Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change

Northern Manus Outer Islands
Papua New Guinea

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ACRONYMS

AusAID	Australian Agency for International Development
CPC	Coral Point Count
CPUE	Catch-per-unit-effort
DFAT	Department of Foreign Affairs and Trade
D-UVC	Distance-sampling Underwater Visual Census
EEZ	Exclusive Economic Zone
FAD	Fish Aggregating Device
FL	Fork length
g	gram(s)
GDP	Gross Domestic Product
GEF	Global Environment Facility
GPS	Global Positioning System
GR	Government Revenue
ha	hectare
ICCAI	International Climate Change Adaptation Initiative (Australia)
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
kg	kilogram(s)
km	kilometre(s)
MCRMP	Millennium Coral Reef Mapping Project
mm	millimeter(s)
MPA	Marine Protected Area
NASA	National Aeronautics and Space Administration
NGO	Non-Government Organisation
PCCSP	Pacific Climate Change Science Program
PERMANOVA	Permutational multivariate analysis of variance
PICTs	Pacific Island Countries and Territories
PNG	Papua New Guinea
PNG NFA	Papua New Guinea’s National Fisheries Authority
PROCFish	Pacific Regional Oceanic and Coastal Fisheries Development Programme
RBt	Reef-benthos transect
SCUBA	Self-Contained Underwater Breathing Apparatus
SEAFRAME	Sea Level Fine Resolution Acoustic Measuring Equipment
SOPAC	Applied Geoscience and Technology Division of SPC
SPC	Secretariat of the Pacific Community
SD	Standard Deviation
SE	Standard Error
SST	Sea-surface temperature
TL	Total length
TNC	The Nature Conservancy
USD	United States dollar(s)
WCS	Wildlife Conservation Society

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EXECUTIVE SUMMARY

Introduction

Considering the concerns of climate change and its impacts on coastal fisheries resources, SPC is implementing the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project with funding assistance from the Australian Government's International Climate Change Adaptation Initiative (ICCAI). This initiative aims to assist Pacific Islands Countries and Territories (PICTs) to determine whether changes are occurring in the productivity of coastal fisheries and, if changes are found, to identify the extent to which such changes could be attributed to climate change, as opposed to other causative factors. This report presents the results of the second round of monitoring conducted in Manus Province, Papua New Guinea, in April-June 2014. Collected data are compared to that from the 2012 baseline survey to examine changes in resource status over time.

Survey Design

Survey work in Manus Province covered six disciplines, including monitoring of water temperature, in-water assessments of finfish and invertebrate resources and the health of benthic habitats, creel surveys and biological monitoring of key reef fishes, and was conducted by staff from SPC's Coastal Fisheries Science and Management Section, PNG National Fisheries Authority and Manus Provincial Fisheries. In-water assessments were conducted at three sites along the northern coast of Manus; Ahus Island, Ponam Reef (Andra Island) and Onetah Island. Creel surveys focused on the fishers of Andra Island. The fieldwork included capacity development of local counterparts by providing training in survey design and methodologies, data collection and entry, and data analysis.

Finfish Surveys

Finfish resources of the study region were surveyed using distance-sampling underwater visual census (D-UVC) methodology, and were conducted across back reef, lagoon reef and outer habitats on the three sites. Finfish communities of Ahus and Andra Islands were surveyed in 2012 and 2014, while finfish communities of Onetah Island were surveyed for the first time in 2014.

Finfish diversity was higher in 2014 than 2012 for all sites and habitats, a result that potentially reflects greater experience within the survey team rather than a true increase in diversity. Similarly, mean density and mean biomass of key finfish families and functional groups at Ahus and Andra appeared either similar or higher in 2014 relative to 2012. In 2014, few differences in finfish communities were amongst Onetah and the neighbouring Ahus site, particularly for back reef habitats. Outer reef habitats of Onetah supported significantly higher densities of Lutjanidae (snappers) and higher biomass of Holocentridae (soldierfish and squirrelfish) than those of neighbouring Ahus Island.

Benthic Habitat Assessments

Benthic habitats of the study region were surveyed using two complementary approaches: a broad-scale method, using manta tows, and a fine-scale method, using a photoquadrat analysis. Benthic habitats of Ahus and Andra Islands were surveyed in 2012 and 2014, while those at Onetah Island were surveyed for the first time in 2014. At Ahus and Andra, little difference was evident in benthic habitat condition amongst surveys via each method. Back and lagoon reef habitats of the Ahus site appeared in poor health, with high cover of macroalgae, dead coral and cyanobacteria. Benthic habitats of Onetah appeared in relatively good health, with both the back reef and outer reef of this site having higher live coral cover than those at Ahus or Andra.

Invertebrate Surveys

Invertebrate resources of the study region were surveyed using two complementary approaches: a broad-scale method, using manta tows, and a fine-scale method, using reef-benthos transects (RBt). Invertebrate communities of Ahus and Andra Islands were surveyed in 2012 and 2014, while those at Onetah Island were surveyed for the first time in 2014. Few significant differences were observed in density of any invertebrate species among the 2012 and 2014 surveys within either the Ahus or Andra sites. Invertebrate diversity at the RBt stations showed a slight increase in 2014 relative to 2012 at both the Ahus and Andra sites. In 2014, invertebrate species diversity was highest at Onetah. Similarly, several differences were observed in densities of individual invertebrate species amongst Onetah and the Ahus and Andra sites. Most noticeably, Onetah supported significantly higher densities of the gastropods of the genera *Cypraea* (in particular *C. annulus* and *C. tigris*), *Tectus* (in particular trochus, *T. niloticus*) and *Turbo* (in particular *Turbo argyrostomus*), and the urchins *Diadema setosum* and *Echinometra mathaei*.

