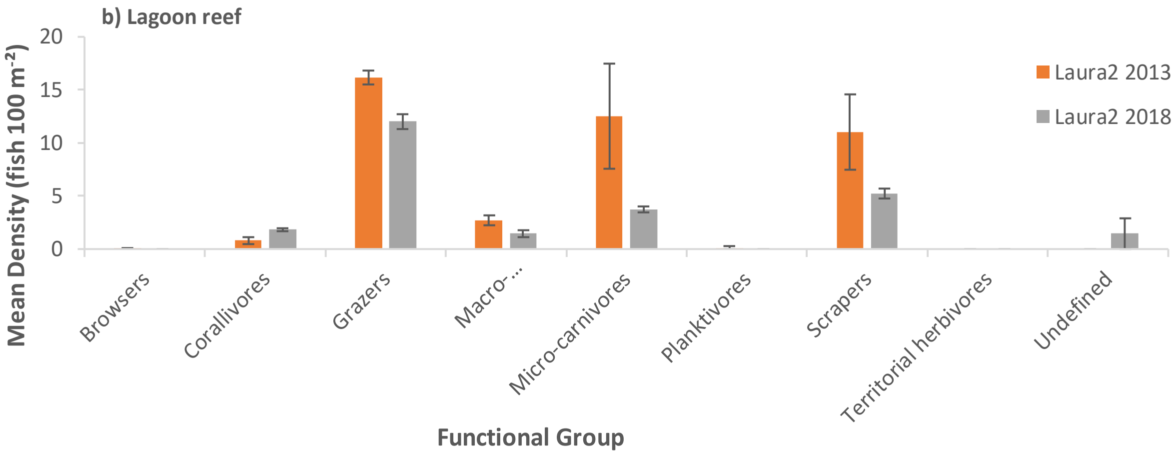


Figure 17: Mean densities (± SE) of Pomacentridae among a) back reef, b) lagoon reef and c) outer reef habitats of the Laura 2 monitoring site during the 2011, 2013 and 2018 surveys





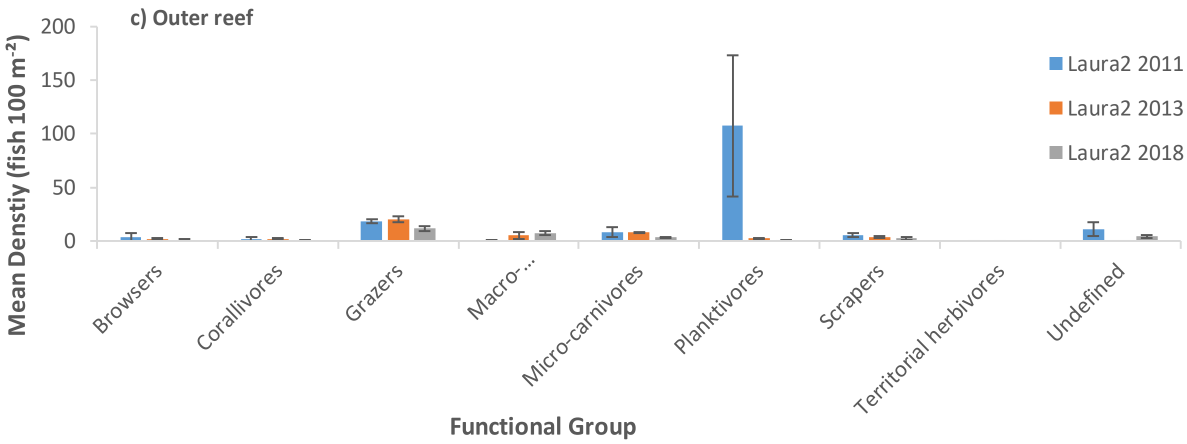


Figure 18: Mean densities (± SE) of key functional groups (excluding Pomacentridae) among a) back reef, b) lagoon reef and c) outer reef habitats of the Laura 2 monitoring site during the 2011, 2013 and 2018 surveys

The timed swims produced lower densities than the standard UVC belt transects, being focused only on fish >35 cm in length. Compared to the standard UVC procedure, however, other families were better represented (Figure 19). In fact, snapper (Lutjanidae) were the most represented due to the presence of a school of Lutjanus gibbus on a few swims. The second family most represented was parrot fish (Scaridae), aligning with the other method. In contrast, surgeonfish (Acanthuridae) were less represented during the swims.

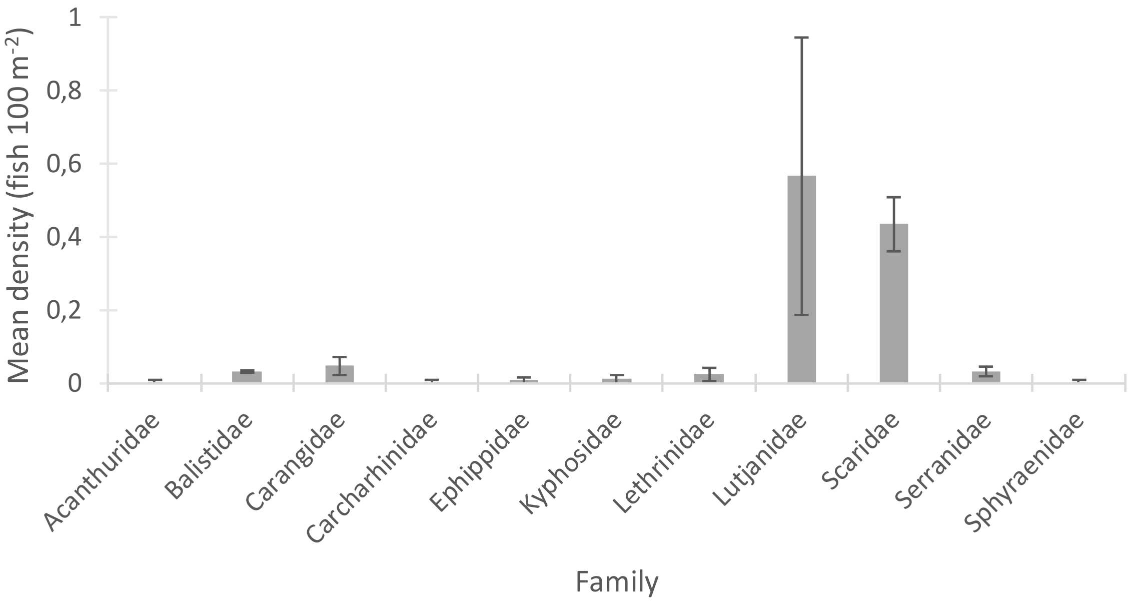


Figure 19: Swim methodology mean densities (± SE) of common large finfish families among the outer reef habitats of the Laura 2 monitoring site during the 2018 survey.

Majuro

Consistent with other monitoring sites, fish relative diversity for selected families observed in the Majuro monitoring site was lower during the 2018 survey than during the 2013 survey for all habitats examined (Table 14). All habitats supported all functional groups except for browsers, which were absent from back reef and lagoon reef habitats in 2018 and from back reef and outer reef habitats in 2011 (Table 14).

Table 14: Total number of species in four key families (Acanthuridae, Chaetodontidae, Scaridae and Siganidae) and the number of functional groups at back, lagoon and outer reef habitats of the Majuro monitoring site, 2011, 2013 and 2018

	Back reef			Lagoon reef			Outer reef			Overall site		
MAJURO	2011	2013	2018	2011	2013	2018	2011	2013	2018	2011	2013	2018
Acanthuridae	9	9	4	6	13	5	4	13	6	11	19	8
Chaetodontidae	5	10	5	8	9	8	3	9	5	12	17	11
Scaridae	3	5	3	6	10	6	3	11	9	7	15	14
Siganidae	0	2	0	0	2	0	0	0	0	0	4	0
Functional group	7/8	8/8	7/8	8/8	8/8	8/8	7/8	8/8	7/8		8/8	

Similar to other sites, a lot of variability was observed among surveys for specific families densities. Labridae of the back reef and Acanthuridae of the lagoon reef seemed lower for the 2018 survey (Figure 20). The pomacentridae density was the most variable for the outer reef habitat, with 2018 densities that seemed lower than in the 2013 survey but higher than in the 2011 survey (Figure 21). In the back reef and outer reef habitats, the micro-carnivore functional group densities seemed lower in 2018 with respect to the other surveys. In the lagoon reef habitat, only the grazers appeared lower than in the 2011 and the 2013 surveys (Figure 22).

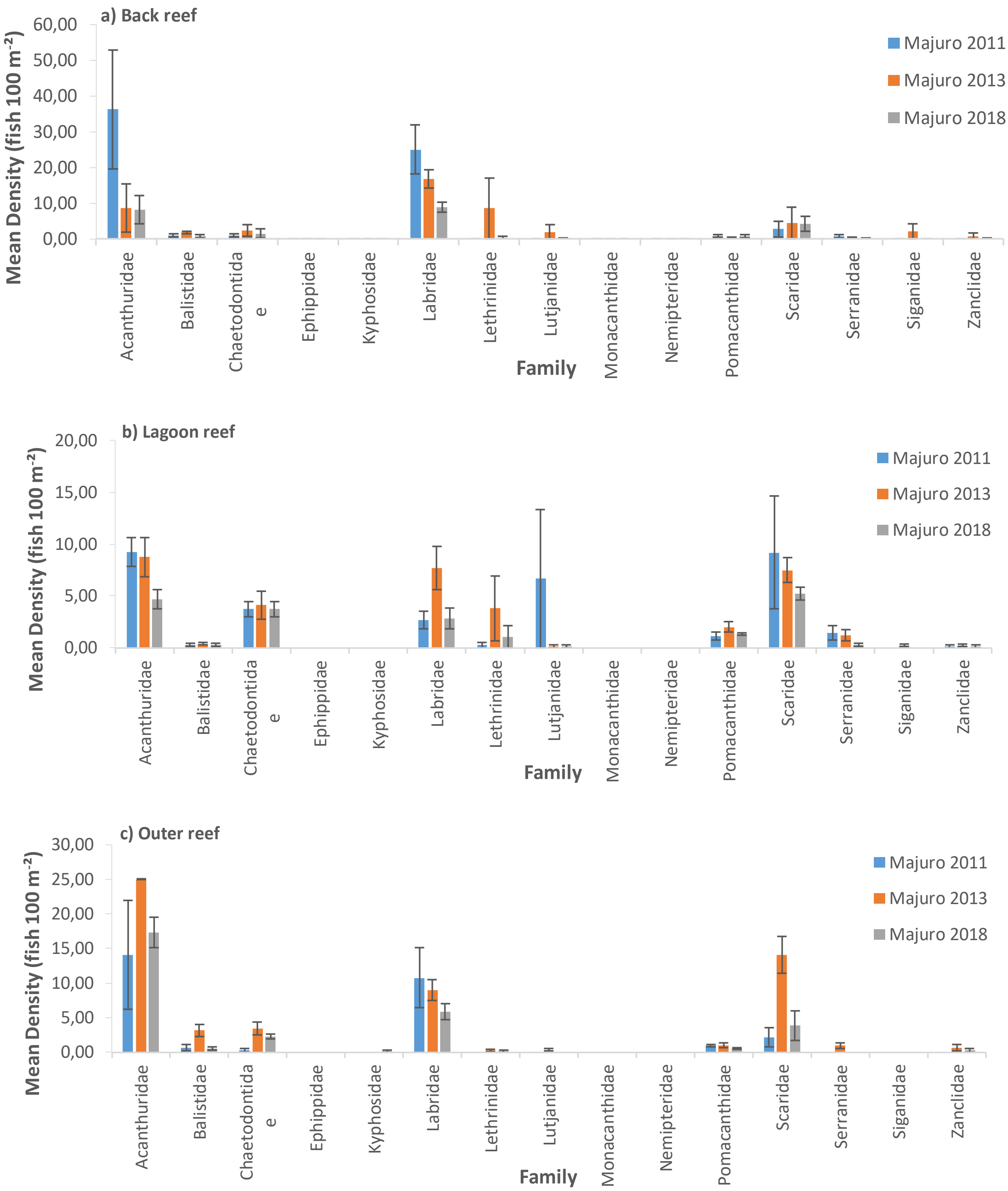


Figure 20: Mean densities (± SE) of common finfish families (excluding Pomacentridae) among a) back reef, b) lagoon reef and c) outer reef habitats of the Majuro monitoring site during the 2011, 2013 and 2018 surveys

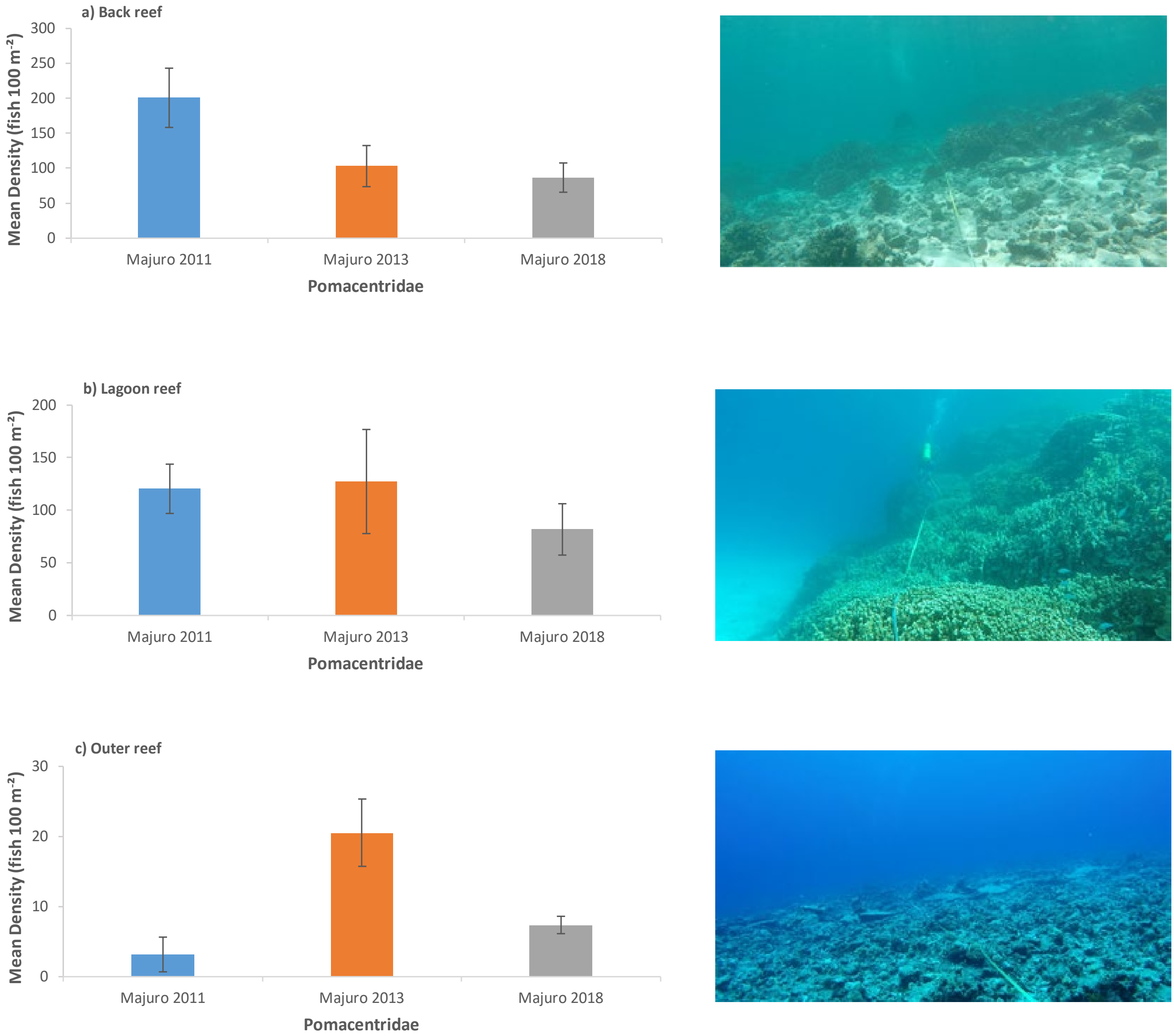
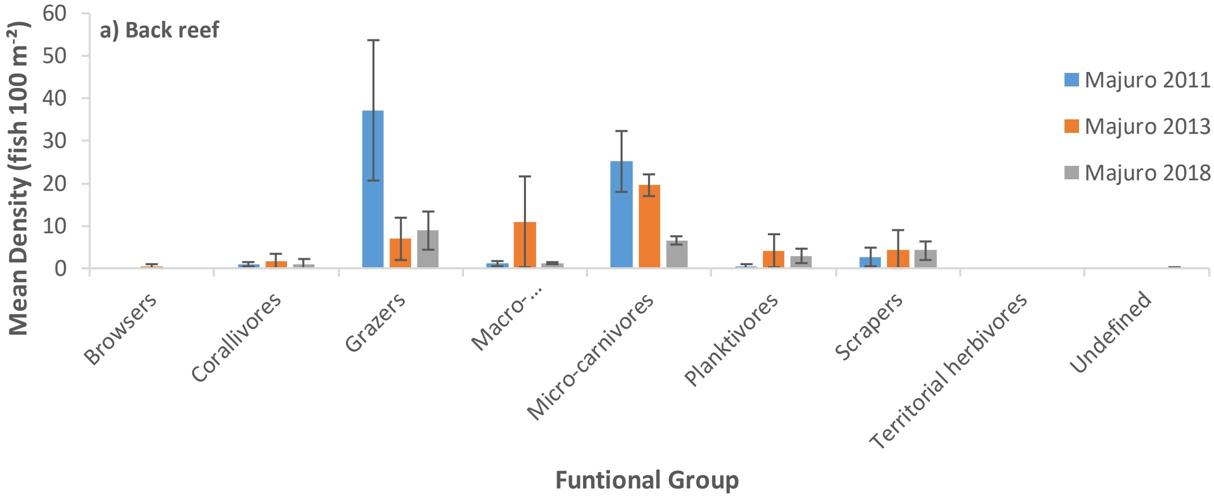
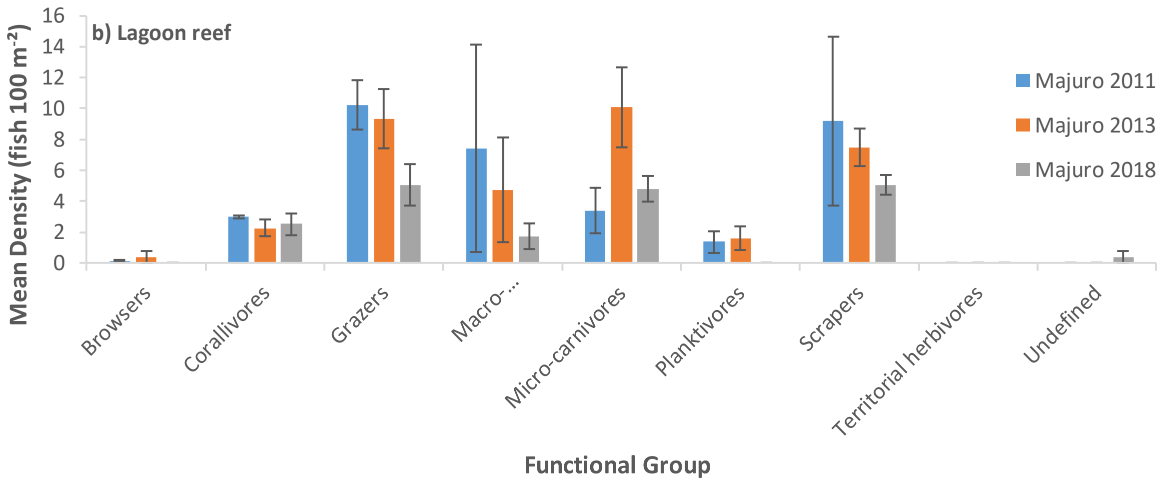


Figure 21: Mean densities (± SE) of Pomacentridae among a) back reef, b) lagoon reef and c) outer reef habitats of the Majuro monitoring site during the 2011, 2013 and 2018 surveys





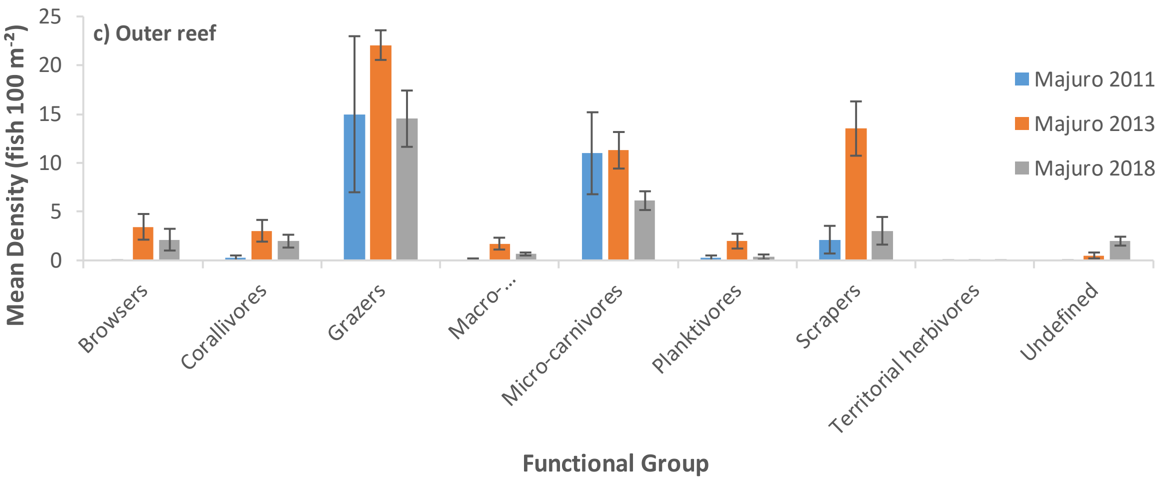


Figure 22: Mean densities (± SE) of key functional groups (excluding Pomacentridae) among a) back reef, b) lagoon reef and c) outer reef habitats of the Majuro monitoring site during the 2011, 2013 and 2018 surveys

Woja MPA

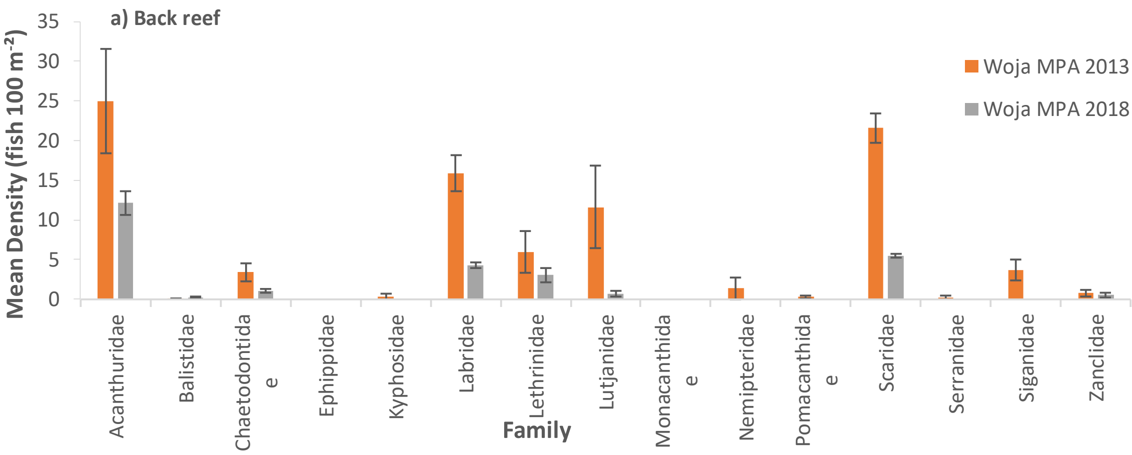
In 2018, finfish communities of the Woja MPA were surveyed at two reef zones: back reef and outer reef. No lagoon reef habitats were available for survey within the MPA.

Consistent with other monitoring sites, coral fish relative diversity observed in the Woja MPA was slightly lower during the 2018 survey compared to 2013 for the two habitats examined (Table 15). All functional groups were observed in both the back reef and outer reef of the MPA during the 2018 and 2013 surveys (Table 15).

Table 15: Total number of species in four key Families (Acanthuridae, Chaetodontidae, Scaridae and Siganidae) and the number of functional groups at back, lagoon and outer reef habitats of the Woja MPA monitoring sites, 2013 and 2018

	Back reef		Outer reef		Overall site	
WOJA MPA	2013	2018	2013	2018	2013	2018
Acanthuridae	9	8	14	7	15	12
Chaetodontidae	10	3	11	11	16	11
Scaridae	10	12	12	9	15	17
Siganidae	3	0	1	1	3	1
Functional group	8/8	8/8	8/8	8/8	8/8	

The families showing the largest differences were the Acanthuridae and Labridae in both habitats and the Lutjanidae and Scaridae in the back reef habitat (Figure 23). Most functional groups seemed lower in the 2018 survey (Figure 25). Macro-carnivores and scrapers, however, showed equivalent results for the outer reef habitat. The Pomacentridae densities seemed relatively similar for both surveys (Figure 24).



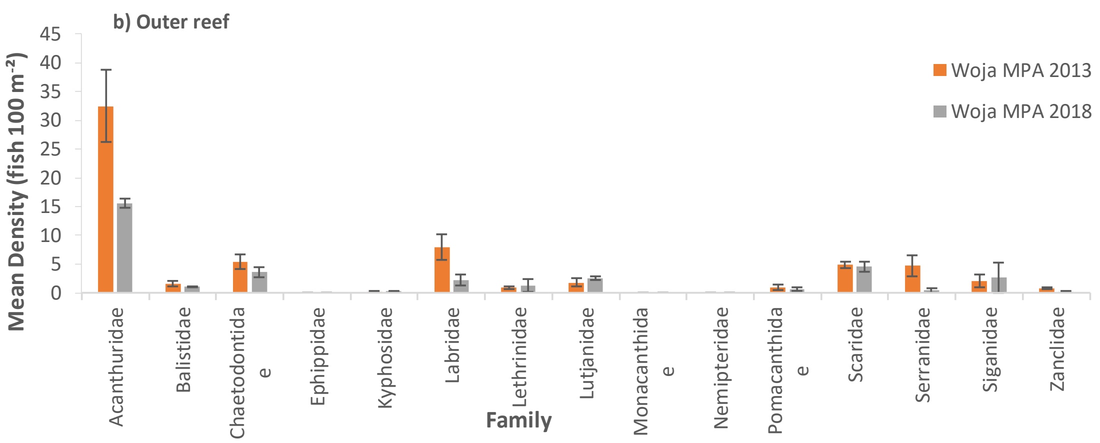


Figure 23: Mean densities (± SE) of common finfish families (excluding Pomacentridae) among a) back reef, b) outer reef habitats of the Woja MPA monitoring site during the 2013 and 2018 surveys

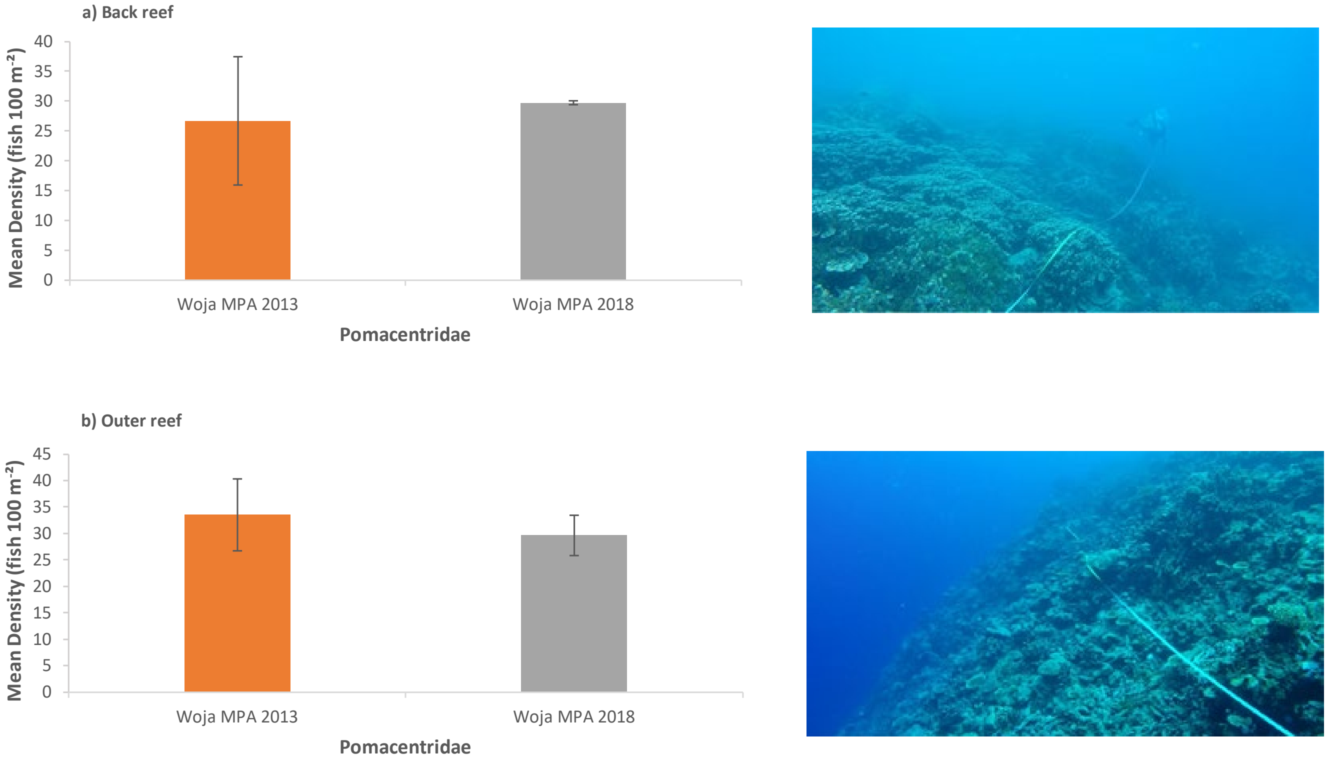


Figure 24: Mean densities (± SE) of Pomacentridae among a) back reef, b) outer reef habitats of the Woja MPA monitoring site during the 2013 and 2018 surveys

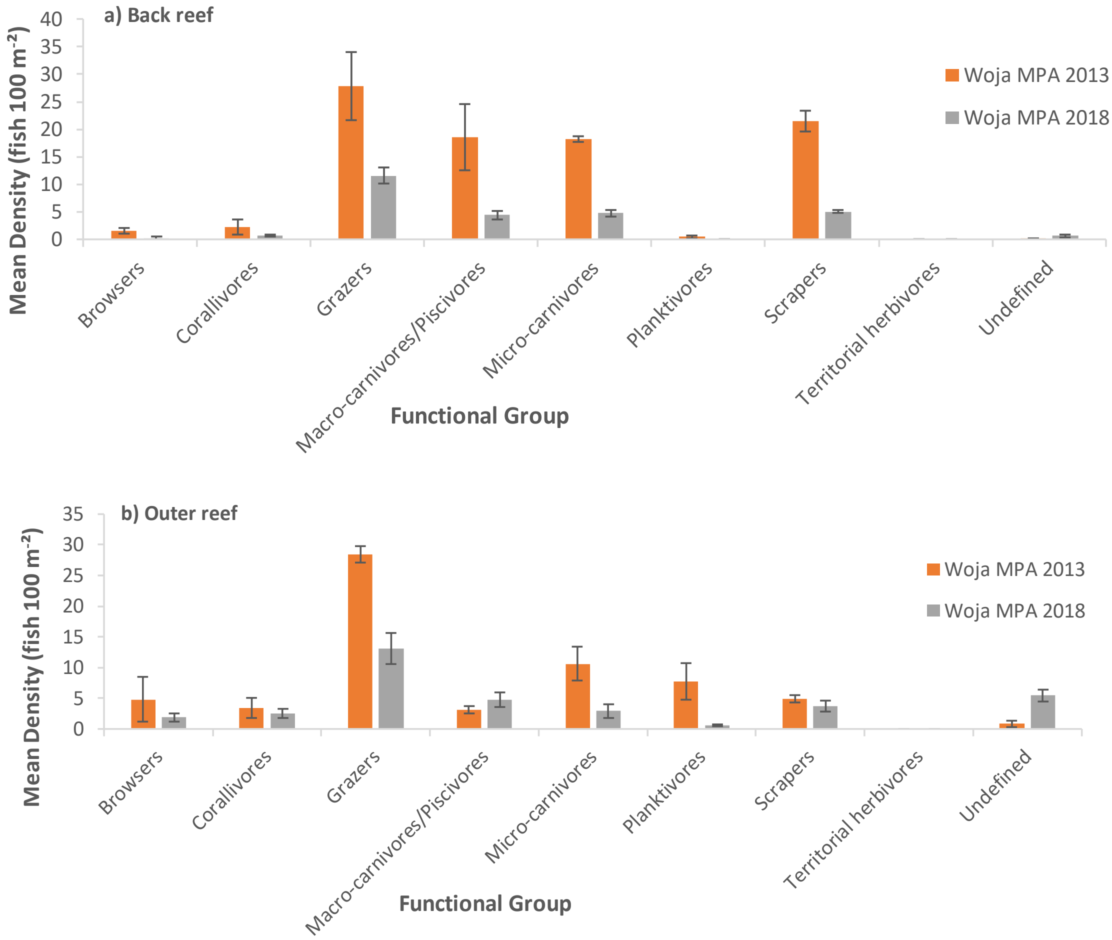


Figure 25: Mean densities (± SE) of key functional groups among a) back reef and b) outer reef habitats of the Woja MPA monitoring site during the 2013 and 2018 surveys

Like Laura 2, the swims methodology results represented very low fish density (Figure 26). In fact, snappers (Lutjanidae) were the most represented due to the presence of schools of *Lutjanus gibbus* on a few swims. The second family most represented was parrotfish (Scaridae) aligning with the standard UVC belt transects. Surgeonfish (Acanthuridae) were, however, slightly less represented during the swims.

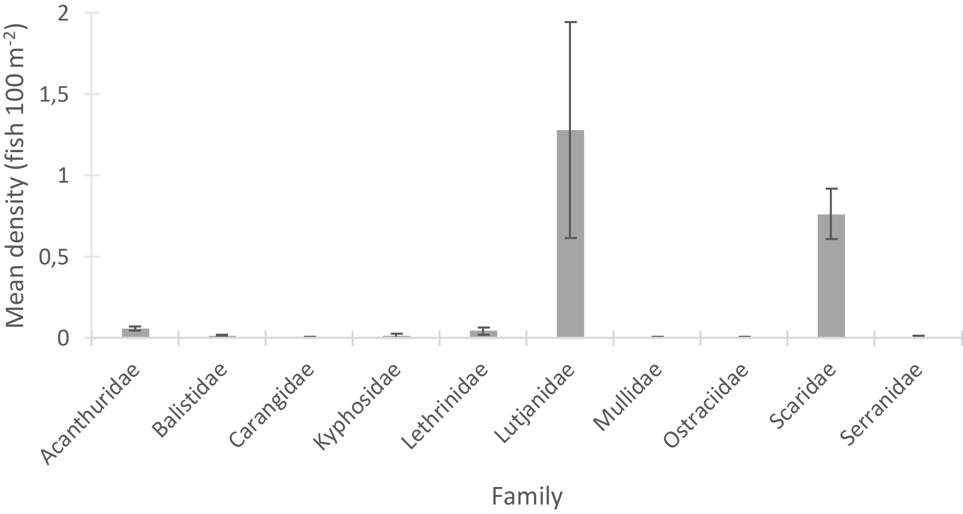


Figure 26: Swim methodology mean densities (± SE) of common large finfish families among the outer reef habitats of the Woja MPA monitoring site during the 2018 survey

Benthos

Community-level patterns

The result of the multivariate regression trees on benthos major categories suggest that the greatest observed change are linked to the habitat surveyed rather than to the site and year of the survey.

The outer reef can be distinguished from the lagoon reef and back reef. Differences between surveys varied across sites.

Among the categories shown in Figure 27, the percentage cover of the major benthic categories studied (live coral, macroalgae, rubble, sand, crustose coralline algae) all showed statistical differences.

For macroalgae, the percentage cover of the *Halimeda* macroalgae showed only statistical difference between the outer reef and the other two habitats (Appendix 5).

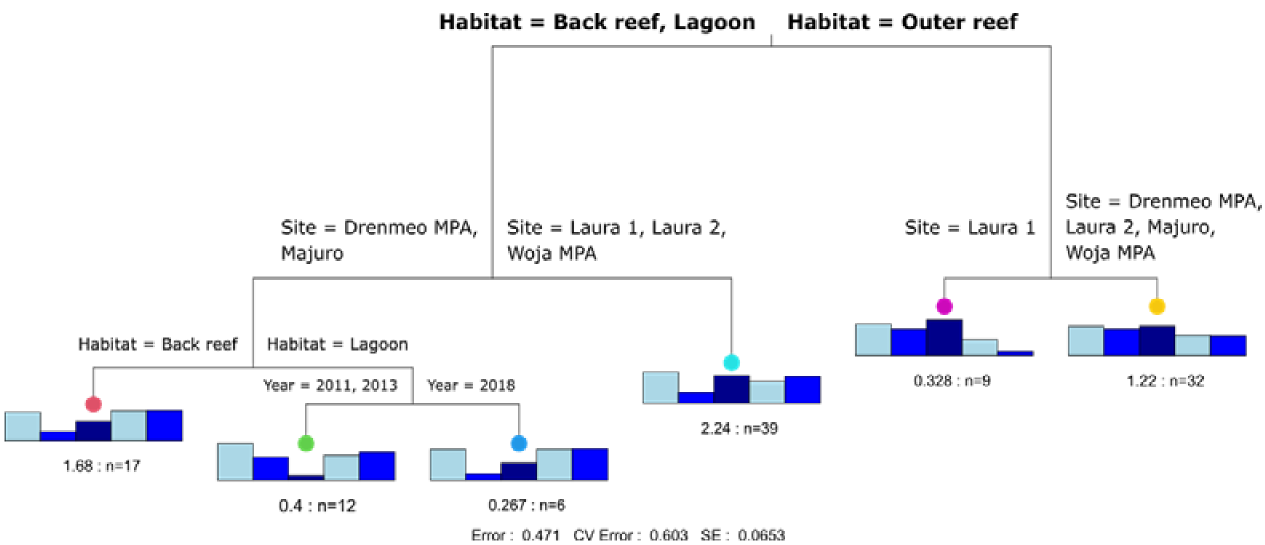


Figure 27: Multivariate regression tree displaying the main patterns in the structure of the main benthic communities across the 2011, 2013 and 2018 surveys

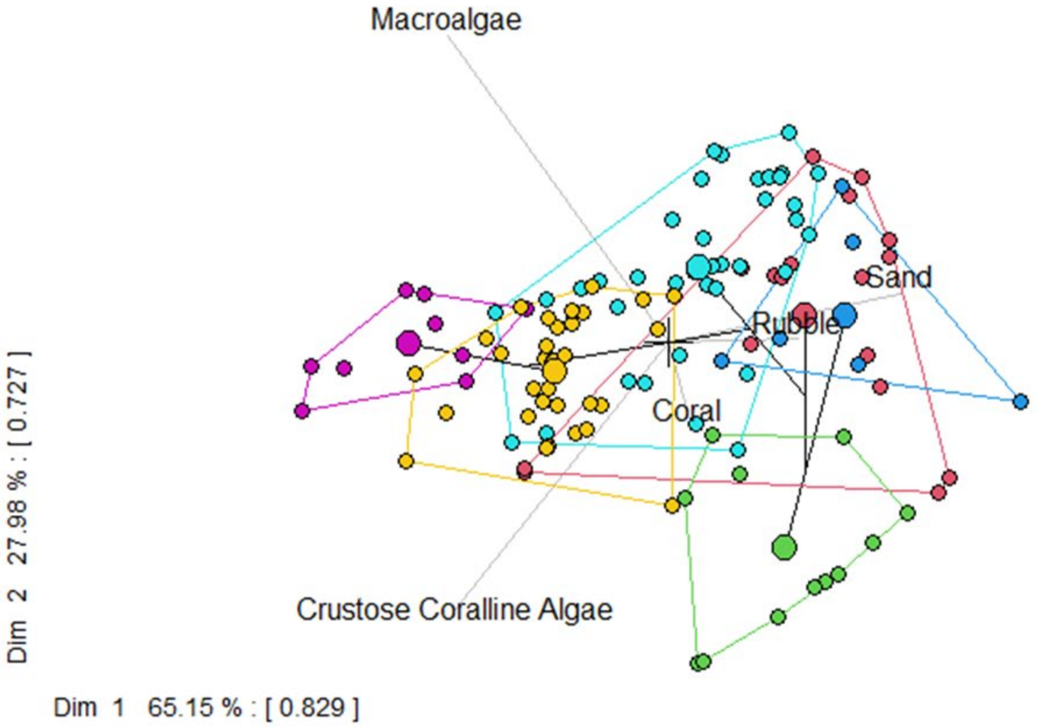


Figure 28: PCA biplot ordination with colours corresponding to the regression tree in Figure 27.
Grey arrows represent the relationship of all categories to the observed community patterns.

Site summaries

Drenmeo MPA

The outer habitat was distinct from the back reef and lagoon reef habitats and only the rubble category was not significantly different in the entire site for all three surveys.

Back reef habitats of the Drenmeo MPA site showed little difference among surveys (Figure 29) with the exception of sand. Despite the important drop in sand cover, the other benthic categories remained relatively stable since 2013. The cover of *Halimeda* algae increased from 0.14 ± 0.14% in 2013 to 3.40 ± 1.80% in 2018. In general, back reef habitats during all three surveys (2011, 2013, 2018) were characterised by a relatively high percentage cover of sand and rubble, and a low percentage cover of live hard corals (Figure 29).

In contrast, lagoon reefs of the Drenmeo MPA were dominated by hard corals (Figure 29) primarily represented by *Porites* corals species of various shapes. A decrease in the percentage cover of live hard coral (whether due to slightly different transects or to environmental changes) and a slight increase in the cover of macroalgae and rubble were evident between the 2013 and 2018 surveys.

Benthic habitat composition on the outer reefs of the Drenmeo MPA site between the 2013 and 2018 surveys (Figure 29) showed no differences. During all surveys, this habitat type was characterised by a high cover of macroalgae (incl. *Microdictyon* and calcified algae of the genus *Halimeda*) and live corals (primarily *Acropora, Montipora* and *Pocillopora*) (Figure 29).

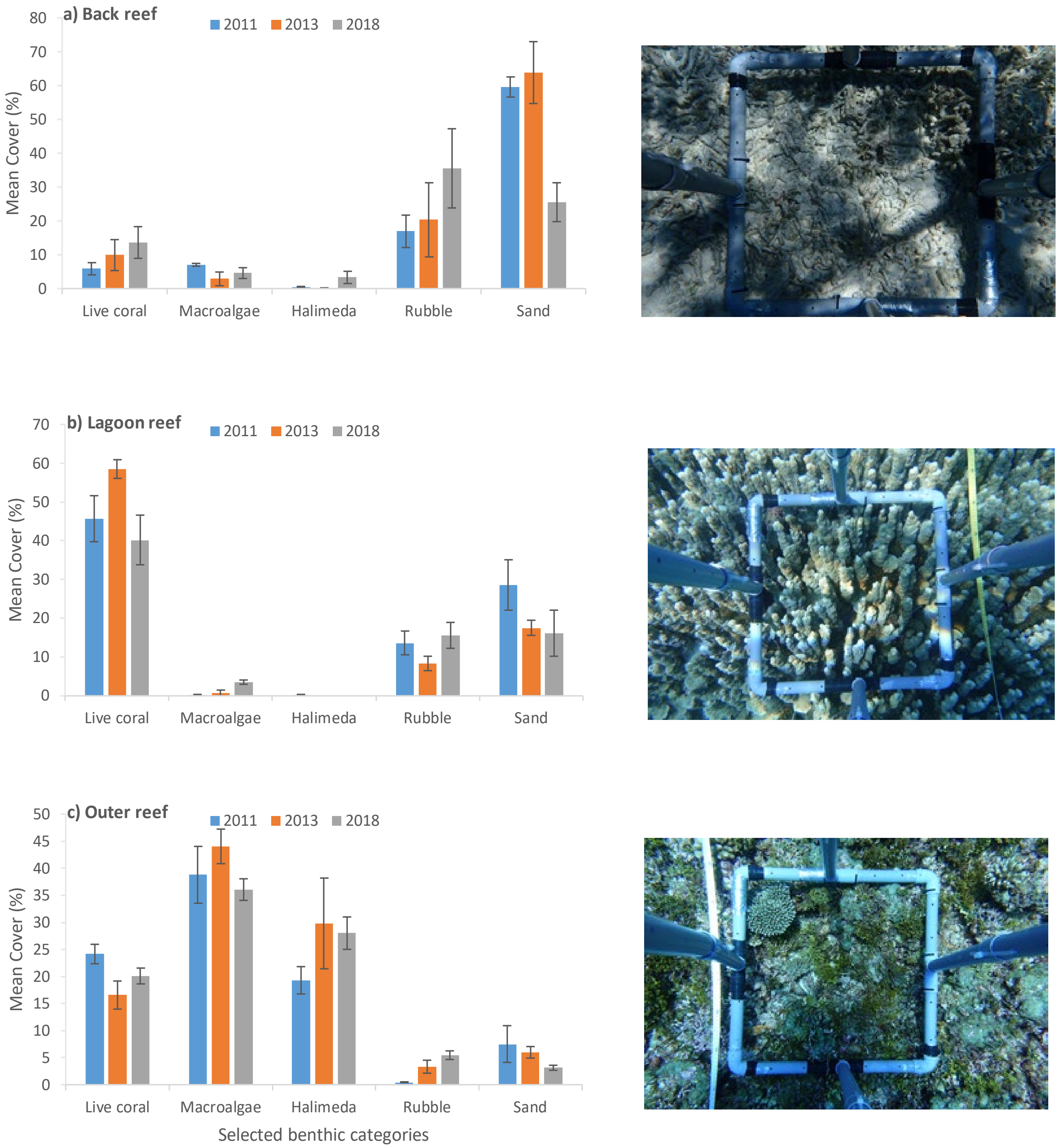


Figure 29: Percentage cover of selected benthic categories (right) and associated 2018 dominant category/taxa (left) at a) back reef, b) lagoon reef and c) outer reef transects of the Drenmeo MPA monitoring site in the 2011, 2013 and 2018 surveys. Dominant taxa: a) rubble; b) *Porites rus* coral; and c) *Halimeda spp* macroalgae.