Creel surveys

Creel surveys were conducted for the first time in 2014, and focused on fishers of Andra Island. A total of 623 surveys were completed, with information collected of fisher demographics, fishing behavior, locations/habitats fished, distances travelled, time spent fishing, catch (including length and weight data for all individuals caught) and fisher perceptions. Data were collected for a range of fishing practices, including bottom fishing (12 surveys), drop-stone lining (six surveys), day and night spearfishing (six and nine surveys, respectively), mixed reef gleaning by female fishers (14 surveys), and trolling (18 surveys).

Perceptions of fishers on the status of resources were collected during 38 surveys. The majority of fishers surveyed indicated that they had seen changes in the fishery in the last few years, with 66% of all respondents claiming they considered their catches had decreased compared to five years ago, and 61% of all respondents claiming sizes of fish had decrease compared to five years ago. Differences were observed amongst fishing sectors and genders, with fishers returning from reef-based activities more likely to believe catch quantities and sizes had decreased than those returning from nearshore/oceanic fishing, and female fishers generally more likely to believe catch quantities and sizes had decreased than male fishers.

Biological Monitoring

Biological monitoring of key reef fish species within the study region was included for the first time during the 2014 survey, and focused on two commonly harvested species: humpback red snapper (*Lutjanus gibbus*), and orangespine surgeonfish (*Naso lituratus*), and two unharvested (‘control’) species: redfin butterflyfish (*Chaetodon lunulatus*) and striated surgeonfish (*Ctenochaetus striatus*). Demographic parameters, including von Bertalanffy growth function parameters, age structures and total, natural and fishing mortality rates were determined for each species (where possible) to provide a baseline for northern Manus for future comparisons. Fishing mortality of *N. lituratus* was above the optimal rate indicating that this species is fished above its optimum level. This may, however, be an artefact of small sample sizes and greater sampling of this species is recommended.

Recommendations for Management

Several key management recommendations are prescribed from observations during the current study that will help improve the resilience of the coastal fisheries of the northern Manus outer islands to both long-term (e.g. climate change) and short-term (e.g. overfishing) stressors. These include:

1) Reduce nutrient input by replacing platform toilets with composting systems.
2) Re-deployment of the Fish Aggregating Device (FAD).
3) Creation of locally managed Marine Protected Areas.
4) Place restrictions on destructive or highly efficient fishing practices, in particular night-time spearfishing.
5) Maintain the national closure of sea cucumber fisheries.
6) Protect sharks and other iconic and ecologically-significant species.
7) Maintain healthy catchments on mainland Manus.
8) Strengthen stakeholder awareness programs and exchange of information on coastal fisheries, the marine environment and climate change.

Ultimately, any decision regarding management of reef resources should be done in consultation and collaboration with the communities of Andra and Ahus Islands. To be successful, management strategies will require the support of the entire community.

Introduction

Project Background

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

The purpose of this project is to assist PICTs to:

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

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

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

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

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

The Approach

Monitoring impacts of climate change on coastal fisheries is a complex challenge. To facilitate this task, a set of monitoring methods was selected from the SPC expert workshop 'Vulnerability and Adaptation of Coastal Fisheries to Climate Change: Monitoring Indicators and Survey Design for Implementation in the Pacific' (Noumea, 19–22 April 2010) of scientists and representatives of many PICTs. These methods include monitoring of water temperature using temperature loggers, finfish and invertebrate resources using SPC resource assessment protocols, and photo quadrats for assessing benthic habitats supporting coastal fisheries (Table 1). The methods were prioritized as they were considered indicators for the oceanic environment, habitats supporting coastal fisheries, and finfish and invertebrate resources. In parallel, SPC is currently implementing database backend and software to facilitate data entry, analysis and sharing between national stakeholders and the scientific community as well as providing long-term storage of monitoring data.

Five pilot sites were selected for monitoring: Federated States of Micronesia (Pohnpei), Kiribati (Abemama Atoll), Marshall Islands (Majuro Atoll), Papua New Guinea (Manus Province) and

Tuvalu (Funafuti Atoll). Their selection was based on existing available data such as fish, invertebrate and socio-economic survey data from the Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish), multi-temporal images (aerial photographs and satellite images) from the Applied Geosciences and Technology Division of SPC (SOPAC), the presence of Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME), as well as their geographical location.

This report presents the results of the second round of field surveys for the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project conducted in Manus Province, PNG, between April and June 2014 by a team from SPC's Coastal Fisheries Science and Management Section and staff from PNG's National Fisheries Authority (NFA) and Manus Provincial Fisheries. Collected data are compared against those of the baseline survey of the study region conducted in 2012 (Moore et al. 2012). Recommendations for management and future monitoring events are also provided.

Table 1 Summary of activities and variables measured during the monitoring program in Manus, PNG, 2014.

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

Papua New Guinea

Background

The independent nation of Papua New Guinea consists of the eastern half of New Guinea Island and approximately 700 offshore islands between the equator and 12°S, and 140°E–160°E (Figure 1). The country's geography is diverse and, in places, extremely rugged. A spine of mountains, the New Guinea Highlands, runs the length of New Guinea Island, which is mostly covered with tropical rainforest. Dense rainforests can also be found in the lowland and coastal areas as well as the very large wetland areas surrounding the Sepik and Fly Rivers. The highest peak is Mount Wilhelm at 4,697 m (SOPAC 2010). The total land area of PNG is around 462,243 km^2, while the Exclusive Economic Zone (EEZ) totals approximately 2.4 million km^2 (Bell et al. 2011). The population of Papua New Guinea is approximately 7.4 million of which around 40% live in the highlands and 18% in urban areas (SOPAC 2010, The World Bank 2014). The capital, Port Moresby, is located in the south-east and has a population of approximately 500,000. Eighty-five percent of the population live a subsistence lifestyle in rural areas. These people depend on traditional agriculture and fishing for their livelihoods. Mining and oil production are the main sources of revenue for Papua New Guinea, accounting for 60% of export earnings and 20% of government revenue (GR). Agricultural crops are still a major source of revenue, in particular copra, coffee, palm oil and cocoa (PCCSP 2011).

Figure 1 Map of PNG (from PCCSP 2011).

Fisheries of Papua New Guinea

Oceanic fisheries

PNG has an important, locally based industrial purse-seine tuna fishery that operates within its exclusive economic zone (EEZ). Recent average catches (2004–2008) by this fishery have exceeded 225,000 tonnes per year, with a value of over USD 280 million (Bell et al. 2011). PNG also licenses foreign purse-seine vessels to fish for tuna in its EEZ; these foreign vessels have a recent average annual catch of more than 220,000 tonnes (1999–2008) worth approximately USD 200 million (Bell et al. 2011). Licence fees from vessels involved in this fishery contributed 0.6% to government revenue (GR) in 2007 (Bell et al. 2011).

Coastal fisheries

The coastal fisheries of PNG can be grouped into four broad-scale categories: demersal fish (bottom-dwelling fish associated with mangrove, seagrass and coral reef habitats), nearshore pelagic fish (including tuna, wahoo, mackerel, rainbow runner and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas (Bell et al. 2011). In 2007, the total annual catch of the coastal sector was estimated to be 35,700 tonnes, worth approximately USD 62.5 million (Gillet 2009) (Table 2). The commercial component of this catch was an estimated 5,700 tonnes, while the subsistence catch was an estimated 30,000 tonnes (Gillet 2009) (Table 2). Approximately 80% of the total coastal catch is estimated to be made up of demersal and nearshore pelagic fish (Bell et al. 2011) (Table 3).

Table 2 Annual fisheries and aquaculture harvest in Papua New Guinea, 2007 (Gillet 2009)

Harvest sector	Quantity (tonnes)	Value (Kina)
Offshore locally-based	256,397	1,024,089,635
Offshore foreign-based	327,471	1,143,631,355
Coastal commercial	5,700	80,000,000
Coastal subsistence	30,000	105,000,000
Freshwater	17,500	49,000,000
Aquaculture	200	2,000,000
Total	**637,268**	**2,403,720,990**

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

Coastal fishery category	Quantity (tonnes)	Contribution of catch (%)
Demersal finfish	14,520	41
Nearshore pelagic finfish	13,760	38
Targeted invertebrates	1,300	4
Inter/subtidal invertebrates	6,120	17
Total	**35,700**	**100**

Climate Change Projections for PNG

Air temperature

Historical air temperature data records for PNG are available for Port Moresby (Figure 2). These records show an increase in average daily temperatures of approximately 0.21°C per decade since recording began in 1950 (Figure 2) (PCCSP 2011). Mean air temperatures are projected to continue to rise, with increases of +0.7, +0.8 and +0.7°C (relative to 1990 values) projected for 2030, under the IPCC B1 (low), A1B (medium) and A2 (high) emissions scenarios, respectively (PCCSP 2011) (Table 4).

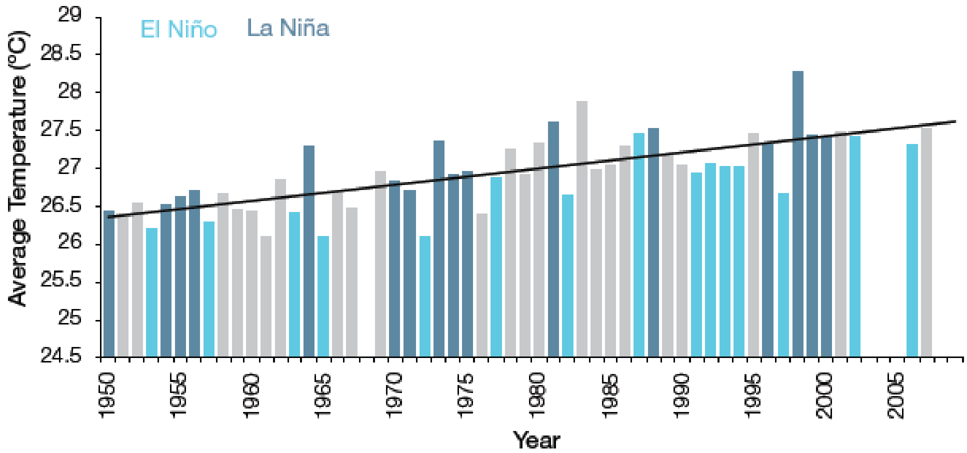


Figure 2 Mean annual air temperature at Port Moresby (1950-2009) (from PCCSP 2011).