Laura 1

The outer habitat was distinguished from the back reef and lagoon reef habitats. The coral and rubble categories were not significantly different in the entire site for all three surveys, while *Halimeda* was statistically different (p=0.001) between the outer reef and the other two habitats.

The benthic composition of the back reef habitats of the Laura 1 site appeared largely similar in the 2013 and 2018 surveys (Figure 30). For all surveys, this habitat was characterised by a high cover of macroalgae (with *Halimeda* representing the highest percentage), live coral and sand. The two highest percentages of live coral were reprensented by the genus *Goniastrea* and by the species *Porites rus*.

Lagoon reef habitats were surveyed only in 2013 and 2018 and were characterised by a drop in coral cover, while the other benthic categories were almost evenly represented in both surveys (Figure 30). The main coral genus represented in this habitat in 2013 was *Acropora,* while in 2018 it was *Montipora*.

A few changes in benthic habitat composition were evident on the outer reefs of the Laura 1 monitoring site (Figure 30). The percentage cover of the macroalgae category and its dominant representative genus *Halimeda* increased by more than 15% between 2013 and 2018, while the cover of live hard coral appeared slightly lower in 2018. The latter category was dominated by the species *Porites rus*.

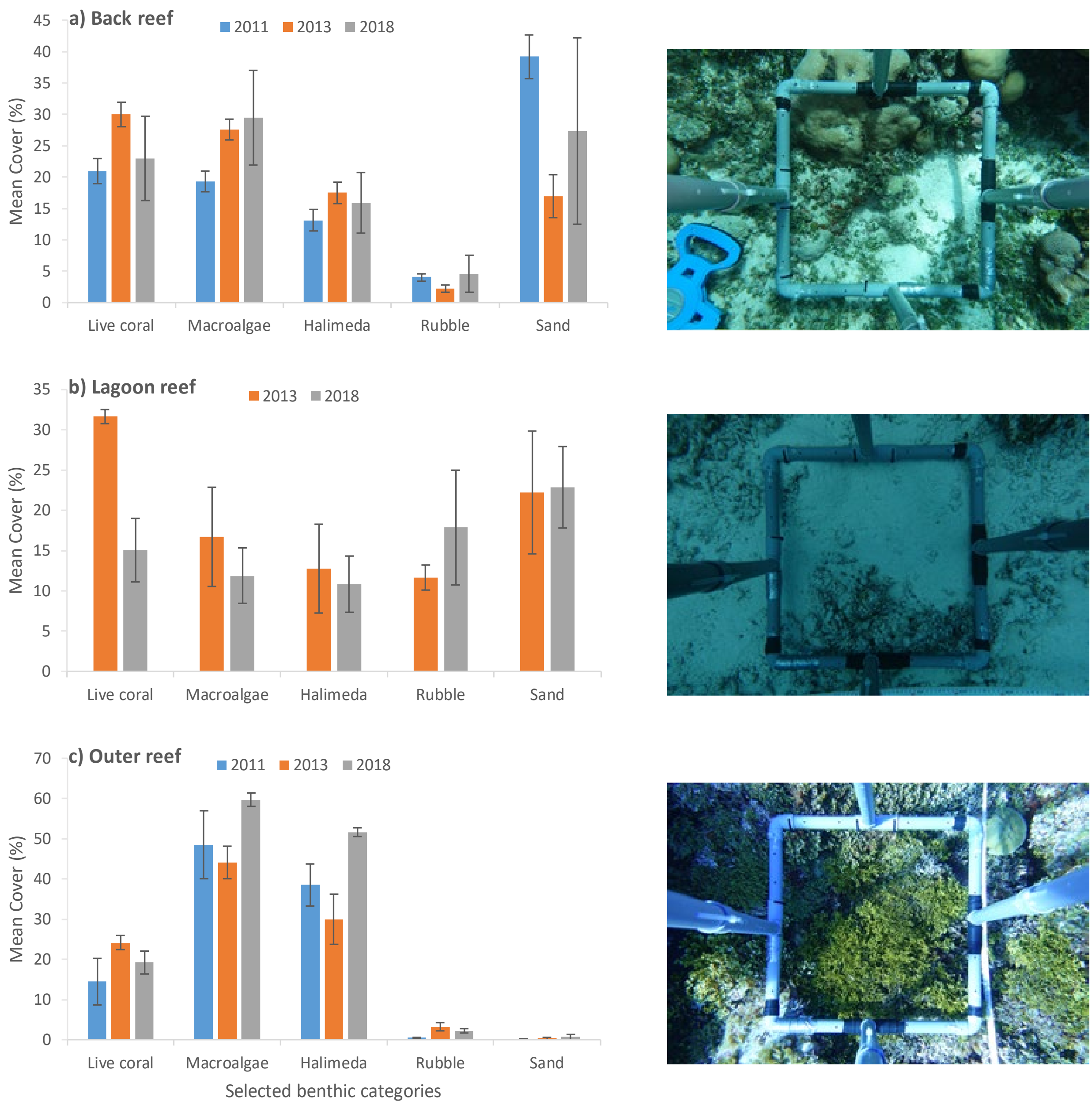


Figure 30: Percentage cover of selected benthic categories (right) and associated 2018 dominant category/taxa (left) at: a) back reef; b) lagoon reef; and c) outer reef transects of the Laura 1 monitoring site in the 2011, 2013 and 2018 surveys. Dominant taxa: a) macroalgae (mixed species); b) sand; and c) *Halimeda spp* macroalgae.

Laura 2

Similar to the Drenmeo MPA and Laura 1 sites, the outer reef was distinct from the back reef and lagoon reef habitats. On the outer reef, the 2018 survey also appeared different from the 2011 and 2013 surveys, while for the other two habitats the 2013 survey was different from the other surveys. All major benthic categories were significantly different across the entire site for all survey years while *Halimeda* showed no statistical differences across habitats or years.

Important changes in cover of benthic categories were observed on the back reef habitats of the Laura 2 site for the three surveys. Compared to 2013, an increase in the mean cover of live coral, macroalgae and its dominant taxa (*Halimeda*) were evident in this habitat (Figure 31). The cover of rubble appeared lower in 2018 compared to 2013. The dominant coral genus in this habitat was *Porites* (massive forms).

Lagoon reef habitats at the Laura 2 site were surveyed for the first time in 2013. Only a few differences were recorded between the 2013 survey and the 2018 survey, characterised by a decrease of sand and *Halimeda* algae. On a more general note, this habitat was characterised by a relatively high cover of live hard coral, primarily dominated by the *Porites* genus (branching types, *Porites rus* massive types) followed by the *Acropora* genus (Figure 31).

Changes in benthic habitat composition were evident on the outer reefs of the Laura 2 site. In 2018, apart from mean rubble cover, all categories had either increased or decreased. An increase in the macroalgae cover and Halimeda (the major representative of macroalgae) and a slight decrease of live coral and sand cover were observed (Figure 31).

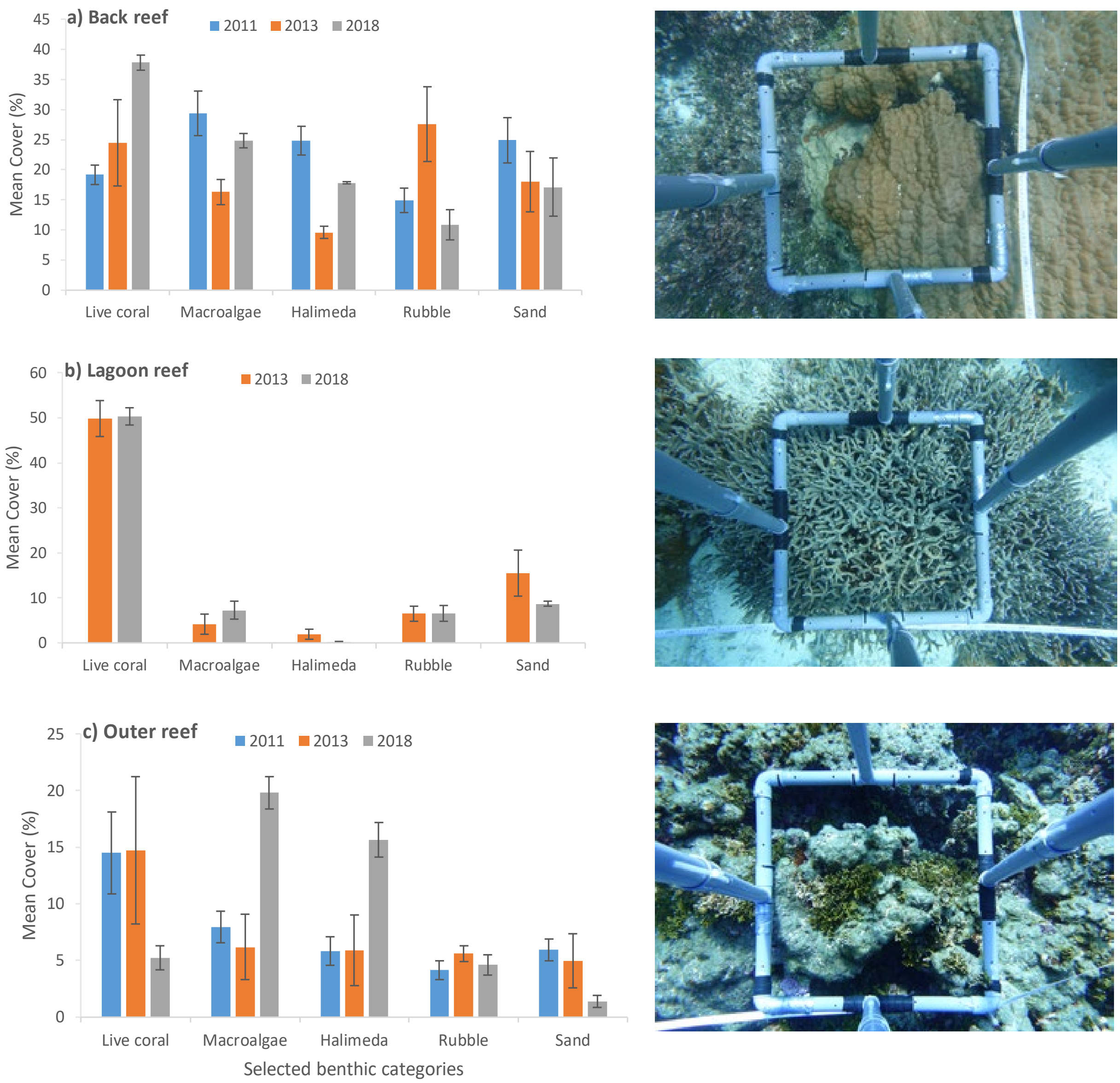


Figure 31: Percentage cover of selected benthic categories (right) and associated 2018 dominant category/taxa (left) at: a) back reef; b) lagoon reef; and c) outer reef transects of the Laura 2 monitoring site in the 2011, 2013 and 2018 surveys. Dominant taxa: a) Porites coral massive form; b) *Porites* coral branching form; and c) *Halimeda spp* macroalgae.

Majuro

The outer reef was distinguished from the back reef and lagoon reef habitats. For the outer reef, the 2011 survey appeared distinct from the other two surveys. The survey year was not a major driver for change for the lagoon and back reef habitats. All the major benthic categories were significantly different within the entire site for all survey years, while the macroalgae genus *Halimeda* was not significantly different.

Only limited changes were visible in the benthic composition of any habitat within the Majuro monitoring site (Figure 32).

The highest present cover of the back reef habitat is mainly represented by sand and rubble (Figure 32). A slight decrease in sand was apparent in 2018 compared to the previous surveys.

A very slight increase in macroalgae was apparent for the lagoon reef habitat between the 2013 and 2018 surveys (Figure 32). This habitat was characterised by important coral cover, largely dominated by the species *Porites rus*.

The outer reef habitat was the habitat showing a slightly higher number of changes. Compared to 2013, there were small drops in the cover of live coral, macroalgae and *Halimeda* (Figure 32), as well as an increase of rubble cover. The outer reef transects composition of the Majuro site were dominated by macroalgae (particularly *Halimeda* spp.) and live coral (in particular *Acropora* spp.).

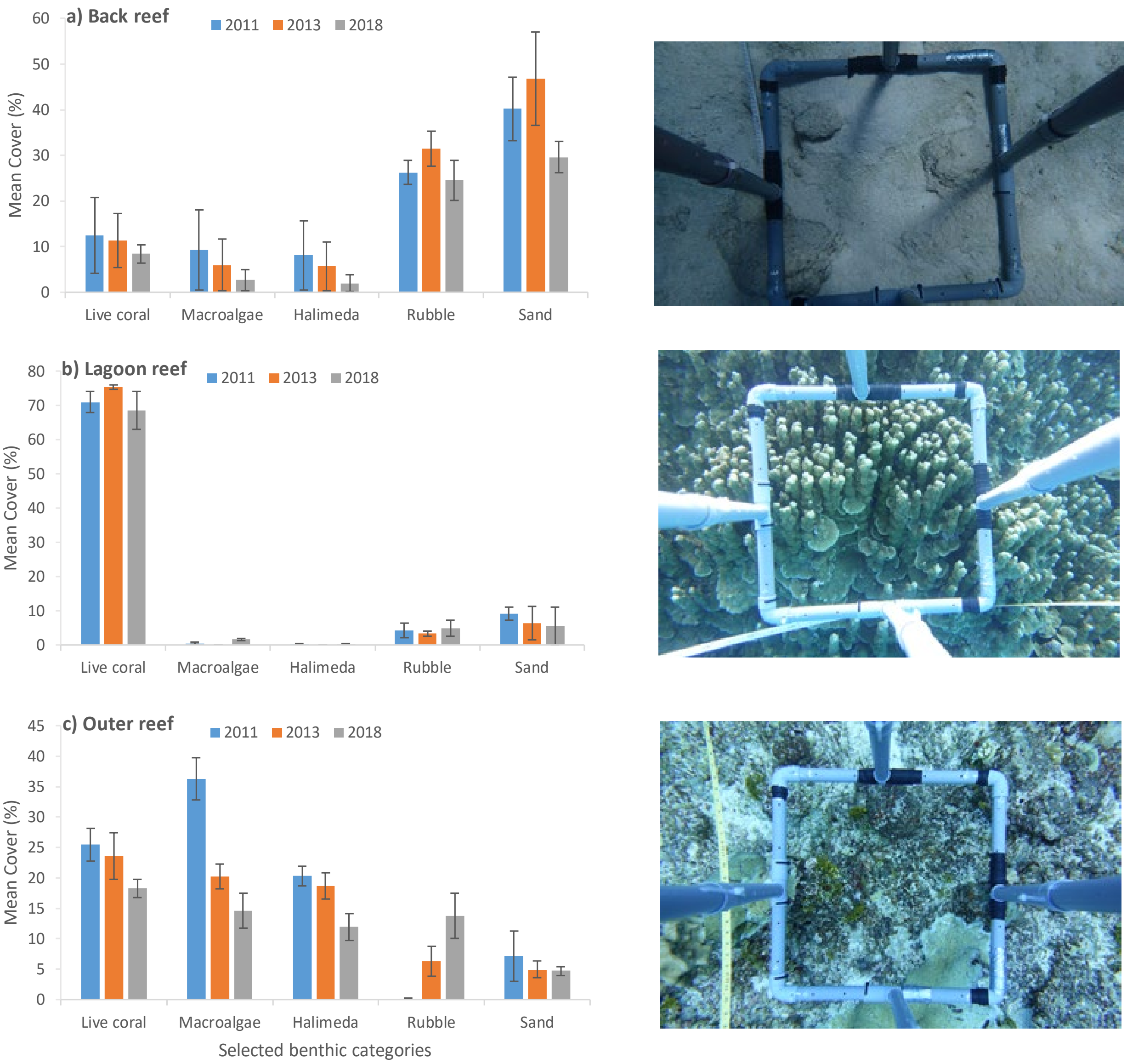


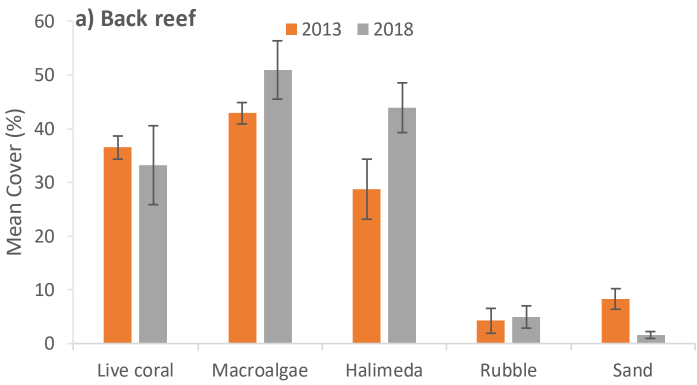
Figure 32: Percentage cover of selected benthic categories (right) and associated 2018 dominant category/taxa (left) at: a) back reef; b) lagoon reef; and c) outer reef transects of the Majuro monitoring site in the 2011, 2013 and 2018 surveys. Dominant category/taxa: a) sand b) *Porites rus* coral c) *Halimeda spp*. Macroalgae.

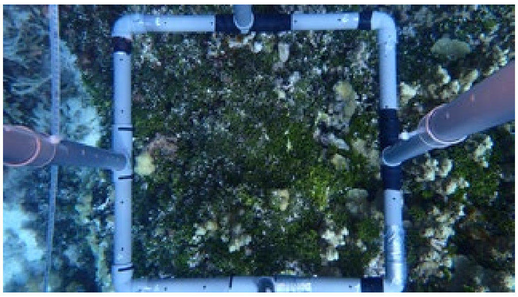
Woja MPA

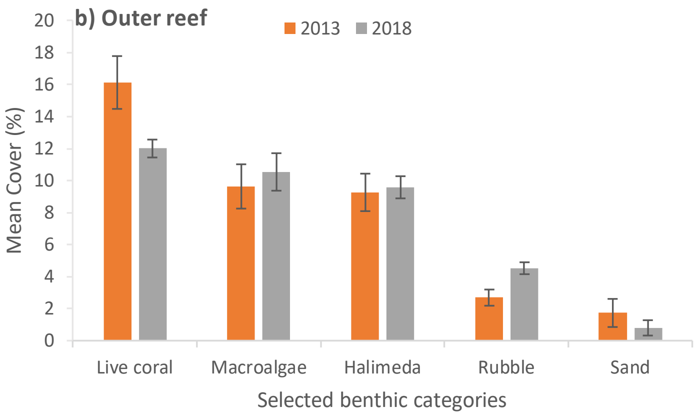
The two habitats surveyed (back reef and outer reef) presented distinct results. Only the rubble category and the macroalgae genus *Halimeda* were not significantly different within the entire site for all three surveys.

The back reefs of this site were characterised by a relatively high cover of macroalgae (predominantly *Halimeda spp*.) and live coral (Figure 33). The dominant coral genus was *Porites,* dominated by the *Porites rus* species. The mean cover of both macroalgae and its dominant representative genus *Halimeda* were slightly higher in 2018 than in 2013. A slight decrease of sand was also apparent between the two surveys.

Outer reef habitats of the Woja MPA were characterised by high cover of live coral (in particular *Acropora* spp.) and macroalgae (including *Halimeda* spp.). A slight decrease of live coral and a slight increase of rubble were recorded in 2018 (Figure 33).







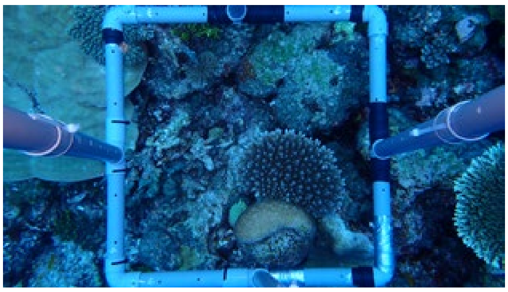


Figure 33: Percentage cover of selected benthic categories (right) and associated 2018 dominant category/taxa (left) at: a) back reef; and b) outer reef transects of the Woja MPA monitoring site in the 2013 and 2018 surveys. Dominant category/taxa: a) *Halimeda spp.* Macroalgae b) live coral Acropora sp.).

Invertebrates

Due to important differences in species diversity and densities, results are reported separately for each survey method.

Manta tow

In general, densities of invertebrates observed during manta tows were low for all surveys, with only *Holothuria atra* observed in densities greater than 150 ind. ha^{-1}. The following differences between surveys were observed (Figure 34, Figure 35).