Table 4 Projected changes in mean air temperature (in °C) projected for Papua New Guinea under various IPCC emission scenarios (from PCCSP 2011)

Emission scenario	2030	2055	2090
B1	+0.7 ± 0.4	+1.1 ± 0.5	+1.6 ± 0.6
A1B	+0.8 ± 0.4	+1.5 ± 0.5	+2.4 ± 0.8
A2	+0.7 ± 0.3	+1.5 ± 0.4	+2.8 ± 0.6

Sea-surface temperature

Sea-surface temperatures in the PNG region have risen gradually since recording began in the 1950s. Since the 1970s the rate of warming has been approximately 0.11°C per decade (PCCSP 2011). In accordance with mean air surface temperatures, sea-surface temperatures are projected to further increase, with increases of +0.6, +0.7 and +0.7°C (relative to 1990 values) projected for 2030, under the IPCC B1 (low), A1B (medium) and A2 (high) emissions scenarios, respectively (PCCSP 2011) (Table 5).

Table 5 Projected changes in sea-surface temperature (in °C) projected for Papua New Guinea under various IPCC emission scenarios (from PCCSP 2011)

Emission scenario	2030	2055	2090
B1	+0.6 ± 0.5	+1.0 ± 0.5	+1.4 ± 0.6
A1B	+0.7 ± 0.4	+1.3 ± 0.5	+2.2 ± 0.7
A2	+0.7 ± 0.5	+1.3 ± 0.5	+2.6 ± 0.7

Sea level rise

As part of the AusAID-sponsored South Pacific Sea Level and Climate Monitoring Project ('Pacific Project') a SEAFRAME (Sea Level Fine Resolution Acoustic Measuring Equipment) gauge was installed at Manus Island, in northern PNG, in September 1994. According to the 2010 Pacific country report on sea level and climate for PNG (http://www.bom.gov.au/pacificsealevel/picreports.shtml), the gauge had been returning high resolution, good quality scientific data since installation and as of 2010 the net trend in sea-level rise at Manus Island (accounting for barometric pressure and tidal gauge movement) was calculated at +5.7 mm per year. Based on empirical modeling, mean sea-level is projected to continue to rise during the 21st century, with increases of up to +20 to +30 cm projected for 2035 and +70 to +140 cm projected for 2100 (Bell et al. 2011). Sea level rise may potentially create severe problems for low lying coastal areas, namely through increases in coastal erosion and saltwater intrusion (Mimura 1999). Such processes may result in increased fishing pressure on coastal habitats, as traditional garden crops fail, further exacerbating the effects of climate change on coastal fisheries.

Ocean acidification

Based on the large-scale distribution of coral reefs across the Pacific and seawater chemistry, Guinotte et al. (2003) suggested that aragonite saturation states above 4.0 were optimal for coral growth and for the development of healthy reef ecosystems, with values from 3.5 to 4.0 adequate for coral growth, and values between 3.0 and 3.5 were marginal. There is strong evidence to suggest that when aragonite saturation levels drop below 3.0 reef organisms cannot precipitate the calcium carbonate that they need to build their skeletons or shells (Langdon and Atkinson 2005).

In the PNG region, the aragonite saturation state has declined from about 4.5 in the late 18th century to an observed value of about 3.9±0.1 by 2000 (PCCSP 2011). Ocean acidification is projected to increase, and thus aragonite saturation states are projected to decrease during the 21st century (PCCSP 2011). Climate models suggest that by 2040 the annual maximum aragonite saturation state for PNG will reach values below 3.5 (the lowest saturation level considered adequate for coral growth (Guinotte et al. 2003)) and continue to decline thereafter (PCCSP 2011). These projections suggest that coral reefs of PNG will be vulnerable to actual dissolution as they will have trouble producing the calcium carbonate needed to build their skeletons. This will impact the ability of coral reefs to have net growth rates that exceed natural bioerosion rates. Increasing acidity and decreasing levels of aragonite saturation are also expected to have negative impacts on ocean life apart from corals; including calcifying invertebrates, non-calcifying invertebrates and fish. High levels of CO_2 in the water are expected to negatively impact the lifecycles of fish and large invertebrates through habitat loss and impacts on reproduction, settlement, sensory systems and respiratory effectiveness (Kurihara 2008, Munday et al. 2009a, Munday et al. 2009b). The impact of acidification change on the health of reef ecosystems is likely to be compounded by other stressors including coral bleaching, storm damage and fishing pressure (PCCSP 2011).

Projected Effects of Climate Change of Coastal Fisheries of PNG

PNG has considerable areas of corals reefs (22,000 km^2), and significant areas of mangroves, deepwater and intertidal seagrasses, and intertidal sand and mud flat habitats (Bell et al. 2011).