- Densities of the sea cucumber *Thelenota anax* at the Majuro site were lower in the 2018 and 2013 surveys than in 2011, decreasing through time from 122±32.79 to 9.72±4.90 and to 6.48±3.63 ind. ha^{-1}.
- Densities of the sea cucumber *Holothuria atra* were different for the Majuro site compared to the other two sites. At the Ajeltake site, densities of the 2018 survey were higher (320.83 ± 89.11 ind. ha^{-1}) than those of the 2013 and 2011 surveys (respectively 66.67 ± 22.93 ind. ha^{-1} and 143.06 ± 80.72 ind. ha^{-1}).

- Densities of the gastropod *Conomurex luhuanus* varied greatly between years, most probably because this methodology included records of this species in 2013 but not during the other assessments due to its small size. A number of other gastropod species were recorded during the three surveys but densities rarely reached 5 ind. ha^{-1}.

Densities of the giant clam *Tridacna maxima* at the Laura site appeared lower in 2018, 2013 and 2011 compared to the PROCFish surveys of the region in 2007, decreasing from 25.35±11.29 to 0.46±0.46 ind. ha^{-1}. In 2018, *T. maxima* densities were lower than in 2013 at the Majuro site. Since the 2007 PROCFish surveys, *Tridacna squamosa* was not recorded in Laura.

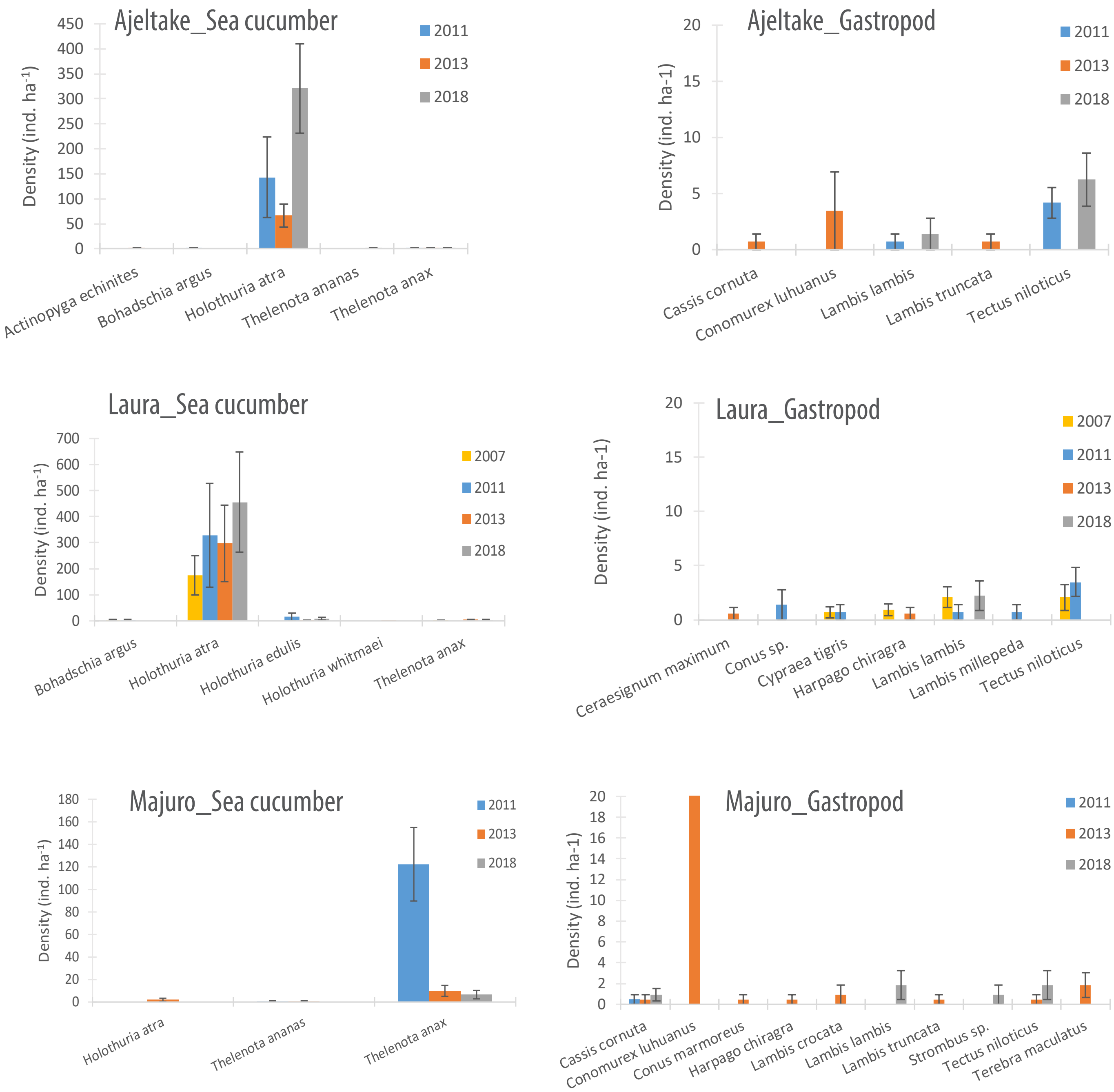


Figure 34: Overall mean density of invertebrate species (± SE) observed during manta tows at Ajeltake (top), Laura (middle) and Majuro (bottom) stations in 2007, 2011, 2013 and 2018

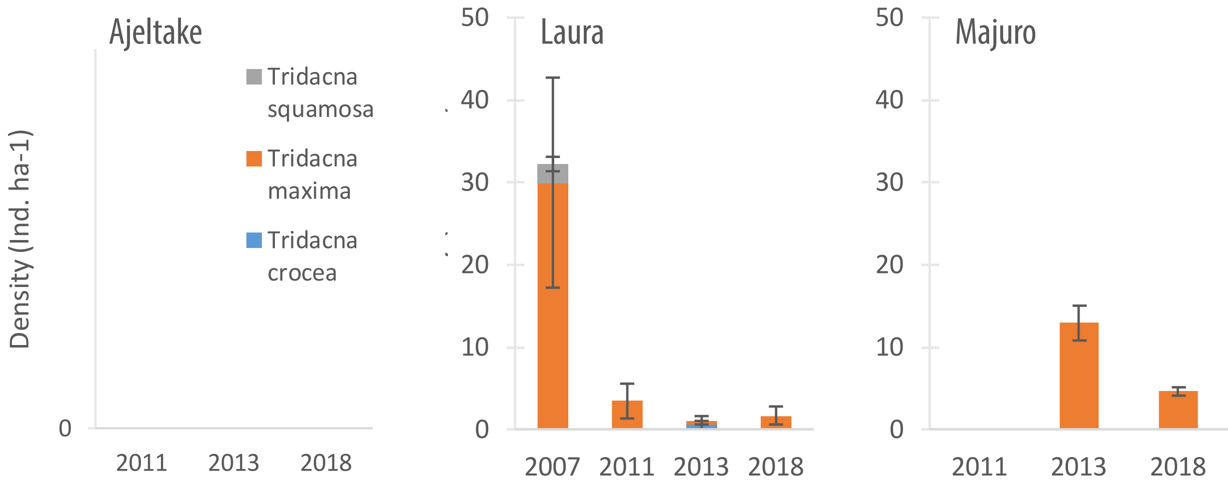


Figure 35: Overall mean density of tridacna species (± SE) observed during manta tows at Ajeltake (left), Laura (middle) and Majuro (right) stations in 2007, 2011, 2013 and 2018

Reef-benthos transects

Invertebrate diversity at RBt stations tended to be lower in 2018 than in 2013 but comparable to 2011 for all monitoring sites (Table 16). The following differences in mean densities were observed across the surveys.

- In 2018, sea-cucumber were found in very low density, with the exception of lollyfish (*Holothuria atra*). The mean density of lollyfish in Woja MPA site was above the reference density (5,600 ind. ha^{-1}) since 2013 and higher than all other sites. The Laura site densities were greater than the Drenmeo MPA and Majuro sites.
- *Bohadschia argus* and *Thelenota ananas* were in slightly greater densities in the Drenmeo MPA site but were found in lower numbers in 2018 and 2013 compared to 2011.
- Densities of *Cononomurex luhuanus* were higher in the Majuro site but were found in lower densities in 2018 and 2013 than in 2011.
- Trochus (*Rochia nilotica*) densities were higher in the Drenmeo MPA site than in any other site.
- During the 2018 survey, giant clams were recorded at all sites. *Tridacna maxima* and/or *T. noae* which used to be recorded as *Tridacna maxima* (Borsa et al. 2015) were present at all sites, while *Hippopus hippopus* was absent from Woja MPA.

Table 16: 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

	Year	No. stations surveyed	No. of genera	No. of species	Diversity
Drenmeo	2011	1	3	3	3.0
	2013	3	15	16	5.3
	2018	3	5	6	2.0
Majuro	2011	4	9	9	2.3
	2013	6	23	26	4.3
	2018	6	13	14	2.3
Laura	2007	22	41	53	2.4
	2011	5	11	12	2.4
	2013	6	18	20	3.3
	2018	6	9	11	1.8
Woja	2013	3	12	12	4.0
	2018	3	8	8	2.7

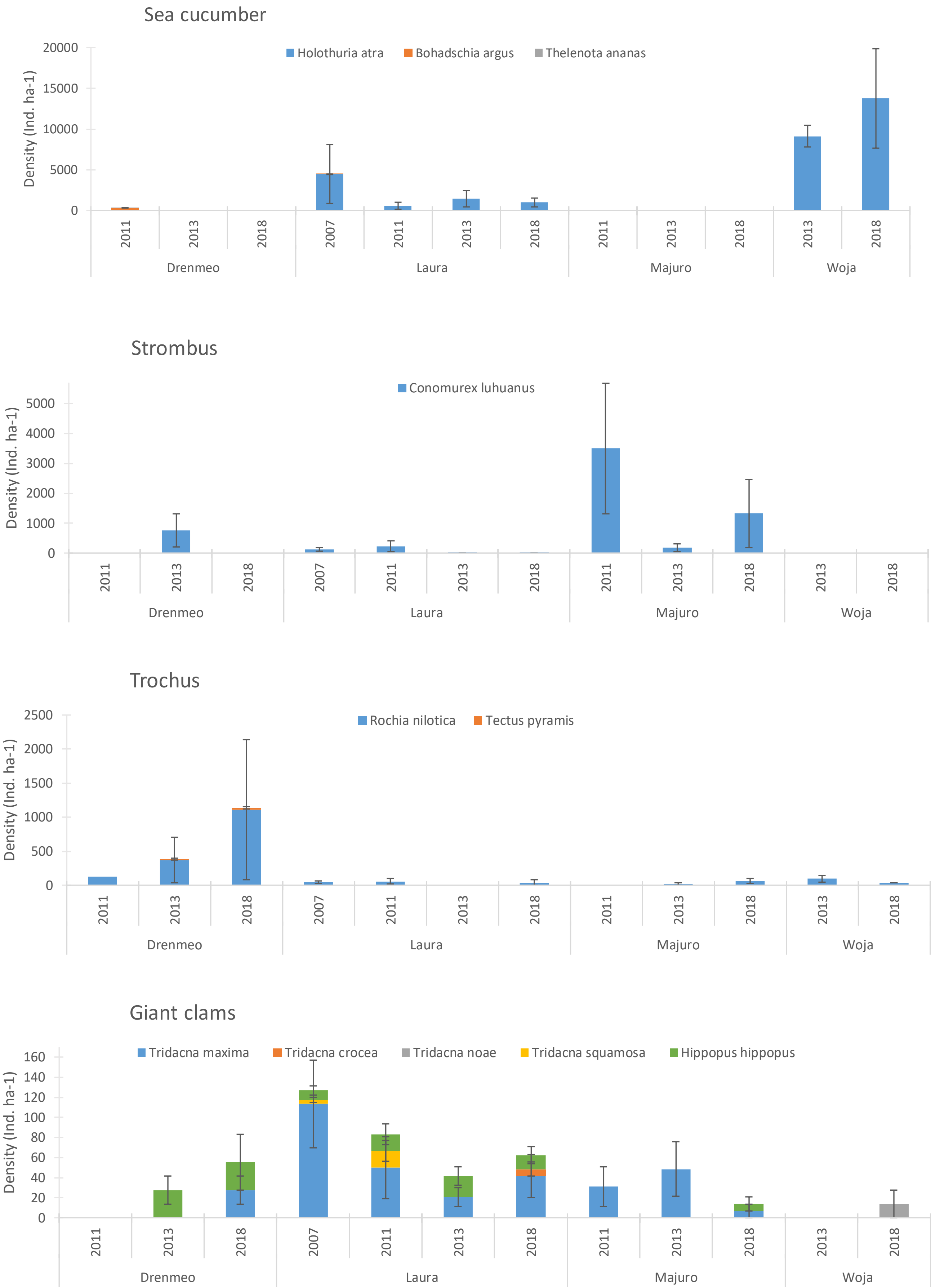


Figure 36: Overall mean density of invertebrate species (± SE) observed during reef-benthos transects at Drenmeo MPA, Laura, Majuro and Woja MPA monitoring stations, 2007, 2011, 2013 and 2018

Creel surveys

Methods

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

- to document fisher demographics, behaviour (e.g. locations fished, distances travelled)
- to provide a 'snapshot' of species composition of each fishery
- to document catch (including length and weight of all individuals caught) and catch-per-unit-effort for monitoring purposes
- to compare the 2013 and 2018 snapshots surveys.

Data collection

Data collection protocol followed a previous survey (Moore et al. 2014) and the creel and market survey manual produced by SPC (Kaly et al. 2016). More details are given in Appendix 8.

While several market points were identified during the survey, it was deemed not possible to conduct the survey at any of these locations. Therefore, fishers who were in contact with MIMRA were contacted by telephone to determine when they were going fishing and arrange a meeting time and place to conduct the surveys.

Data analysis

Summary statistics, including mean number of fishers, mean trip duration, mean catch (abundance and weight) and mean CPUE (catch per unit effort for abundance and weight) were compiled for each fishing method. Analyses were performed on both taxonomic and functional group levels, with functional groups consistent with those used in the UVC surveys. Where weight data were not recorded (i.e. when the fish was gutted or damaged), length-weight relationships from published records (Kulbicki et al. 2005; Froese and Pauly 2019) were used to estimate weight. Length-frequency plots were established for key target species and were compared against length-at-maturity (where known) to estimate the percentage of immature individuals in the catch. CPUE was calculated for each fishing method, based on the number of fish or estimated weight of fish caught per fisher per hour.

Due to the low number of creel interviews conducted during each survey, no statistical analyses were conducted comparing the 2013 and 2018 surveys.

Creel results

In 2018, a total of 11 creel surveys were completed, with 1,583 individual fish belonging to 112 species and 17 families identified, measured and weighed. All fishers surveyed were men.

Table 17: Data summary of creel surveys conducted at Majuro Atoll, 2013 and 2018

Predominant fishing method	Bottom fishing		Spearfishing	
Survey Year	2013	2018	2013	2018
No. creel surveys	5	5	8	6
Total number of fishers surveyed	17	14	41	26
Mean time spent fishing (h)	6.8 ± 0.50	11.8 ± 1.11	4.4 ± 0.50	6 ± 1.52
Mean no. of fishers per trip	3.4 ± 0.20	2.8 ± 0.37	5.1 ± 0.60	4.3 ± 0.42
Average number of fish per trip	51.2 ± 7.90	151 ± 34.12	186.1 ± 31.20	138 ± 25.50
Average catch weight per trip (kg)	29.18 ± 4.68	51.71 ± 8.86	55.9 ± 10.0	51.02 ± 10.12
Average CPUE by abundance (number of fish $fisher^{-1}$ h^{-1})	2.24 ± 0.34	5.20 ± 1.79	8.7 ± 1.10	8.00 ± 2.67
Average CPUE by weight (kg $fisher^{-1}$ h^{-1})	1.27 ± 0.19	1.67 ± 0.38	2.59 ± 0.37	2.66 ± 0.78

Bottom fishing

Five surveys where bottom fishing was the main fishing activity were completed. The bottom fishing trips involved an average of 2.8±0.4 fishers and lasted 11.8±1.1 h (Table 17). The average catch per trip corresponded to 51.7±8.9 kg and 151±34.2 individual fish. CPUE was 5.2±1.8 fish fisher^{-1} h^{-1} or 1.7±0.4 kg fisher^{-1} h^{-1} (Table 17). The overall catch per trip (fish number and weight) was much higher than in 2013 but the trip duration was much longer. The 2018 CPUE by abundance was more than twice that of 2013, whereas the 2018 CPUE by weight was only slightly higher. Comparison of these two snapshot surveys suggest that bottom fishing trips involve fewer fishers, tend to last longer, and target a larger amount of smaller fish.

The catch was dominated by macro-carnivores/piscivores of the families Lutjanidae, Lethrinidae and Serranidae (Figure 37, Appendix 9). About a quarter of the catch was represented by micro-carnivores from the Carangidae family, while about another quarter of the catch was represented by planktivores of the Holocentridae family. The catch was more diverse than that of the 2013 survey and the proportion of catch represented by the Serranidae was less. For example, *Epinephelus polyphekadion* represented 51% of the catch abundance in 2013 but only 7% in 2018.

In 2018, a total of 755 individual fishes from 48 species were observed in the bottom fishing catches, the most common of which were scads *Selar sp.* (representing 16% of total catch by number and 11% of the total catch by weight), *Myripristis adusta* (15% of total catch by number and 9% of the total catch by weight), *Lutjanus gibbus* (14% of total catch by number and 11% of the total catch by weight) and *Myripristis berndti* (11% of the total catch by number and 6% of the total catch by weight) (Appendix 9).

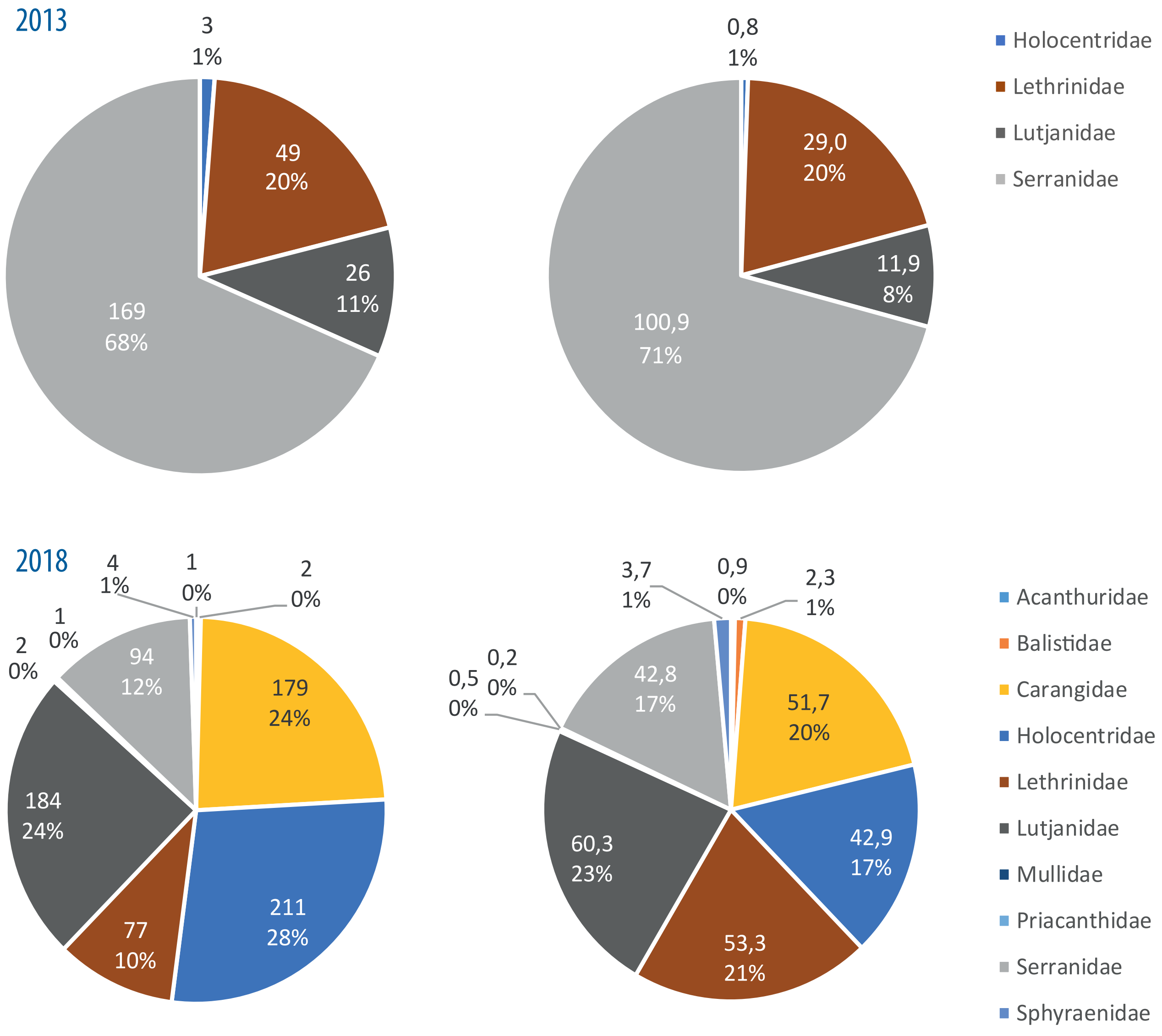


Figure 37: Percentage contribution by total number (left) and total weight (right) of families caught by bottom fishing, Majuro Atoll, August 2013 and 2018

Spearfishing

Six surveys where spearfishing was the main fishing activity were completed. With the exception of a single trip, all spearfishing trips were conducted at night. The trips involved an average of 4.3±0.4 fishers, with a mean duration of 6±1.5 h (Table 17). The average catch per trip was 51±10.1 kg, or 138±25.5 individual fish. The average CPUE was 8±2.7 fish fisher^{-1} h^{-1}for abundance and 2.7±0.78 kg fisher^{-1} h^{-1} for weight (Table 17). The overall catch per trip (fish number and weight) and the number of fishers were slightly lower and the trip duration was slightly longer than in the 2013 survey. The CPUE per fisher was, however, similar to the 2013 survey, both for abundance and weight.