Climate change is expected to add to the existing local threats to the aquatic ecosystems of PNG, resulting in declines in the area and quality of all habitats (Table 6). Accordingly, all coastal fisheries categories in PNG are projected to show progressive declines in productivity due to both the direct (e.g. increased SST) and indirect effects (e.g. changes to fish habitats) of climate change (Table 7) (Bell et al. 2011).

Table 6 Projected changes in coastal fish habitat in PNG under various IPCC emission scenarios (from Bell et al. 2011)

Habitat	**Projected change (%)**		
	B1/A2 2035	**B1 2100***	**A2 2100**
Coral cover[a]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60
Seagrass area	-5 to -20	-5 to -30	-10 to -35

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

Table 7 Projected changes to coastal fisheries production in PNG under various IPCC emission scenarios (from Bell et al. 2011)

Coastal fisheries category	**Projected change (%)**		
	B1/A2 2035	**B1 2100***	**A2 2100**
Demersal fish	-2 to -5	-20	-20 to -50
Nearshore pelagic fish[a]	0	-10	-15 to -20
Targeted invertebrates	-2 to -5	-10	-20
Inter/subtidal invertebrates	0	-5	-10

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

1. Implementation of the Project in PNG

Site Selection

Manus Province, and more specifically the northern outer islands of Ahus and Andra, was selected as a pilot site for the 2012 surveys under the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project within PNG following consultations with PNG's NFA. In 2014, Onetah Island was included in the study. The three islands were selected as they offered a number of advantages as study sites, most notably:

- A SEAFRAME gauge was installed in the region in September 1994 as part of the South Pacific Sea Level and Climate Monitoring project for purposes of recording sea level rise, air temperature, water temperature, wind speed and direction and atmospheric pressure;

- Fish, invertebrate and socio-economic data were collected by SPC under the PROCFish/C project in Andra Island in 2006 (Friedman et al. 2008);

- Andra and Ahus Islands have been previously assessed by the Wildlife Conservation Society (WCS) and were one of the areas flagged for conservation action in Manus by The Nature Conservancy (TNC) in 2009 (Hamilton et al. 2009). The region is also the focus of an intergrated socio-ecological study by the ZMT in Bremen, Germany;

- In 2014 Onetah Island was officially flagged to become a marine protected area by the Ahus community in collaboration with TNC;

- Both Ahus and Andra Islands represent closed systems (people from the site fish in well-defined fishing grounds);

- The sites offer a 'natural laboratory', displaying similar physical characteristics while ranging from uninhabited (Onetah) to relatively density inhabited (Ahus);

- Non-governmental organization (NGOs) and provincial fisheries offices are located in Lorengau, the capital of Manus Province, which simplifies logistics.

Ahus, Andra and Onetah are coral islands located on the barrier reef on the northern part of the high island of Manus, located at latitude 1°55´S and longitude 146°57´E. Each island is relatively small in size, measuring approximately one kilometre long and less than 500 m wide. Travel to the islands from Lorengau (the provincial centre of Manus) takes about an hour by fibreglass speed boat, which is the principal mode of transport to these islands. The communities of Ahus and Andra are divided into clans. There is no principal chief on either island, but there are heads of clans and a village council (Friedman et al. 2008). Reef ownership is by clan. Ownership of the reef at Ahus extends from the outer-, lagoon and back-reefs surrounding the island to the mainland coastline. Ownership of the reef at Andra extends from the outer reef across the lagoons right to the mainland coastline and halfway between Ahus to the east and Ponam Island to the west, including the eastern side of Ponam reef (Figure 3). Access to the reefs is restricted to community members (Friedman et al. 2008).

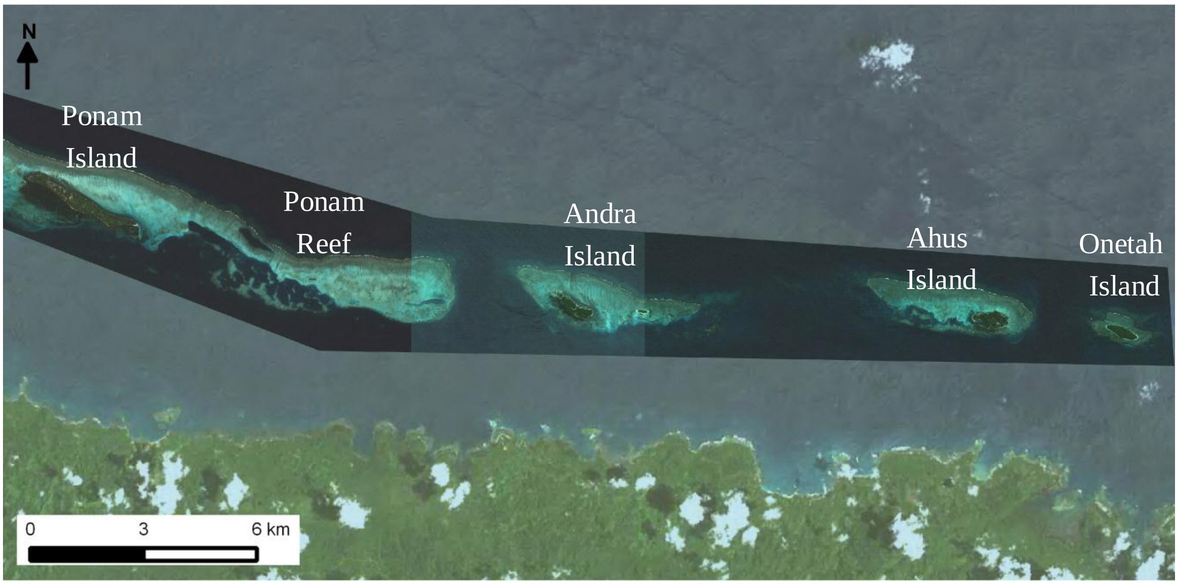


Figure 3 Northern Manus outer islands showing the study sites of Ahus and Onetah Islands and Ponam Reef (Andra Island).

Fisheries of the study region

The waters of the study region support a highly diverse fish fauna. A total of 665 individual fish species were recorded from the waters surrounding Manus Island during survey work by TNC in 2006 (Allen 2009). Subsequently, fishing is an important activity for the people of Ahus and Andra Islands. Socio-economic survey work conducted at Andra as part of the PROCFish surveys by SPC in 2006 revealed that 50% of households are dependent on fisheries as a primary income, while the remaining 50% are dependent on fisheries as a secondary income (Friedman et al. 2008). Per capita consumption of fresh fish was found to be approximately 36 kg/person/year (Friedman et al. 2009). Fishing methods vary among habitats. Most frequently, handlines and spears are used to catch fish on the sheltered coastal reefs, deep-bottom lining and trolling are the main methods used on the outer reef, and handlining, spear and collecting techniques are used in the lagoon. Fishing typically always involves a boat (100% of households on Andra own a boat); mostly paddling canoes (Friedman et al. 2008).

In late 2012, PNG's National Fisheries Authority installed a Fish Aggregating Device (FAD) off the northern coast of Andra to provide better access to pelagic stocks and reduce fishing pressure on reef habitats. This FAD was operational for under a year before breaking its mooring and being towed into the lagoon, where it remains (Figure 4).

Relative to finfish, consumption of invertebrates (edible meat weight only) on Andra is considerably lower, at approximately 6.5 kg/person/year (Friedman et al. 2009). Invertebrates are mainly harvested by women gleaning on reef-top habitats (Friedman et al. 2008). During open seasons, harvesting of sea cucumbers and trochus (*Tectus niloticus*) plays an important role in generating income. During one open season, the average catch (dry weight) of beche-de-mer per family on Andra was reported to be 100-150 kg, totalling 8.5–12.75 t (dry weight), while a total harvest of 11 t of trochus shell was reported for one two-day open season (Friedman et al. 2008).

Lime production for betel nut chewing is a significant source of income for the Andra community. Lime powder is made from hard corals (predominantly *Acropora* species), which are harvested from the reefs surrounding Andra Island (Figure 5). Lime powder is sold at the Lorengau market or to nearby villages. Branching *Porites* species are also harvested and crushed to make paths (B. Moore, *pers. obs.*).

Figure 4 The FAD in the shallows at Andra Island.

Figure 5 *Acropora* spp. corals collected for lime production on Andra Island.

Habitat Definition and Selection

Coral reefs are highly complex and diverse ecosystems. The NASA Millennium Coral Reef Mapping Project (MCRMP) has identified and classified coral reefs of the world in about 1000 categories. These very detailed categories can be used directly to try to explain the status of living resources or be lumped into more general categories to fit a study's particular needs. For the purposes of the field surveys, three general reef types were categorised:

1) Back reef slope (inner/lagoon side of outer reef/main reef body);
2) Lagoon reef (patch reefs within the lagoon); and
3) Outer reef (ocean-side of barrier reef).

Capacity Building

One of the key objectives of the project is to train local Fisheries Officers in undertaking monitoring programs and resource assessments. The activities carried out under this project were conducted in a participatory manner, with staff from PNG's NFA and Manus Provincial Fisheries involved in the original design, implementation of survey activities and analysis of resulting data. This is to build local capacity and to provide staff with the skills so regular re-assessments of the pilot sites can be carried out in the future (Figure 6).

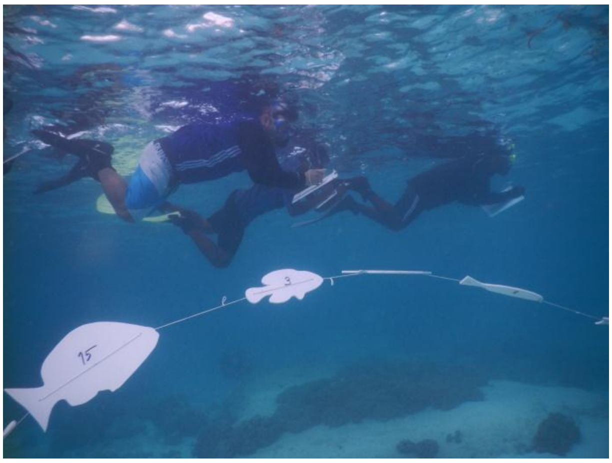


Figure 6 Members of the survey team practicing fish size estimation.