Thirteen families were observed in the spearfishing catch, which was dominated by grazers and to a lesser extent by macro-carnivores/piscivores and lobsters. Species from the Acanthuridae, Lutjanidae, Serranidae and Palinuridae (lobster) dominated the total catch, both for abundance and weight (Figure 38, Appendix 9). A total of 877 individuals (fish or lobster) from 66 species were observed in the spearfishing catch (Appendix 9). In comparison to the 2013 survey, the proportion of catch represented by the Holocentridae and Siganidae had largely decreased, while the proportion represented by Lutjanidae had increased.

The most common species caught were *Naso lituratus* (representing 13% of total catch by abundance and 11% by weight), *Lutjanus gibbus* (11% of total catch by abundance and 10% by weight), *Epinephelus polyphekadion* (6% of total catch by abundance and 9% by weight), *Panulirus penicillatus* (6% of total catch by abundance and 11% by weight) and *Siganus argenteus* (7% of the total catch by abundance and 5% by weight) (Appendix 9). The proportion of catch of a few species had drastically changed since the 2013 survey. For example, the abundance of *Acanthurus lineatus* and *Siganus argenteus* dropped from 18% to 2% and from 24 % to 7 %, respectively, while *Naso lituratus* and *Lutjanus gibbus* increased from 7% to 13% and from 2% to 11%, respectively.

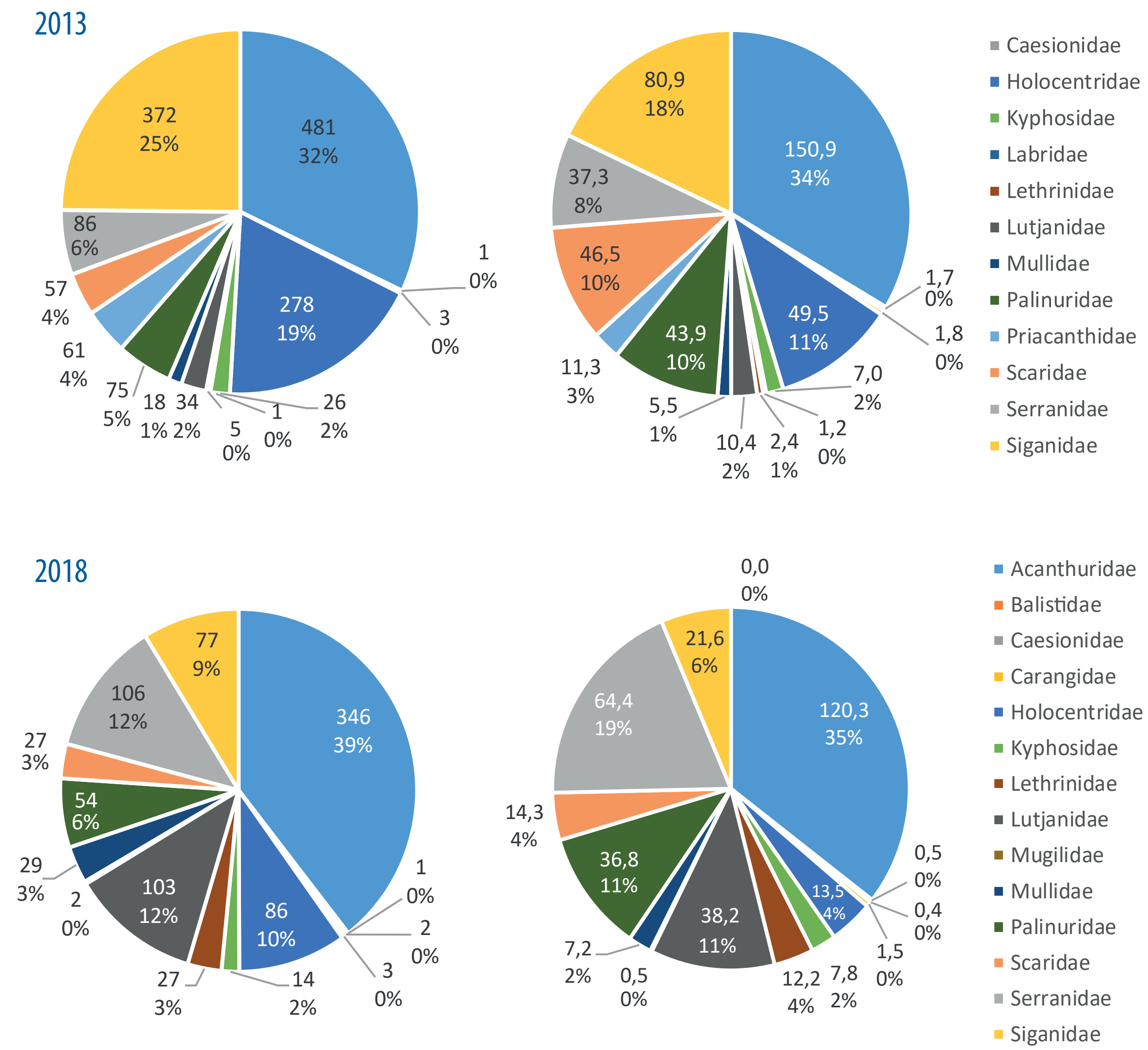


Figure 38: Percentage contribution by total number (left) and total weight (right) of families caught by spearfishing, Majuro Atoll, August 2013

Fisher experiences and perceptions

Fisher demographics and perceptions were collected during eight surveys[2] in 2018 and six surveys in 2013. The experience of the lead fishers interviewed varied greatly across the two surveys but in both surveys a greater proportion of fishers had less than 10 years' experience. Interestingly, the fishers surveyed in 2018 were not the same fishers as in 2013, suggesting a high turn-over of fishers on Majuro, due either to the change of activity (employment) or the fishing ground (atoll). More fishers indicated that they had seen no changes in the fishery in the last few years than did the fishers in 2013. Only 50% of all fishers stated that their catches had decreased compared to five years ago, and 75% stated that the size of fish had not changed compared to five years ago (Figure 40).

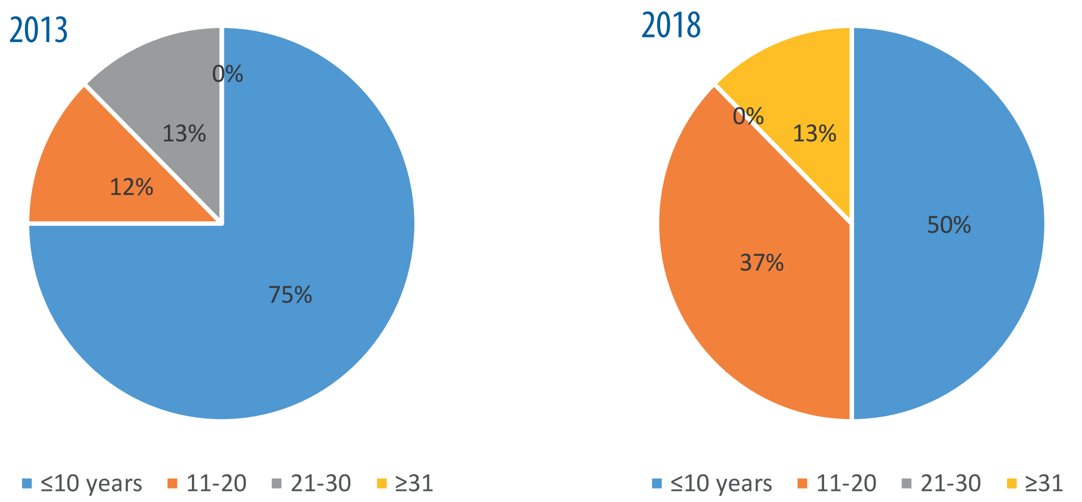


Figure 39: Lead fisher experience in fishing activities

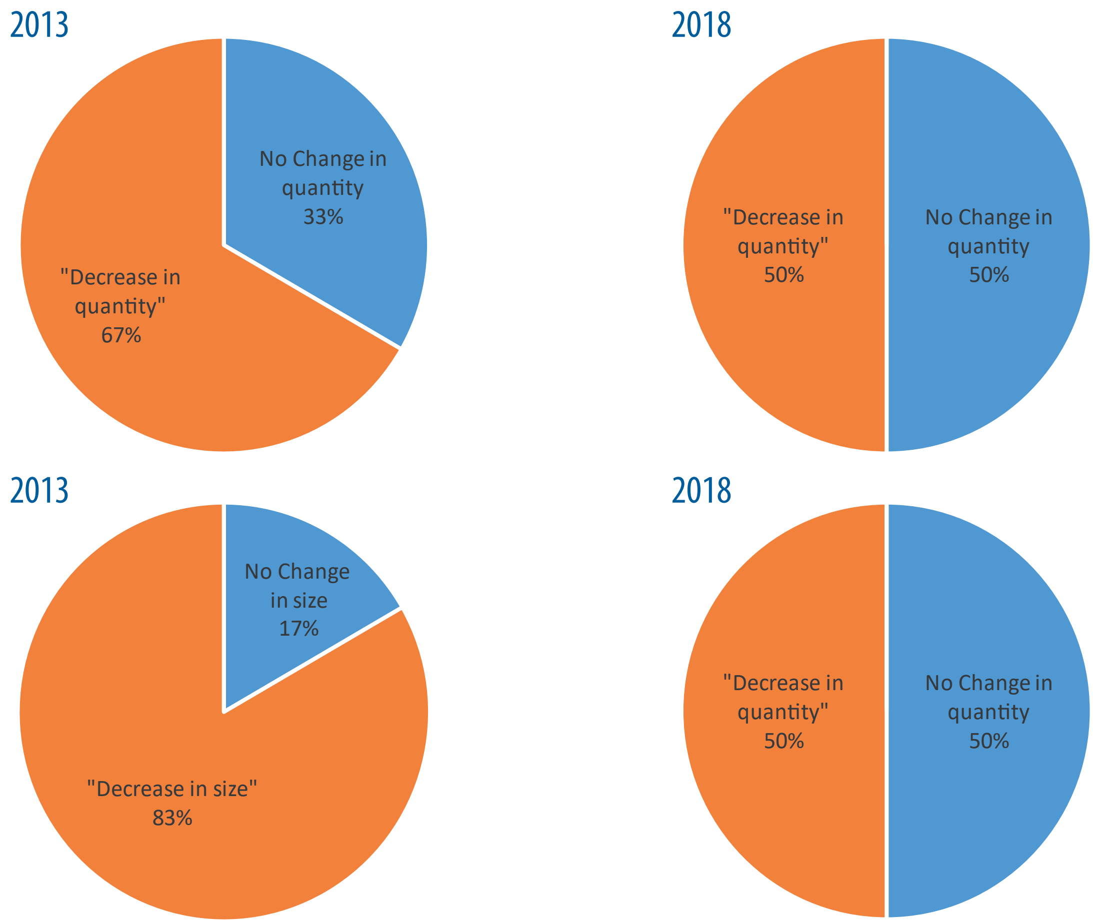


Figure 40: Responses of lead fishers to questions on perceptions on whether catch quantities (top) or fish sizes (bottom) had changed over the last five years

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

Length frequencies

Length frequency plots for seven of the most commonly observed species in 2018 from bottom fishing and spearfishing catches are presented in Figure 41. When possible, size distribution comparisons were made with the 2013 survey.

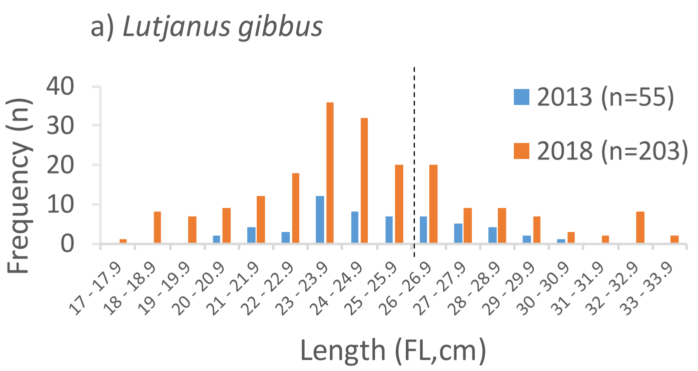
Lutjanus gibbus size distribution was very similar in the two surveys, although the sample size was different. The overall size range was slightly larger in 2018 (for both large and small individuals). Only about 30% of all individuals caught were above the size at maturity of 26.3 mm (average size between male and female) proposed for New Caledonia population (Moore 2019). When referring to the Palau maturity size estimate of 27.5 cm (Prince et al. 2015), fewer than 20% of individuals caught had reached maturity.

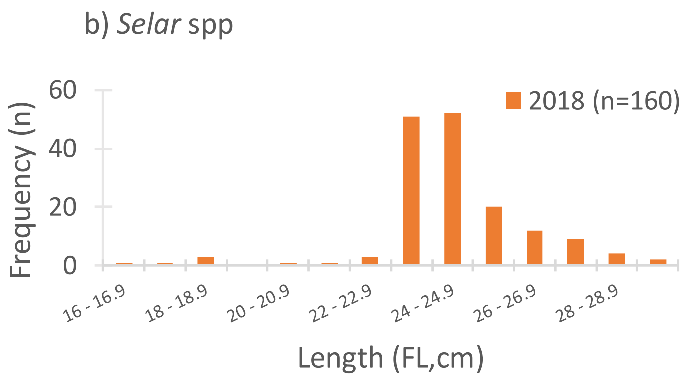
Both *Naso lituratus* and *Myripristis berndti* presented similar sample size and size distribution for the two surveys. All *N. lituratus* measured were above the length at 50% maturity (145 mm for female and 178 mm for male) estimated for Guam (Taylor et al. 2014).

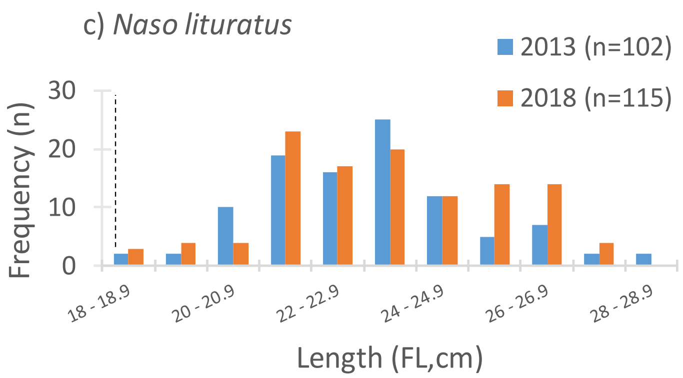
E. polyphekadion displayed a large size range, with a relatively similar pattern for both surveys, except that in 2018 there was an absence of high numbers for the size class 30–30.9 cm. During this survey, only 27% of all individuals caught were above the estimated length at 50% maturity of 352 mm proposed for populations in Pohnpei (Rhodes et al. 2011).

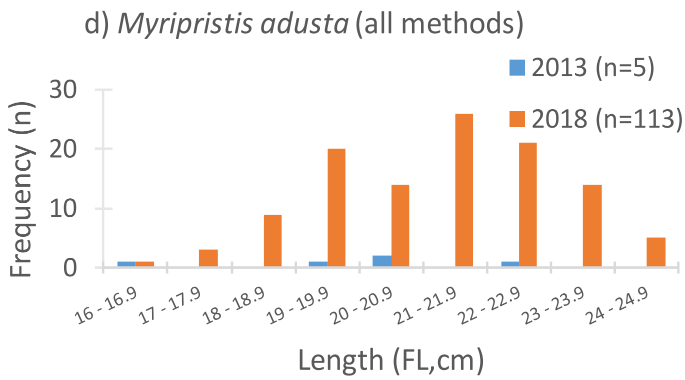
Myripristis adusta size distribution had a similar trend as *M. berndti,* with slightly larger individuals consistent with the biology *M. adusta* reaching a larger size.

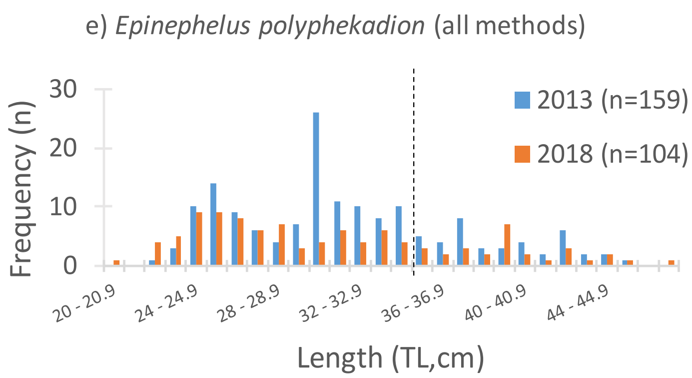
The size of Scads (*Selar spp*.) was concentrated in two size classes (24–24.9 cm and 25–25.9 cm) reflecting the schooling nature of those fish.

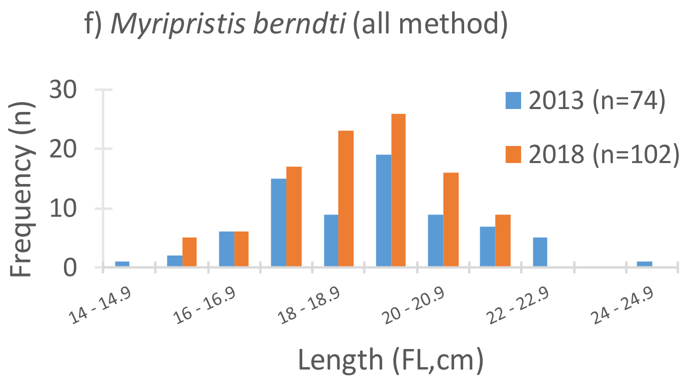












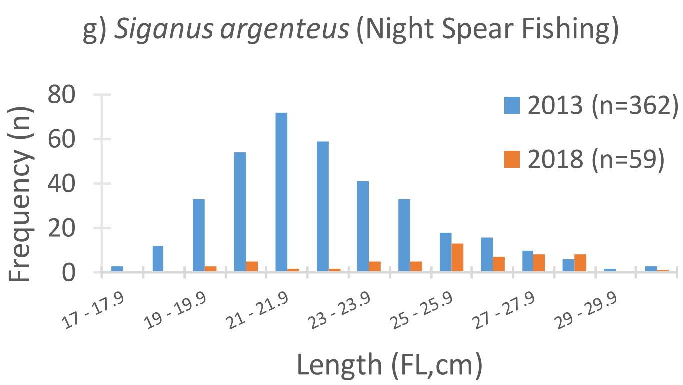


Figure 41: Length frequency of the most commonly observed finfish species during creel surveys at Majuro Atoll, 2013. Dashed lines indicate estimated lengths at 50% maturity for a few species from: (a) Moore 2019; (c) Taylor et al. 2014; and (e) Rhodes et al. 2011.

Biological monitoring of selected reef fish species

Methods

Sample collection

Biological monitoring of key reef fish species at Majuro Atoll focused on six commercially harvested species – humpback red snapper (*Lutjanus gibbus*), orangespine unicornfish (*Naso lituratus*), blotcheye soldierfish (*Myripritis bernti*), bluespine unicornfish (*Naso unicornis*) and peacock grouper (*Cephalopholis argus*) – and three 'control' species – redfin butterflyfish (*Chaetodon lunulatus*), striated surgeonfish (*Ctenochaetus striatus*) and honeycomb grouper (*Epinephelus merra*) – which were included to control for the effects of fishing. Fish were collected from commercial fishers during creel surveys or by fisheries-independent spearfishing or by fisheries-independent handlining. 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. When possible, sex was determined from a macroscopic examination of the gonads. Gonads were removed from all specimens (where gonads were able to be identified) for later macro- and microscopic observations. Sagittal otoliths (hereafter referred to as otoliths) were removed from all specimens for ageing purposes, cleaned, dried and stored in plastic vials until processing.

Delays in processing

Due to delays in sample processing, the results of the biological sampling cannot be presented in this report but will be published in the fisheries newsletter when they are available.

The number of biological samples requiring further analysis for each species is presented in Table 18.

Table 18: 2018 sampled individuals requiring processing (otolith preparation, sectioning and reading, gonad microscopic analysis)

Species	Species fisheries status	n sampled	n with 1 or 2 otoliths	n gonads sampled
Cephalopholis argus	Commercial	24	24	24
Lutjanus gibbus		83	83	83
Lutjanus kasmira		17	17	17
Myripristis bernti		68	67	68
Naso lituratus		83	79	83
Naso unicornis		38	38	38
Chaetodon lunulatus	Control	42	41	42
Ctenochaetus striatus		52	52	52
Epinephelus merra		41	40	22

Conclusions and recommendations

Since the 2013 survey, monitoring effects of chronic disturbances such as climate change remains a challenging prospect. It 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 are outlined below to help improve the resilience of the coastal fisheries of Majuro Atoll by addressing both long-term (e.g. climate change) and short-term (e.g. overfishing) stressors. Some of these were described in the 2013 report (Moore et al. 2014) and were revised, using the results of the current study. 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.

Management recommendations

1. **Continue to expand the network of locally managed marine protected areas.** Over the years, tools were developed in the country to increase the expansion of marine protected areas through community-based management. To fulfill the objectives of the Micronesia Challenge of effectively conserving 30% of near-shore marine resources, the Reimaanlok National Conservation Area Plan was created in 2007. The protected areas network (PAN)Act was also developed in 2015 but was not implemented. To maintain biodiversity, ecosystem functioning and resilience, and to confer benefits to adjacent fisheries, it is highly recommended that the protected areas 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: (i) by creation of new protected areas; and/or (ii) expanding the existing protected areas. Both Drenmeo and Woja MPA sites showed little difference in finfish density relative to comparably-situated areas that are open to fishing, which suggests that the current design is ineffective for protecting fish populations. However, in Drenmeo, densities of trochus were greater than in any other site surveyed, suggesting the availability of a suitable habitat for the species. These results highlight the fact that 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) 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 affected 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.
2. **Place restrictions on destructive or highly efficient fishing practices, in particular night-time spearfishing.** While the fine-scale benthic assessment suggests higher cover of macroalgae along the inhabited coast (south and south-west), the dominant taxa was mainly formed by *Halimeda* algae, which do not reflect the usual eutrophication taxa involved in coral-algae shifts. However, in closer proximity to shores, the 2013 survey revealed the presence of fleshy macroalgae, probably resulting from heavy fishing pressure on herbivorous fishes, higher levels of eutrophication and relatively poor tidal flushing. While only small macroalgae cover increases were observed across sites in 2018, the decrease in coral cover visible on the outer habitats of several sites (Majuro, Laura 2 and Woja) may result in a higher risk of macroalgae overgrowth. In the context of climate change, reducing the fishing pressure on browsing and scraping herbivorous fishes would improve the resilience of the reef to recover from regular bleaching events through increased grazing of algae. As in 2013, only a few browsing herbivores were observed during the in-water assessments in 2018, but this functional group represented a significant proportion of the spearfishing catch observed during both the 2013 and 2018 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. At the same time, incentives should be offered to move fishing effort away from reef resources and onto small pelagics.

3. **Assess and monitor grouper catches.** While the number of serranids caught by fishers tended to be lower in this survey, groupers continue to represent an important proportion of catch. The relatively large number of *Epinephelus polyphekadion* remains a cause for concern and illustrates a need for further investigation. The abundance of this species in catches is suggestive of a spawning aggregation being targeted. *E. polyphekadion* is listed as 'vulnerable' on the IUCN Red list due to their susceptibility to over-fishing, particularly of spawning aggregations. Analysis of catches across the atoll over a longer period would help to resolve the problem. Should a spawning aggregation be identified, management measures, such as seasonal closures, should be implemented to ensure its protection. Many Pacific Island countries and territories have implemented or are in the process of implementing seasonal restrictions on the harvest of groupers. For example, closed seasons are established in Fiji, Solomon Islands and Palau for several species, including *E. polyphekadion* for variable periods. In combination with seasonal restrictions, a minimum harvest size was also imposed for this species in Palau and Solomon islands during the open season. Such restrictions could be embedded within a larger coastal fisheries management plan or a set of domestic fishing regulations (see Item 6 below).

4. **Monitor the export of reef fish to ensure its sustainability**. On two occasions during the survey, fish sellers declared they were exporting fish to the US market. The main fish targeted for this export was *Lutjanus gibbus* (the species is listed as 'of least concern' on the IUCN Red list). During the underwater surveys, this species was observed in schools during the timed swims but hardly seen during standard finfish belt transect assessments. The species was an important component of the creel survey catch (both spearfishing and bottom fishing) but a large proportion of the catch was below the size at maturity proposed in other countries of the region, suggesting an over-exploitation of the species. To have a sustainable fishery for this species, there is a critical need for understanding the status of its population. Therefore, a dedicated survey should be undertaken across the atoll to determine local size and age-at-maturity, and the level of fishing mortality. Local fishing regulations should be established according to the results of this analysis (e.g. minimum harvest size) and, if results permit, exports could continue under appropriate regulation. As mentioned in the previous section, implementation of such regulations could be embedded within a larger coastal fisheries management plan or a set of domestic fishing regulations.

5. **Manage the invertebrate fishery.** Overall densities of invertebrates of local interest, such as sea-cucumber, giant clams, conch and trochus, are low across the atoll and reduce the potential for commercial and/or artisanal harvests. Since the sea-cucumber fishery reopened after the 2011 national harvest ban, only very limited information has been available on local harvest and export. During the 2018 survey, very limited numbers of medium or high value sea-cucumber species were observed on the atoll. Limited change was visible between the 2018 and 2013 surveys, so it is recommended that the sea-cucumber fishery be closed until a proper management plan of the fishery is implemented and a suitable assessment is conducted. While the Drenmeo site showed highly variable but healthy densities of trochus, densities on the other sites of the atoll remained too low for commercial fishing. Lobsters, which were not observed during in-water assessment but present in fishers' catch, could be monitored through a dedicated creel survey to determine the status of the population.

6. **Develop and implement coastal fisheries management plans / regulations.** Since 2013, coastal fisheries have gained critical recognition but Marshall Islands finfish and invertebrate resources remain largely unregulated. While assessments are needed to fill in scientific gaps, there is enough information available to implement specific management decisions. To ensure fish are available for future generations, it is strongly recommended that a coastal fisheries management plan / regulations should be developed, addressing various fishing activities (e.g. fishing gear 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 programmes and exchange of information on coastal fisheries, the marine environment and climate change.** As encouraged through the Reimaanlok programme, actively engaging with communities is key to successful coastal fisheries management. Therefore, in addition to current efforts, education or awareness programmes 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.

Future monitoring recommendations

To assess the success of management interventions and to 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, regular data collection programmes are needed. While important variability can be measured on marine resources at relatively short temporal scales, only long-term monitoring and collection of high quality data can provide the power to detect trends. The continuation of this monitoring programme at regular intervals is recommended and some recommendations for future assessments based on the 2018 and previous surveys are provided below.

- The 2018 and 2013 surveys highlighted the need to establish a 'core' coastal fisheries monitoring team in MIMRA, as well as in other relevant organisations (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 the team's monitoring capacity and reduce surveyor bias that may otherwise preclude the detection of 'real' trends. The recent expansion of the coastal fisheries team presents a good opportunity for MIMRA staff to specialise.
    - In conjunction with the establishment of a core monitoring team, the use of simultaneous video transects for finfish assessment could be investigated with the objective of training staff to specialise and reduce potential bias, especially when more than one surveyor is taking part in a survey.
- Improve the finfish and habitat survey design in order to increase the power to detect statistical differences between surveys and understand ongoing trends. To reduce the potential for type II errors (i.e. failing to detect difference where differences exist) it is strongly recommended that additional transects or stations be established.
    - Finfish analyses have demonstrated that lagoon reef habitats have the more restricted community than other habitats. In addition, communities in lagoon habitats tend to overlap with back reef habitats. Due to time constraints, it might be preferable to multiply the number of stations or transects in back reef and outer reef habitats and maintain only one lagoon station within the entire atoll (where the number of transects can be increased).
    - Keep standard UVC procedures as simple as possible by surveying a defined set number of families (see Table 9) and recording approximate fork length (using 5 cm size class). An example of a finfish survey form is provided in Appendix 10.
    - Continue to test the swim method by increasing the number of swim transects and stations, as this method seems to provide a better relationship between fish population and fish targeted for the local market. In the next survey, each swim station could increase the number of transects by one, and one new station could be established on the northern side of the atoll (at the Majuro or Drenmeo site).
    - It is recommended that permanent stakes be established at the beginning of the finfish and benthic habitat assessment stations and that transects should be consecutive (spaced by 5 to 10 m) in order to reduce diving effort. Survey depth and direction need to remain the same between surveys. This is to ensure the same habitat is assessed each time, with the aim of reducing variability associated with transect positioning.
- Improve the invertebrate design in order to provide more valuable information about commercial species.
    - Due to very low densities of large invertebrates in Majuro, the manta tow survey method provides little information and potential for comparison across surveys. The effort allocated to this method could be re-invested in more fine-scale surveys through the multiplication of reef benthos transects across the atoll.
    - Identify a core list of invertebrate species to survey to ease the survey process and increase data quality.
- Document records of bleaching events occurring in Majuro Atoll and (when information is available) on outer islands and store related information in a dedicated database at MIMRA. This is to allow a better understating of the ecosystem dynamics and trends observed for the benthic habitat assessment between surveys.
- As suggested by the 2013 survey, 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) within the study region be monitored.

- Temperature data loggers should be checked regularly (on a six-monthly to annual interval between visits) and coordination between MIMRA and SPC should be established to regularly replace them. This should help to avoid losing data (due to flat batteries) or loggers.
- If there is a specific need to monitor pinnacle reefs in the lagoon, this could be done on a small subset but, given the results of previous surveys indicating strong similarities with back reef areas, it is more logistically practical to increase sites in the back reef area. In addition, due to the small sizes of many of these reefs, modified designs of the present survey methods or alternative monitoring approaches may be required for these habitats (e.g. smaller transects, stationary points counts for monitoring finfish).
- The creel surveys conducted at Majuro Atoll represent 'snapshots' of fisher behaviour, fishing patterns and catches at the time of surveys and may not be representative of fishing activities year-round or even for the surveyed period. Some important variability was measured between the 2013 and 2018 surveys, notably for bottom fishing. Therefore, prior to conducting further snapshot surveys, a comparison of results of the 2013 and 2018 snapshot surveys against the one-year market survey conducted in Majuro in 2018–2019 is recommended. The findings of this survey could suggest specific periods for conducting snapshot surveys (such as targeting spawning aggregations).
- It is highly recommended that the biological monitoring programme be expanded by increasing the sample sizes of species collected here and the 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 the catch and effort and length frequency data in isolation. This is 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 dependence and aggregative nature) and density-dependence issues (Newman and Dunk 2002). The length frequency of *Lutjanus gibbus* and the existing market for export suggest that the species is a priority for biological sampling. While many staff at MIMRA are already experienced in sampling, it could be beneficial for the team to build the capacity of at least one staff member on collection and analysis of gonads and otoliths. Benefits would be multiple, as it would address costly and lengthy analysis and help fill essential scientific gaps to implement management regulations.

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Appendices

Appendix 1: Fish species functional group

Species	Functional group
Abudefduf septemfasciatus	Territorial herbivores
Abudefduf sp.	Planktivores
Abudefduf vaigiensis	Planktivores
Acanthurus achilles	Grazers
Acanthurus blochii	Grazers
Acanthurus gahhm	Grazers
Acanthurus guttatus	Grazers
Acanthurus lineatus	Grazers
Acanthurus maculiceps	Grazers
Acanthurus mata	Planktivores
Acanthurus nigricans	Grazers
Acanthurus nigricauda	Grazers
Acanthurus nigrofuscus	Grazers
Acanthurus nigroris	Grazers
Acanthurus olivaceus	Grazers
Acanthurus pyroferus	Grazers
Acanthurus sp.	Grazers
Acanthurus thompsoni	Planktivores
Acanthurus triostegus	Grazers
Amblyglyphidodon aureus	Planktivores
Amblyglyphidodon curacao	Planktivores
Amblygobius phalaena	Micro-carnivores
Amphiprion clarkii	Planktivores
Amphiprion melanopus	Planktivores
Amphiprion perideraion	Planktivores
Amphiprion sp.	Planktivores
Amphiprion tricinctus	Planktivores
Anampses melanurus	Micro-carnivores
Anampses meleagrides	Micro-carnivores
Anampses neoguinaicus	Micro-carnivores
Anampses sp.	Micro-carnivores
Anampses twistii	Micro-carnivores
Anyperodon leucogrammicus	Macro-carnivores/Piscivores
Anyperodon sp.	Macro-carnivores/Piscivores
Aphareus furca	Macro-carnivores/Piscivores
Arothron caeruleopunctatus	Micro-carnivores
Arothron hispidus	Micro-carnivores
Arothron meleagris	Micro-carnivores
Aspidontus taeniatus taeniatus	Micro-carnivores
Aulostomus chinensis	Micro-carnivores
Balistapus undulatus	Micro-carnivores
Balistoides conspicillum	Macro-carnivores/Piscivores

Species	Functional group
Bodianus axillaris	Macro-carnivores/Piscivores
Caesio caerulaurea	Planktivores
Caesio sp.	Planktivores
Caesio teres	Planktivores
Carangoides ferdau	Macro-carnivores/Piscivores
Caranx melampygus	Macro-carnivores/Piscivores
Centropyge bicolor	Grazers
Centropyge bispinosus	Grazers
Centropyge flavissima	Grazers
Centropyge flavissimus	Grazers
Centropyge loricula	Grazers
Centropyge loriculus	Grazers
Centropyge vrolikii	Grazers
Cephalopholis argus	Macro-carnivores/Piscivores
Cephalopholis urodeta	Macro-carnivores/Piscivores
Cetoscarus bicolor	Scrapers
Cetoscarus ocellatus	Scrapers
Chaetodon auriga	Micro-carnivores
Chaetodon baronessa	Corallivores
Chaetodon bennetti	Corallivores
Chaetodon citrinellus	Corallivores
Chaetodon ephippium	Micro-carnivores
Chaetodon kleinii	Corallivores
Chaetodon lineolatus	Micro-carnivores
Chaetodon lunula	Corallivores
Chaetodon lunulatus	Corallivores
Chaetodon melannotus	Corallivores
Chaetodon mertensii	Micro-carnivores
Chaetodon meyeri	Corallivores
Chaetodon ornatissimus	Corallivores
Chaetodon plebeius	Corallivores
Chaetodon punctatofasciatus	Corallivores
Chaetodon rafflesii	Corallivores
Chaetodon reticulatus	Corallivores
Chaetodon semeion	Micro-carnivores
Chaetodon sp.	Corallivores
Chaetodon tinkeri	Planktivores
Chaetodon trifascialis	Corallivores
Chaetodon ulietensis	Micro-carnivores
Chaetodon vagabundus	Micro-carnivores
Cheilinus chlorourus	Micro-carnivores
Cheilinus fasciatus	Macro-carnivores/Piscivores

Species	Functional group
Cheilinus sp.	Macro-carnivores/Piscivores
Cheilinus trilobatus	Macro-carnivores/Piscivores
Cheilinus undulatus	Macro-carnivores/Piscivores
Chlorurus bleekeri	Scrapers
Chlorurus microrhinos	Scrapers
Chlorurus sordidus	Scrapers
Chlorurus sp.	Scrapers
Chromis acares	Planktivores
Chromis amboinensis	Planktivores
Chromis analis	Planktivores
Chromis atripectoralis	Planktivores
Chromis atripes	Planktivores
Chromis margaritifer	Planktivores
Chromis retrofasciata	Planktivores
Chromis sp.	Planktivores
Chromis ternatensis	Planktivores
Chromis viridis	Planktivores
Chromis weberi	Planktivores
Chromis xanthura	Planktivores
Chrysiptera biocellata	Territorial herbivores
Chrysiptera brownriggii	Territorial herbivores
Chrysiptera sp.	Territorial herbivores
Chrysiptera traceyi	Territorial herbivores
Chrysiptera unimaculata	Territorial herbivores
Cirrhilabrus exquisitus	Planktivores
Cirrhitichthys oxycephalus	Micro-carnivores
Coris aygula	Macro-carnivores/Piscivores
Coris batuensis	Micro-carnivores
Coris gaimard	Micro-carnivores
Ctenochaetus striatus	Grazers
Ctenochaetus strigosus	Grazers
Dascyllus aruanus	Planktivores
Dascyllus melanurus	Planktivores
Dascyllus reticulatus	Planktivores
Dascyllus trimaculatus	Planktivores
Elagatis bipinnulata	Micro-carnivores
Epibulus insidiator	Macro-carnivores/Piscivores
Epinephelus fuscoguttatus	Macro-carnivores/Piscivores
Epinephelus hexagonatus	Macro-carnivores/Piscivores
Epinephelus howlandi	Macro-carnivores/Piscivores
Epinephelus merra	Macro-carnivores/Piscivores
Forcipiger flavissimus	Micro-carnivores
Forcipiger longirostris	Micro-carnivores
Gnathodentex aureolineatus	Macro-carnivores/Piscivores
Gomphosus varius	Micro-carnivores
Gracila albomarginata	Macro-carnivores/Piscivores
Halichoeres chrysus	Micro-carnivores

Species	Functional group
Halichoeres hortulanus	Micro-carnivores
Halichoeres margaritaceus	Micro-carnivores
Halichoeres marginatus	Micro-carnivores
Halichoeres melanurus	Micro-carnivores
Halichoeres prosopeion	Micro-carnivores
Halichoeres richmondi	Micro-carnivores
Halichoeres scapularis	Micro-carnivores
Halichoeres sp.	Micro-carnivores
Halichoeres trimaculatus	Micro-carnivores
Hemigymnus fasciatus	Micro-carnivores
Hemigymnus melapterus	Micro-carnivores
Hemitaurichthys polylepis	Planktivores
Heniochus acuminatus	Planktivores
Heniochus chrysostomus	Corallivores
Heniochus monoceros	Micro-carnivores
Heniochus varius	Corallivores
Hipposcarus longiceps	Scrapers
Hologymnosus doliatus	Micro-carnivores
Kyphosus vaigiensis	Browsers
Labrichthys unilineatus	Corallivores
Labroides bicolor	Micro-carnivores
Labroides dimidiatus	Micro-carnivores
Labroides rubrolabiatus	Micro-carnivores
Labroides sp.	Micro-carnivores
Labropsis micronesica	Micro-carnivores
Lethrinus harak	Macro-carnivores/Piscivores
Lethrinus olivaceus	Macro-carnivores/Piscivores
Lethrinus sp.	Macro-carnivores/Piscivores
Lutjanus bohar	Macro-carnivores/Piscivores
Lutjanus fulviflamma	Macro-carnivores/Piscivores
Lutjanus fulvus	Macro-carnivores/Piscivores
Lutjanus gibbus	Macro-carnivores/Piscivores
Lutjanus malabaricus	Macro-carnivores/Piscivores
Lutjanus monostigma	Macro-carnivores/Piscivores
Lutjanus semicinctus	Micro-carnivores
Lutjanus vitta	Micro-carnivores
Macolor macularis	Planktivores
Macolor niger	Planktivores
Macropharyngodon meleagris	Micro-carnivores
Malacanthus latovittatus	Micro-carnivores
Melichthys niger	Planktivores
Melichthys vidua	Planktivores
Monotaxis grandoculis	Macro-carnivores/Piscivores
Monotaxis heterodon	Macro-carnivores/Piscivores
Mulloidichthys flavolineatus	Macro-carnivores/Piscivores
Mulloidichthys vanicolensis	Micro-carnivores
Myripristis adusta	Planktivores

Species	Functional group
Myripristis berndti	Planktivores
Myripristis kuntee	Planktivores
Myripristis murdjan	Planktivores
Myripristis pralinia	Planktivores
Myripristis sp.	Planktivores
Myripristis violacea	Planktivores
Myripristis vittata	Planktivores
Myripristis woodsi	Planktivores
Naso annulatus	Planktivores
Naso brevirostris	Browsers
Naso caesius	Planktivores
Naso hexacanthus	Planktivores
Naso lituratus	Browsers
Naso thynnoides	Planktivores
Naso unicornis	Browsers
Naso vlamingii	Planktivores
Nectamia bandanensis	Micro-carnivores
Nemateleotris helfrichi	Planktivores
Neoglyphidodon melas	Territorial herbivores
Neoniphon argenteus	Planktivores
Neoniphon sammara	Planktivores
Novaculichthys taeniourus	Macro-carnivores/Piscivores
Ostorhinchus luteus	Planktivores
Oxycheilinus digrammus	Macro-carnivores/Piscivores
Oxycheilinus unifasciatus	Macro-carnivores/Piscivores
Oxymonacanthus longirostris	Corallivores
Paracirrhites arcatus	Micro-carnivores
Paracirrhites forsteri	Micro-carnivores
Parapercis clathrata	Micro-carnivores
Parupeneus barberinoides	Micro-carnivores
Parupeneus barberinus	Micro-carnivores
Parupeneus bifasciatus	Micro-carnivores
Parupeneus cyclostomus	Micro-carnivores
Parupeneus multifasciatus	Micro-carnivores
Parupeneus pleurostigma	Micro-carnivores
Parupeneus sp.	Micro-carnivores
Parupeneus trifasciatus	Micro-carnivores
Pempheris oualensis	Micro-carnivores
Pentapodus aureofasciatus	Micro-carnivores
Pervagor aspricaudus	Territorial herbivores
Plagiotremus laudandus	Micro-carnivores
Platax orbicularis	Micro-carnivores
Plectroglyphidodon dickii	Territorial herbivores
Plectroglyphidodon johnstonianus	Territorial herbivores
Plectroglyphidodon lacrymatus	Territorial herbivores
Plectroglyphidodon leucozonus	Territorial herbivores
Plectropomus areolatus	Macro-carnivores/Piscivores

Species	Functional group
Plectropomus laevis	Macro-carnivores/Piscivores
Plectropomus laevis	Macro-carnivores/Piscivores
Pomacanthus imperator	Micro-carnivores
Pomacanthus sp.	Micro-carnivores
Pomacentrus bankanensis	Territorial herbivores
Pomacentrus coelestis	Territorial herbivores
Pomacentrus grammorhynchus	Territorial herbivores
Pomacentrus moluccensis	Territorial herbivores
Pomacentrus pavo	Planktivores
Pomacentrus simsiang	Territorial herbivores
Pomacentrus sp.	Territorial herbivores
Pomacentrus sp.	Territorial herbivores
Pomacentrus sp.	Territorial herbivores
Pomacentrus sp.	Territorial herbivores
Pomacentrus sp.	Territorial herbivores
Pomacentrus sp.	Territorial herbivores
Pomacentrus sp.	Territorial herbivores
Pomacentrus vaiuli	Territorial herbivores
Pomacentrus yoshii	
Priacanthus hamrur	Planktivores
Pseudanthias dispar	Planktivores
Pseudanthias pascalus	Planktivores
Pseudobalistes flavimarginatus	Micro-carnivores
Pseudobalistes fuscus	Micro-carnivores
Pseudocheilinus evanidus	Micro-carnivores
Pseudocheilinus hexataenia	Micro-carnivores
Pseudocheilinus tetrataenia	Micro-carnivores
Ptereleotris evides	Planktivores
Ptereleotris microlepis	Planktivores
Pterocaesio marri	Planktivores
Pterocaesio tile	Planktivores
Pygoplites diacanthus	Micro-carnivores
Rachycentron canadum	Macro-carnivores/Piscivores
Rhinecanthus aculeatus	Micro-carnivores
Sargocentron sp.	Micro-carnivores
Scarus altipinnis	Scrapers
Scarus dimidiatus	Scrapers
Scarus flavipectoralis	Scrapers
Scarus frenatus	Scrapers
Scarus ghobban	Scrapers
Scarus globiceps	Scrapers
Scarus niger	Scrapers
Scarus oviceps	Scrapers
Scarus psittacus	Scrapers
Scarus rivulatus	Scrapers
Scarus schlegeli	Scrapers
Scarus sp.	Scrapers

Species	Functional group
Scarus spinus	Scrapers
Scarus tricolor	Scrapers
Scolopsis lineatus	Micro-carnivores
Siganus argenteus	Grazers
Siganus fuscescens	Grazers
Siganus puellus	Grazers
Siganus spinus	Grazers
Siganus vulpinus	Grazers
Stegastes albifasciatus	Territorial herbivores
Stegastes nigricans	Territorial herbivores
Stethojulis bandanensis	Micro-carnivores
Stethojulis strigiventer	Micro-carnivores
Strongylura incisa	Micro-carnivores
Sufflamen bursa	Micro-carnivores
Sufflamen chrysopterus	Micro-carnivores