A Comparative Approach Only

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

2. Monitoring of Water Temperature

Methods

To monitor sea surface temperature at a local scale, two RBR TR1060 temperature loggers were deployed at the Ahus Island site in August 2011, with one established on the outer reef and one inside the lagoon (Figure 7; Table 8). The loggers were calibrated to an accuracy of ±0.002ºC and programmed to record temperature every five minutes. Loggers were housed in a PVC tube with holes to allow flow of water and encased in a concrete block (Figure 8). These blocks were then secured to the sea floor using rebars.

Due to obvious battery life flaws in the RBR TR1060 loggers, both of these loggers were replaced with a superior model (Sea-Bird SBE 56) on the 26th May 2012. The Sea-Bird SBE 56 loggers were housed in the original housing system. Theses loggers were then retrieved, and a second set of Sea-Bird SBE 56 loggers deployed on the outer reef and in the lagoon, in early May 2014.

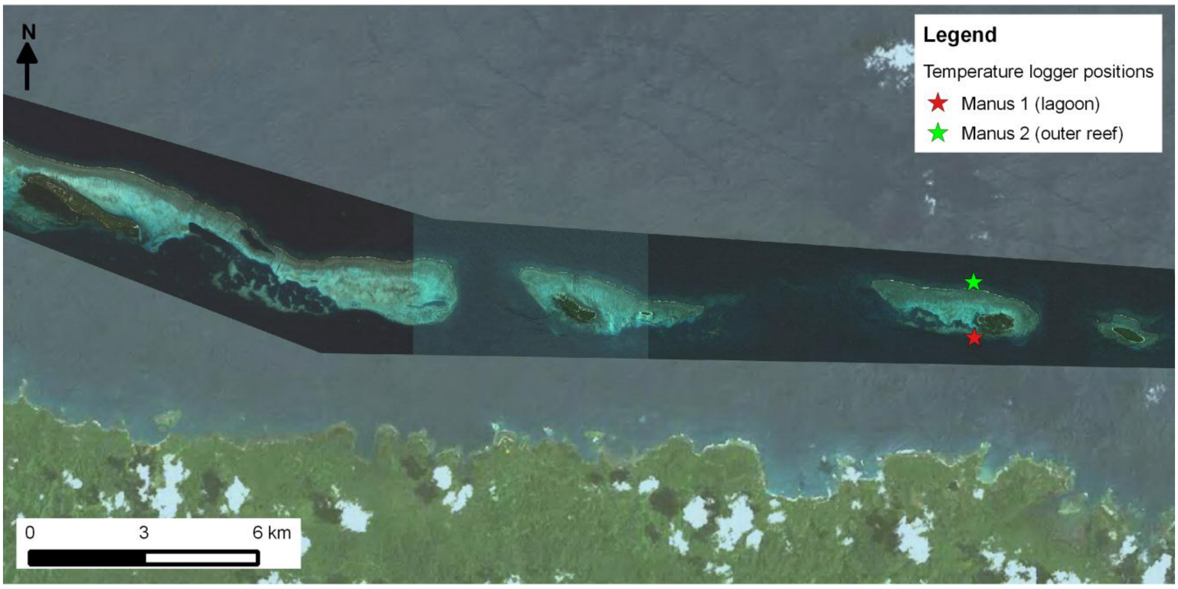
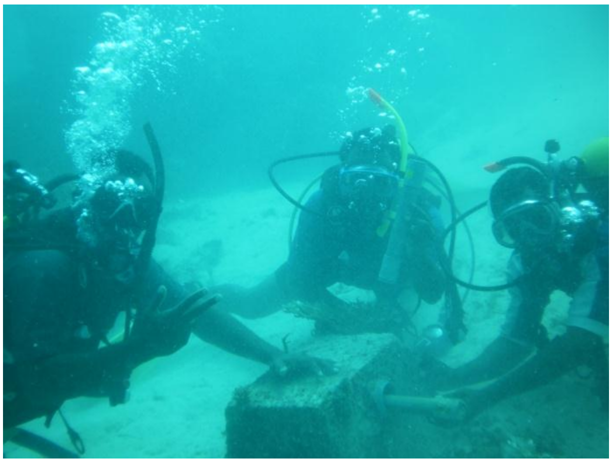


Figure 7 Locations of water temperature loggers deployed at the study site.

Table 8 Details of temperature loggers deployed at Ahus Island.

Details	Manus 1	Manus 2
Deployment date	01/08/2011	01/08/2011
Location	Ahus Island, Manus Province	Ahus Island, Manus Province
Habitat	Back reef inside lagoon	Outer reef
Longitude (E)	147.096533	147.096366
Latitude (S)	1.945	1.9318166
Depth	10 m	10 m

Figure 8 NFA and Manus provincial fisheries staff replacing the temperature logger in the lagoon of Ahus Island.



Results

Both RBR TR1060 loggers collected temperature data for approximately 3 months before failing. These loggers have subsequently been removed. In contrast, the Seabird SBE 56 loggers collected water temperature data continuously on both the outer reef and within the lagoon from their deployment in late May 2012 to their retrieval in May 2014.

Both loggers showed high correlation in water temperatures of the outer reef and lagoon (Figure 9). Water temperatures were typically highest around the austral summer. Average daily water temperatures in 2013 were generally higher than any other year on both the outer reef and in the lagoon. A drop in temperature was recorded by both loggers in Feb-March 2014 (Figure 9).