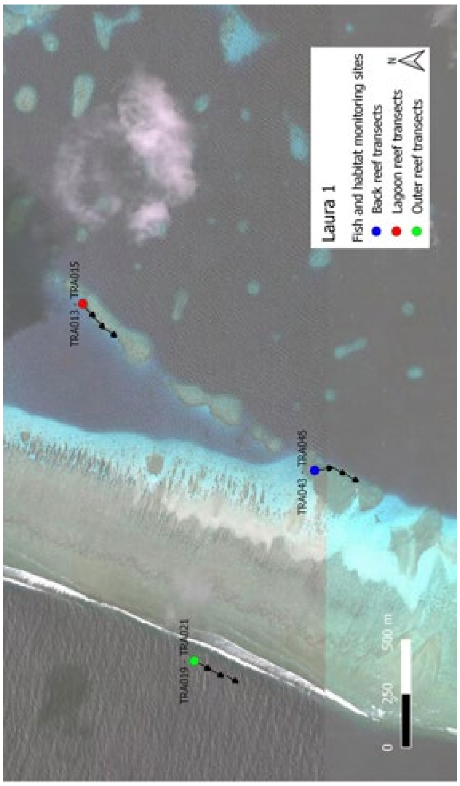
Species	Functional group
Thalassoma amblycephalum	Planktivores
Thalassoma hardwicke	Micro-carnivores
Thalassoma lunare	Micro-carnivores
Thalassoma lutescens	Micro-carnivores
Thalassoma purpureum	Micro-carnivores
Thalassoma quinquevittatum	Micro-carnivores
Thalassoma sp.	Micro-carnivores
Thalassoma trilobatum	Micro-carnivores
Triaenodon obesus	Macro-carnivores/Piscivores
Valenciennea sexguttata	Micro-carnivores
Valenciennea strigata	Micro-carnivores
Zanclus cornutus	Micro-carnivores
Zebrasoma flavescens	Grazers
Zebrasoma scopas	Grazers
Zebrasoma veliferum	Grazers

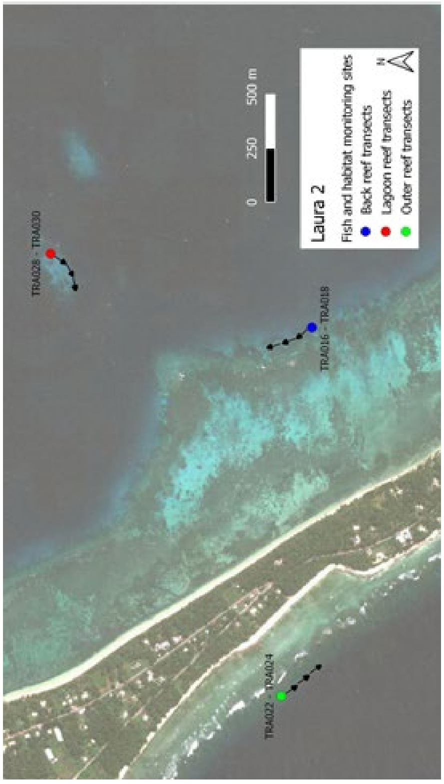
Appendix 2: Statistical analysis for Finfish

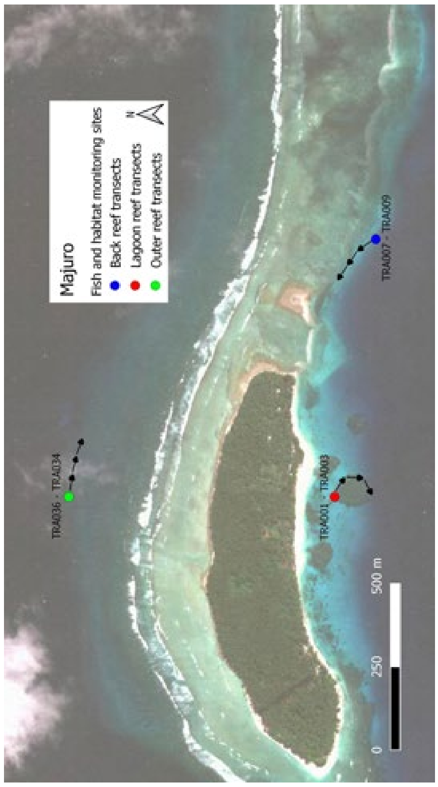
- Sites, survey year and habitat type factors were statistically tested as shown below.
    - To test density results of the most common families (Table 9) and functional groups the analysis involved:
    - a Bray-Curtis dissimilarity matrix;
        - data transformation to get closer to non-significant results
    - family densities were square root transformed and functional groups were fourth root transformed;
    - a non metric multi dimensional scaling ;
    - a permanova; and
- a multivariate regression tree.
    - To test total fish density and pomacentrid density the analysis involved:
    - comparison of multiple test (Levene's test, General linear model);
    - a permanova; and
- a univariate regression tree.

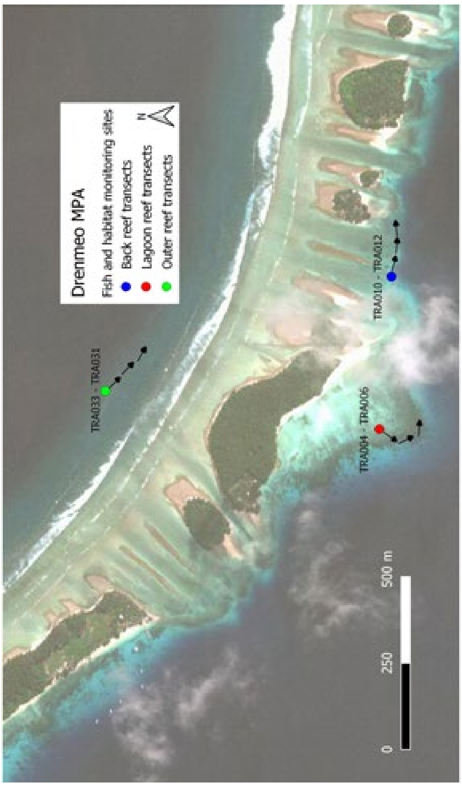
Appendix 3: GPS coordinates (in decimal degrees) and transect direction of finfish and benthic habitat surveys conducted at the Drenmeo MPA, Laura 1, Laura 2, Majuro, Woja MPA monitoring sites

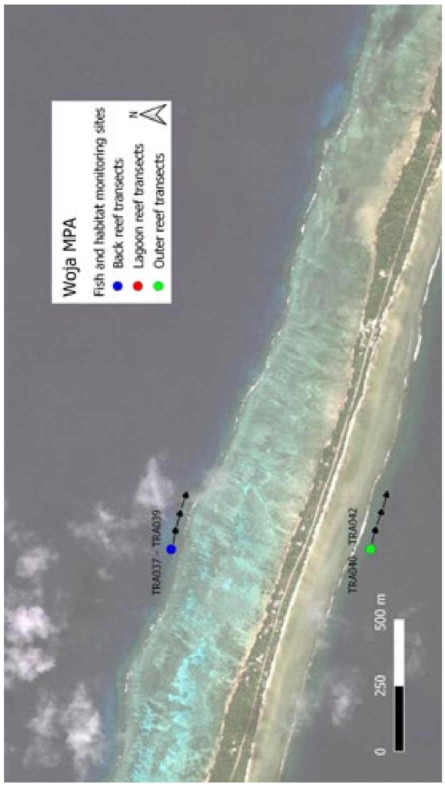
Site	Habitat	Transect	Latitude (N)	Longitude (E)	Depth (m)	Years monitored
Drenmeo MPA	Back reef	T10, T11 & T12	7.120948	171.3207	1	2011, 2013, 2018
	Lagoon reef	T4, T5 & T6	7.121252	171.3165	2–4	2011, 2013, 2018
	Outer reef	T31, T32 & T33	7.12845	171.3182	9–11	2011, 2013, 2018
Laura 1	Back reef	T43, T44 & T45	7.185116	171.0504	3–4	2011, 2013, 2018
	Lagoon reef	T13, T14 & T15	7.194836	171.0572	2–3	2013, 2018
	Outer reef	T19, T20 & T21	7.190153	171.0425	9–10	2011, 2013, 2018
Laura 2	Back reef	T16, T17 & T18	7.13215	171.0506	1–2	2011, 2013, 2018
	Lagoon reef	T28, T29 & T30	7.139219	171.0532	7–8	2013, 2018
	Outer reef	T22, T23, T24	7.132972	171.0409	9–10	2011, 2013, 2018
Majuro	Back reef	T7, T8 & T9	7.15572	171.2203	3–6	2011, 2013, 2018
	Lagoon reef	T1, T2 & T3	7.156845	171.2132	3–4	2011, 2013, 2018
	Outer reef	T34, T35 & T36	7.164115	171.213	10	2011, 2013, 2018
Wooja MPA	Back reef	T37, T38 & T39	7.094728	171.1298	3–4	2013, 2018
	Outer reef	T40, T41 & T42	7.08788	171.13	9–10	2013, 2018


Laura 1
Fish and habitat monitoring sites
Back reef transects
Lagoon reef transects
Outer reef transects
N
TRA013 - TRA015
TRA043 - TRA045
TRA019 - TRA021
0
250
500 m


Laura 2
Fish and habitat monitoring sites
Back reef transects
Lagoon reef transects
Outer reef transects
N
TRA028 - TRA030
TRA016 - TRA018
TRA022 - TRA024
0
250
500 m


Majuro
Fish and habitat monitoring sites
Back reef transects
Lagoon reef transects
Outer reef transects
N
TRA036 - TRA034
TRA001 - TRA003
TRA007 - TRA009
0
250
500 m


Drenmeo MPA
Fish and habitat monitoring sites
Back reef transects
Lagoon reef transects
Outer reef transects
N
TRA033 - TRA031
TRA004 - TRA006
TRA010 - TRA012
0
250
500 m


Woja MPA
Fish and habitat monitoring sites
Back reef transects
Lagoon reef transects
Outer reef transects
N
TRA037 - TRA039
TRA040 - TRA042
0
250
500 m

Appendix 4: Fine scale benthic habitat assessment methodology

Data collection

Fine-scale benthic habitat assessments were conducted using a photoquadrat approach at the same locations and transects as the finfish assessments (Figure 5) 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 m². Transects were laid parallel to the reef. A GPS position was recorded at the beginning of each transect.

Selection of quadrat from the three habitats of the Laura 1 site (from left to right: back reef, lagoon reef, outer reef)

Picture processing

The habitat photographs were analysed using an SPC online tool – Coral Photoquadrat Survey – (https://www.spc.int/CoastalFisheries/FieldSurveys/FieldSurveysHome) adapted from the "Coral Point Count with Excel extension" programme (Kohler and Gill 2006). Using this software, five randomly generated points were created on the downloaded photographs. The substrate under each point was identified, based on the substrate categories listed below.

1. Live hard coral – cover of different types of live hard coral, identified to genus level (Porites species were further divided into Porites, Porities-rus and Porites-massive categories.
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
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 and visible corallites with no polyps present, while bleached coral was defined as white coral with polyps still present. All data processing and identifications were checked by an experienced surveyor.

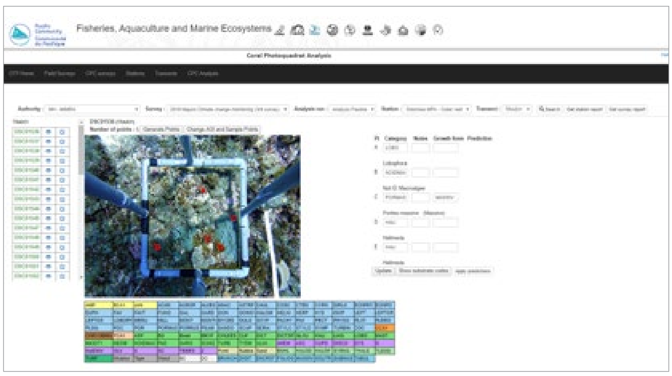
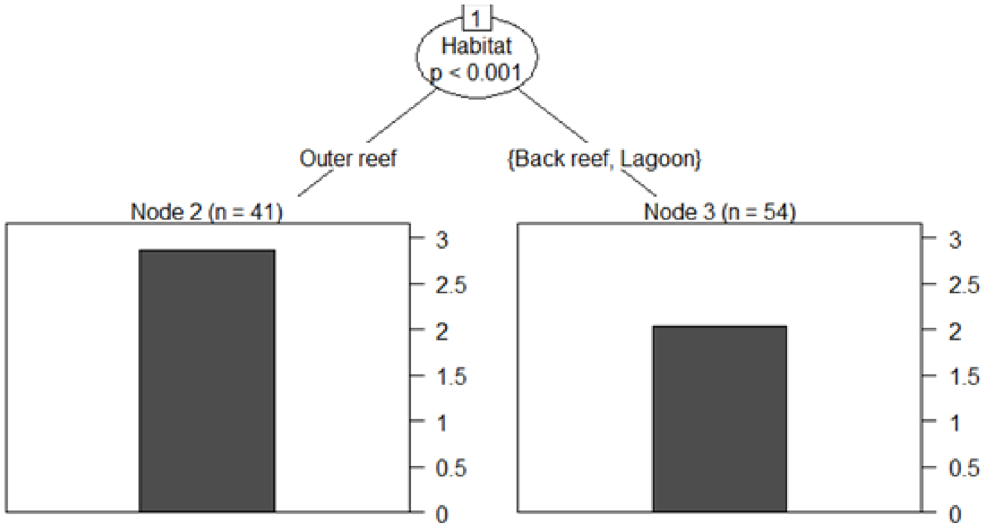


Illustration of the analysis of one photoquadrat using "Coral Photoquadrat Survey" online programme (https://www.spc.int/CoastalFisheries/FieldSurveys/FieldSurveysHome)

Appendix 5: Statistical analysis for benthic habitat assessment

Sites, survey year and habitat type factors were statistically tested as shown below.

- To test coverage of the major benthic categories communities the analysis involved:
    - a Bray-Curtis dissimilarity matrix;
    - data transformation to get closer to non-significant results:
        - percentage cover of major categories were log transformed;
    - a non metric multi dimensional scaling ;
    - a permanova; and
    - a multivariate regression tree.
- To test differences specific to Halimeda cover:
    - data transformation consistent with above;
        - percentage cover of Halimeda were log transformed;
    - comparison of multiple test (Levene's test, general linear model);
    - a permanova; and
    - a univariate regression tree (see below).

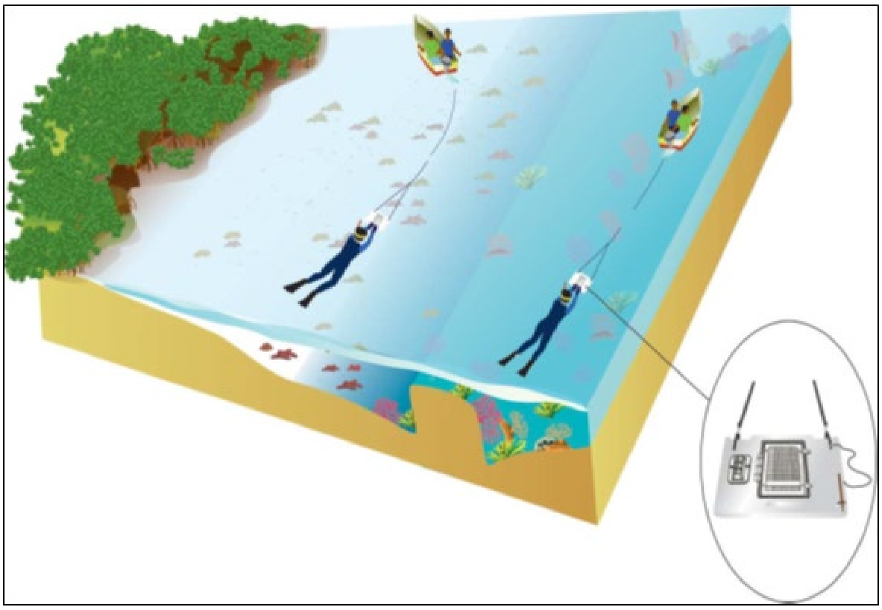


Halimeda univariate tree: outer reef habitat statistically different from the other two habitats

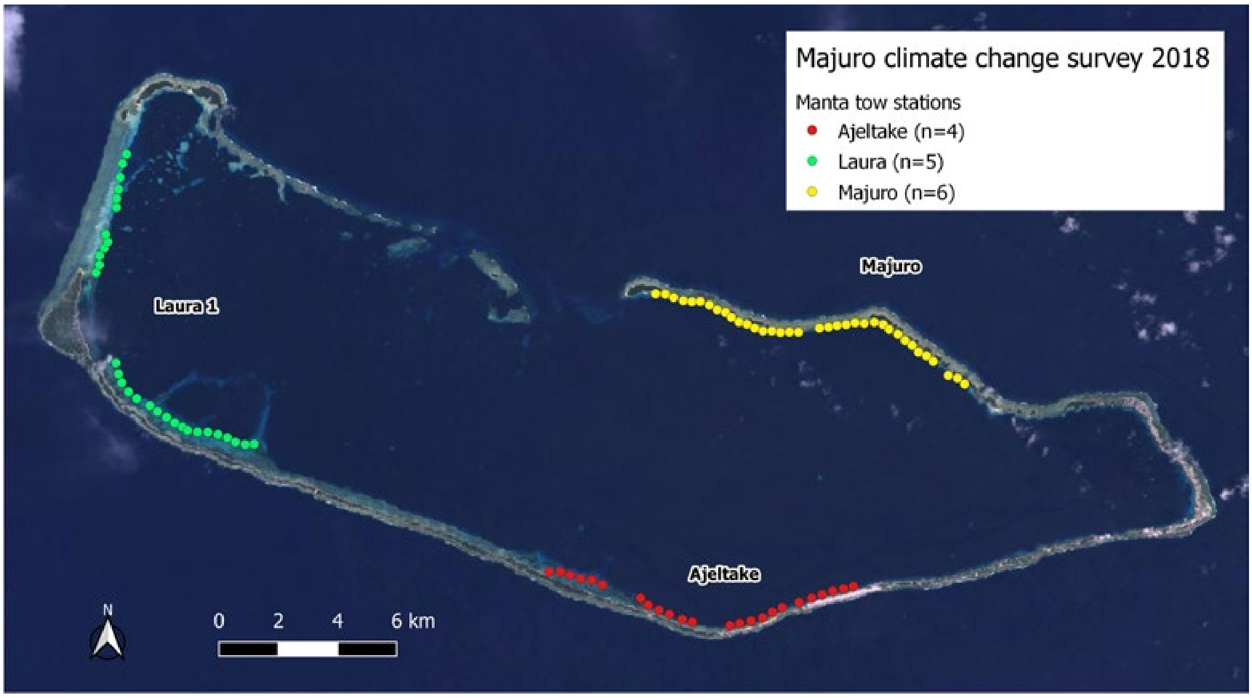
Appendix 6: Invertebrate survey methodologies

Broad-scale assessments

Invertebrate resources of Majuro Atoll were surveyed using two complementary techniques: (i) manta tows; and (ii) reef-benthos transects (RBt). Broad-scale assessments were conducted by manta tow in three sites of Majuro Atoll: Laura, Majuro and Ajeltake. 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 4 km/hour (Table 10). The snorkeller's observation belt was two metres wide and tows were conducted at depths typically ranging from one to ten metres. Each tow replicate was 300 m in length and was calibrated using the odometer function in the trip computer option of a Garmin GPS. Six 300 m manta tow replicates were conducted in each station, with the start and end GPS positions of each tow recorded to an accuracy of within ten metres.



Diagrammatic representation of the broad-scale survey method (manta tow) used at Majuro Atoll during the 2011, 2013 and 2018 surveys



Location of manta tow monitoring transects at Majuro Atoll

GPS coordinates (in decimal degrees) of manta tow survey conducted at the Ajeltake, Laura 1, Majuro, monitoring sites

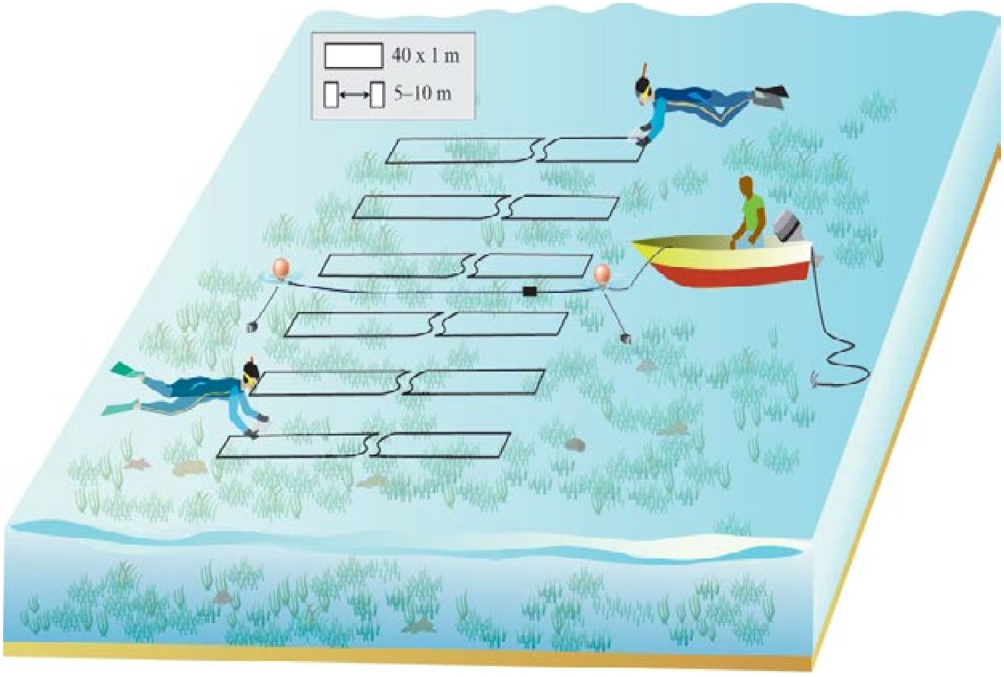
Site	Station No.	Replicate	Latitude–s	Longitude–s	Latitude–e	Longitude–e
Ajeltake	Manta 5	1	7.072217	171.1823	7.071967	171.184933
	Manta 5	2	7.0722	171.1858	7.071567	171.188067
	Manta 5	3	7.071167	171.1887	7.0711	171.191433
	Manta 5	4	7.070167	171.1918	7.069817	171.194483
	Manta 5	5	7.0697	171.1954	7.0688	171.1979
	Manta 5	6	7.068267	171.1986	7.0682	171.20105
	Manta 6	1	7.064217	171.2102	7.062333	171.211917
	Manta 6	2	7.06205	171.2125	7.060883	171.214883
	Manta 6	3	7.060567	171.2157	7.059467	171.218183
	Manta 6	4	7.059233	171.219	7.058167	171.221367
	Manta 6	5	7.057733	171.2228	7.05705	171.225433
	Manta 6	6	7.0569	171.2259	7.056183	171.2285
	Manta 7	1	7.05585	171.2375	7.0564	171.240317
	Manta 7	2	7.0565	171.2405	7.05695	171.243067
	Manta 7	3	7.057233	171.244	7.057983	171.2466
	Manta 7	4	7.058233	171.2475	7.059517	171.24995
	Manta 7	5	7.059933	171.2505	7.06105	171.253017
	Manta 7	6	7.061317	171.2535	7.062217	171.25605
	Manta 8	1	7.062917	171.2586	7.063733	171.261233
	Manta 8	2	7.064183	171.2624	7.065017	171.2651
	Manta 8	3	7.065317	171.2657	7.0661	171.26825
	Manta 8	4	7.066383	171.2689	7.066783	171.27155
	Manta 8	5	7.06705	171.2722	7.067817	171.274767
	Manta 8	6	7.067783	171.2752	7.068333	171.277867
Laura 1	Manta 1	1	7.16355	171.0438	7.1658	171.044433
	Manta 1	2	7.1659	171.0448	7.168567	171.04465
	Manta 1	3	7.168717	171.0448	7.170917	171.046133
	Manta 1	4	7.171033	171.0463	7.17275	171.047267
	Manta 1	5	7.17295	171.0473	7.17515	171.046667
	Manta 1	6	7.175267	171.0467	7.177617	171.04775
	Manta 16	1	7.11485	171.078	7.114283	171.080383
	Manta 16	2	7.114183	171.0811	7.11315	171.083633
	Manta 16	3	7.113183	171.0839	7.112017	171.086233
	Manta 16	4	7.1118	171.0864	7.11125	171.08915
	Manta 16	5	7.1111	171.0893	7.111067	171.092
	Manta 16	6	7.111233	171.0921	7.110533	171.0944
	Manta 2	1	7.183467	171.0499	7.185683	171.05075
	Manta 2	2	7.186183	171.05	7.18885	171.05045
	Manta 2	3	7.189	171.0506	7.191717	171.051167
	Manta 2	4	7.192667	171.0511	7.19535	171.051667
	Manta 2	5	7.196883	171.0518	7.199483	171.052833
	Manta 2	6	7.199767	171.053	7.202367	171.053733
	Manta 3	1	7.136017	171.0498	7.13335	171.050183
	Manta 3	2	7.13265	171.0506	7.130183	171.051467
	Manta 3	3	7.129983	171.0516	7.1279	171.053367
	Manta 3	4	7.127183	171.0537	7.125467	171.055833

Site	Station No.	Replicate	Latitude–s	Longitude–s	Latitude–e	Longitude–e
Laura 1	Manta 3	5	7.125117	171.0562	7.123667	171.058467
	Manta 3	6	7.123	171.0602	7.12125	171.062217
	Manta 4	1	7.121167	171.0625	7.119967	171.064817
	Manta 4	2	7.1194	171.0652	7.117883	171.0677
	Manta 4	3	7.117717	171.0677	7.1166	171.070117
	Manta 4	4	7.116417	171.0701	7.1157	171.0721
	Manta 4	5	7.11545	171.0718	7.113967	171.073967
	Manta 4	6	7.114917	171.0748	7.113767	171.07735

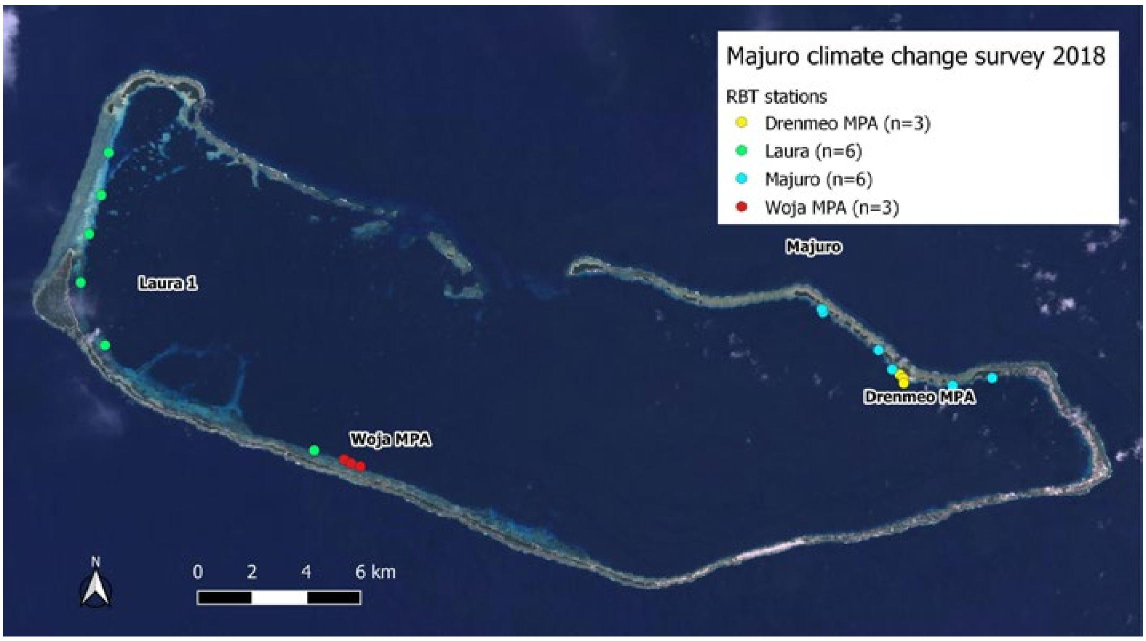
Majuro	Manta 10	1	7.1571	171.2148	7.156917	171.217583
	Manta 10	2	7.157	171.2177	7.155983	171.22015
	Manta 10	3	7.155933	171.2202	7.155067	171.222867
	Manta 10	4	7.155	171.2232	7.15465	171.225567
	Manta 10	5	7.1547	171.2258	7.15475	171.2282
	Manta 10	6	7.154783	171.2283	7.153683	171.230583
	Manta 11	1	7.15365	171.2311	7.15225	171.233467
	Manta 11	2	7.1522	171.2336	7.151433	171.236083
	Manta 11	3	7.15135	171.2362	7.1496	171.237667
	Manta 11	4	7.149933	171.2379	7.148533	171.24005
	Manta 11	5	7.148467	171.2403	7.147983	171.242633
	Manta 11	6	7.1478	171.2427	7.1467	171.244867
	Manta 12	1	7.1466	171.2451	7.146617	171.245333
	Manta 12	2	7.145733	171.2476	7.145883	171.2478
	Manta 12	3	7.145733	171.2503	7.1457	171.2504
	Manta 12	4	7.1453	171.2529	7.14535	171.253033
	Manta 12	5	7.145417	171.2557	7.14545	171.255817
	Manta 12	6	7.145383	171.2585	7.145467	171.258633
	Manta 13	1	7.1466	171.2648	7.14705	171.267433
	Manta 13	2	7.1469	171.2676	7.1476	171.270183
	Manta 13	3	7.147383	171.2702	7.14775	171.27305
	Manta 13	4	7.147683	171.273	7.148317	171.275817
	Manta 13	5	7.14825	171.2757	7.147967	171.278467
	Manta 13	6	7.14805	171.2785	7.14865	171.281183
	Manta 14	1	7.1484	171.2816	7.147917	171.2841
	Manta 14	2	7.147717	171.2842	7.146167	171.28595
	Manta 14	3	7.1462	171.2861	7.145217	171.288433
	Manta 14	4	7.144767	171.2889	7.143	171.290983
	Manta 14	5	7.142867	171.2911	7.141517	171.292967
	Manta 14	6	7.14135	171.2933	7.139383	171.294967
	Manta 15	1	7.139267	171.2952	7.138317	171.297517
	Manta 15	2	7.138183	171.2976	7.136533	171.299617
	Manta 15	3	7.136467	171.2997	7.134667	171.3014
	Manta 15	4	7.132167	171.3042	7.131383	171.306883
	Manta 15	5	7.131367	171.3071	7.129533	171.3091
	Manta 15	6	7.129533	171.3092	7.127233	171.31085

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. In total, 18 RBt stations were established in Majuro Atoll, with stations established at the Laura (n = 6), Woja MPA (n = 3), Majuro (n = 6) and Drenmeo MPA (n = 3) regions. 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 the difficulty of measuring the size of these organisms. Each transect was 40 m long with a 1 m wide observation belt, conducted at depths ranging from one to three metres. The two snorkellers conducted three transects each, totalling six 40 m transects for each RBt station. The GPS position of each station was recorded in the centre of the station.



Diagrammatic representation of the fine-scale survey method (reef benthos transects) used at Majuro Atoll during the 2011, 2013 and 2018 surveys



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

GPS coordinates (in decimal degrees) of reef benthos transect stations survey conducted at the Drenmeo MPA, Laura 1, Laura 2, Majuro, Woja MPA monitoring sites

Site	Station No.	Latitude	Longitude	Depth
Drenmeo MPA	RBt 19	7.12175	171.3165	1.25
	RBt 12	7.123067	171.3154	1.5
	RBt 9	7.120117	171.3167	0.75
Laura 1	RBt 3	7.182717	171.0491	1
	RBt 2	7.169783	171.0451	1.5
	RBt 15	7.097767	171.1202	2.5
	RBt 4	7.19685	171.0516	1
	RBt 1	7.15365	171.0423	1
	RBt 5	7.132783	171.0504	0.5
Majuro	RBt 7	7.1311	171.3084	1.75
	RBt 11	7.121883	171.3462	1.95
	RBt 8	7.124717	171.3129	0.75
	RBt 10	7.1193	171.333	1.65
	RBt 14	7.14475	171.2894	1.5
	RBt 13	7.143667	171.2897	1.5
Woja MPA	RBt 16	7.094683	171.1301	2
	RBt 18	7.092367	171.1355	2
	RBt 17	7.093467	171.1324	2

Appendix 7: Creel survey methodologies

This section provides more details on the design of the creel survey conducted in 2018.

During the survey, following the guidance from the SPC creel and market survey manual (Kaly et al. 2016), the lead fisher was asked questions relating to the fishing trip: the number of fishers, fishing methods used, locations fished, distance travelled, and costs involved. Their usual 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 lobster carapace length was measured to the nearest mm and weighed to the nearest 10 g. A copy of the survey form used in the creel surveys is shown below.

Creel survey carried out by: [enter organisation or department]		Landing no:	
Survey name:			
Province / Island + Country:			
Date of this replicate (day/month/year):		Currency used:	
Survey Site:			
Latitude (DD):		Longitude (DD):	
Interviewers' / surveyors' names:	1.	2.	
	3.	4.	
C1: Basic information on fishers			
Lead fisher's name:			
Date of birth (DOB):		Gender:	
Address (name of village / town / city:			
Vessel ID/Name:			
Is the fisher fishing with other people?	Yes ☐ | No ☐		

Total number of fishers?			
→ (data on other fishers in the landing today)			
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 many days per month do you go fishing? /month	How many months a year do you fish (i.e. excluding closed fishing seasons)? 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 sites? List by priority			
Other site 1:(most often)		How often? /month	
Other site 2:		HHow often? /month	
Other site 3:		How often? /month	
Other site 4:(least often)		How often? /month	
Why do you fish?	Subsistence ☐ | Income ☐ | Other ☐		
Please provide details:			
About how much of this catch will be eaten at home or sold?	% kept	% sold	
How much do you expect to earn from this catch overall?	Value:		
What is your estimate of the total weight of this catch (estimated by you, not the fisher)?	kg		

C3: Species sizes, and C4: Species weights

Record all sizes in the catch in **cm** (to nearest 0.1 cm) and all weights in **kg**

(Repeat this page if you need more space)

Species name	**Size type**	**Size (cm)**	**Weight (kg)**	**Fishing method**
e.g. Lutjanus gibbus	FL	23.2	0.25	Handline

C5: Effort data for CPUE

How many hours were spent on the fishing trip today?		hrs

Fishing method and gear used for each fish product (separate pelagic fish, reef fish, crabs, lobsters, etc.), how many methods were involved and how much time spent doing each activity

Fish product	Methods / gear used	No. gear	No. hours	Day or night?
1.				
2.				
3.				
4.				

Did you lose or damage any gear during this fishing trip? What was it? How much will it cost to replace or repair the item?		
Gear item	Lost or damaged?	Cost to replace or repair
1.		
2.		
3.		
4.		

Please list any other costs associated with **this fishing trip,** including fuel, wages, bait, ice, food, drink, or any other items.	
Item	Purchase price:
1.	
2.	
3.	
4.	
What is the distance to the farthest site you fished at today?	km
Where did you leave from?	

How many sites did you stop and fish at? Where are they?		
Site	Location (on map, lat/long, or distance to each fishing ground)	Time spent at location (hrs)
1.		
2.		
3.		
4.		

What kind of boat was used today?	
Construction:	Wood ☐ | Fibreglass ☐ | Plastic ☐ | Steel ☐ | Concrete ☐
Type of boat:	| No boat ☐ | Motor boat ☐ | Sail boat ☐ | Canoe ☐
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 ☐ | Anchor ☐ | Mirror ☐ | Water ☐ | EPIRB ☐ | GPS ☐ | Flares ☐ | Bailer / Bilge ☐ | Extra fuel ☐ | Other (please specify) ☐

C6: Catch prices	
Where will you use or sell **this** catch?	Home ☐ | Market ☐ | Buyer domestic ☐ | Buyer export ☐ Roadside ☐ | Resort/Restaurant ☐ | Retail Shop ☐ |

How are the items sold (units of sale) and for what price?

Fish product	Unit of sale	No. per unit	Price per unit of sale	Price per item
1.				
2.				
3.				
4.				

C7: Perceptions of fishers	
What is the main fishing activity for this landing? Clam/Trochus fishery ☐ | Nearshore/Oceanic fishery ☐ | Other invertebrates fishery ☐ | Reef/Lagoon fishery ☐ | Deepwater snapper fishery ☐ | Sea-cucumber fishery ☐	
How long have you been fishing?	Years
How long have you been fishing in this fishery (e.g. nearshore/oceanic fishery, reef/lagoon fishery, deepwater snapper fishery, sea-cucumber fishery)?	Years
What other types of fisheries have you been involved with in the past (e.g. nearshore/oceanic fishery, reef/lagoon fishery, deepwater snapper fishery, sea cucumber fishery)?	
Are you fishing in other fisheries now? Yes ☐ | No ☐	Describe:
Are you fishing in the same **areas** as you were five years ago? Yes ☐ | No ☐	Please explain:
Are you catching the same **quantities** as you were five years ago? Same ☐ | Increase ☐ | Decrease ☐	Please explain:
Are you catching the same **size** as you were five years ago? Same ☐ | Increase ☐ | Decrease ☐	Please explain:
If catches are **different**, what has changed?	
Do you have any **concerns** about the resource(s)?	

Appendix 8: Number of individuals observed from various methods during creel surveys, August 2018 and relative percentage contribution to overall catch by method

Fishing Method	Species	Number observed	% contribution by abundance	% contribution by weight
Bottom Fishing	*Anyperodon leucogrammicus*	1	0.13%	0.16%
	Aphareus furca	2	0.26%	0.22%
	Aprion virescens	4	0.53%	2.95%
	Balistes sp.	1	0.13%	0.17%
	Balistoides viridescens	1	0.13%	0.73%
	Carangoides orthogrammus	1	0.13%	0.28%
	Caranx lugubris	2	0.26%	0.70%
	Caranx melampygus	2	0.26%	0.58%
	Decapterus macarellus	14	1.85%	1.86%
	Epinephelus cyanopodus	1	0.13%	0.21%
	Epinephelus hexagonatus	4	0.53%	0.21%
	Epinephelus howlandi	1	0.13%	0.20%
	Epinephelus maculatus	22	2.91%	4.06%
	Epinephelus polyphekadion	53	7.02%	9.07%
	Epinephelus sp.	8	1.06%	1.71%
	Gnathodentex aureolineatus	1	0.13%	0.05%
	Lethrinus erythracanthus	4	0.53%	1.31%
	Lethrinus lentjan	21	2.78%	3.34%
	Lethrinus obsoletus	3	0.40%	0.48%
	Lethrinus olivaceus	28	3.71%	11.76%
	Lethrinus semicinctus	9	1.19%	0.51%
	Lethrinus sp.	2	0.26%	0.30%
	Lethrinus xanthochilus	7	0.93%	2.32%
	Lutjanus bohar	7	0.93%	3.71%
	Lutjanus fulvus	6	0.79%	0.54%
	Lutjanus gibbus	107	14.17%	11.12%
	Lutjanus kasmira	7	0.93%	0.39%
	Lutjanus monostigma	8	1.06%	1.41%
	Lutjanus semicinctus	1	0.13%	0.14%
	Lutjanus vitta	41	5.43%	2.72%
	Macolor niger	1	0.13%	0.13%
	Monotaxis grandoculis	2	0.26%	0.55%
	Myripristis adusta	111	14.70%	9.36%
	Myripristis berndti	82	10.86%	5.77%
	Myripristis kuntee	1	0.13%	0.03%
	Naso vlamingii	1	0.13%	0.33%
	Neoniphon opercularis	2	0.26%	0.09%
	Parupeneus cyclostomus	2	0.26%	0.21%
	Plectropomus leopardus	1	0.13%	0.54%
	Priacanthus hamrur	1	0.13%	0.07%
	Sargocentron spiniferum	6	0.79%	0.85%
	Sargocentron tiere	8	1.06%	0.45%
	Sargocentron violaceum	1	0.13%	0.05%
	Selar boops	40	5.30%	5.25%
	Selar sp.	120	15.89%	11.30%
	Sphyraena forsteri	4	0.53%	1.43%
	Variola albimarginata	1	0.13%	0.10%
	Variola louti	2	0.26%	0.26%

Fishing Method	Species	Number observed	% contribution by abundance	% contribution by weight
Spearfishing	*Acanthurus blochii*	8	0.91%	0.88%
	Acanthurus guttatus	37	4.22%	2.09%
	Acanthurus lineatus	15	1.71%	0.69%
	Acanthurus mata	33	3.76%	6.51%
	Acanthurus nigricans	3	0.34%	0.14%
	Acanthurus nigricauda	2	0.23%	0.14%
	Acanthurus triostegus	30	3.42%	1.00%
	Anyperodon leucogrammicus	1	0.11%	0.07%
	Balistapus undulatus	1	0.11%	0.16%
	Caesio caerulaurea	2	0.23%	0.11%
	Carangoides orthogrammus	3	0.34%	0.44%
	Cephalopholis argus	4	0.46%	0.32%
	Cetoscarus ocellatus	1	0.11%	0.59%
	Chlorurus frontalis	5	0.57%	0.76%
	Chlorurus microrhinos	1	0.11%	0.20%
	Crenimugil crenilabis	2	0.23%	0.15%
	Epinephelus howlandi	4	0.46%	0.56%
	Epinephelus maculatus	7	0.80%	1.05%
	Epinephelus merra	2	0.23%	0.09%
	Epinephelus polyphekadion	51	5.82%	9.14%
	Epinephelus sp.	7	0.80%	0.73%
	Epinephelus spilotoceps	1	0.11%	0.07%
	Gymnocranius sp.	3	0.34%	0.68%
	Hipposcarus longiceps	13	1.48%	1.79%
	Kyphosus cinerascens	13	1.48%	2.13%
	Kyphosus vaigiensis	1	0.11%	0.16%
	Lethrinus erythracanthus	1	0.11%	0.15%
	Lethrinus harak	3	0.34%	0.40%
	Lethrinus lentjan	1	0.11%	0.15%
	Lethrinus obsoletus	2	0.23%	0.19%
	Lethrinus semicinctus	1	0.11%	0.07%
	Lutjanus bohar	1	0.11%	1.00%
	Lutjanus fulvus	1	0.11%	0.06%
	Lutjanus gibbus	96	10.95%	9.56%
	Lutjanus monostigma	4	0.46%	0.46%
	Macolor niger	1	0.11%	0.17%
	Monotaxis grandoculis	16	1.82%	1.97%
	Mulloidichthys flavolineatus	10	1.14%	0.53%
	Mulloidichthys vanicolensis	2	0.23%	0.12%
	Myripristis adusta	2	0.23%	0.11%
	Myripristis berndti	20	2.28%	0.67%
	Myripristis murdjan	43	4.90%	1.92%
	Myripristis violacea	6	0.68%	0.18%
	Naso brevirostris	44	5.02%	3.97%
	Naso hexacanthus	11	1.25%	1.65%
	Naso lituratus	115	13.11%	11.31%
	Naso unicornis	20	2.28%	3.29%
	Naso vlamingii	28	3.19%	3.82%
	Panulirus penicillatus	54	6.16%	10.86%

Fishing Method	Species	Number observed	% contribution by abundance	% contribution by weight
Spearfishing	*Parupeneus barberinus*	13	1.48%	1.17%
	Parupeneus crassilabris	2	0.23%	0.14%
	Parupeneus cyclostomus	2	0.23%	0.15%
	Plectropomus areolatus	7	0.80%	1.11%
	Plectropomus laevis	1	0.11%	0.16%
	Plectropomus leopardus	8	0.91%	4.16%
	Sargocentron spiniferum	14	1.60%	1.04%
	Sargocentron tiere	1	0.11%	0.04%
	Scarus rivulatus	6	0.68%	0.71%
	Scarus rubroviolaceus	1	0.11%	0.17%
	Siganus argenteus	59	6.73%	5.07%
	Siganus puellus	7	0.80%	0.53%
	Siganus punctatus	8	0.91%	0.61%
	Siganus vermiculatus	1	0.11%	0.04%
	Siganus vulpinus	2	0.23%	0.10%
	Variola albimarginata	3	0.34%	0.24%
	Variola louti	10	1.14%	1.30%

Appendix 9: Example of finfish survey form

Fish form PAGE /

Campaign |_______________| Site |__________________________| Diver |__|__| 50 m Transect |__|__|__|

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

Video transect (Landscape): Yes ☐ No ☐ Associated Photo quadrat: Yes ☐ No ☐

SCIENTIFIC NAME	1-5 cm	6-10 cm	11-15 cm	16-20 cm	21-25 cm	26-30 cm	31-35 cm	36-40 cm	COMMENTS

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ISBN 978-982-00-1372-8