On the outer reef, a maximum average daily temperature of 30.49°C was recorded on the 28th November 2013; while a minimum average daily water temperature of 28.13°C was recorded on the 8th March 2014. The maximum temperature recorded over the collection period was 30.66°C, reached on 15th December 2013. The minimum temperature recorded over the collection period was 28.10°C, reached on 9th March 2014.

In the lagoon, a maximum average daily temperature of 30.54°C was recorded on the 2nd December 2013; while a minimum average daily water temperature of 27.99°C was recorded on the 8th March 2014. The maximum temperature recorded over the collection period was 30.82°C, reached on 3rd December 2013. The minimum temperature recorded over the collection period was 27.70°C, reached on 7th March 2014.

Loggers will be continuously retrieved and re-deployed to maintain water temperature monitoring within the study region.

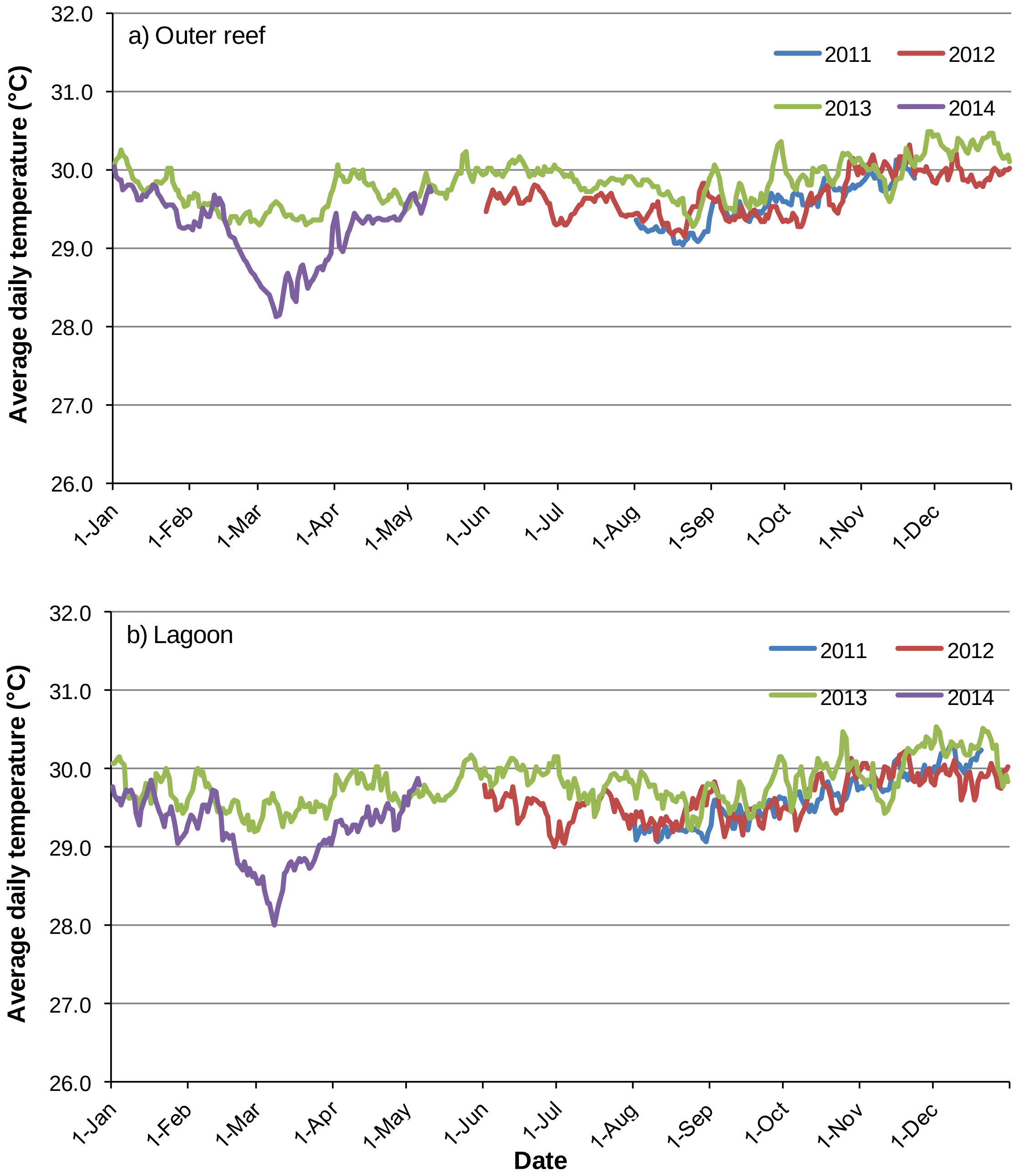


Figure 9 Mean daily water temperature in the a) outer-reef and b) lagoon at Ahus Island. See Figure 6 for logger locations.

3. Finfish Assessments

Methods

Data collection

Fish on reef habitats were surveyed using distance-sampling underwater visual census (D-UVC) methodology. Finfish assessments were conducted at each of the three sites within the study region: Ponam Reef (hereafter termed Andra monitoring site), Ahus Island (Ahus monitoring site) and Onetah Island (Onetah monitoring site), with two stations established in each site. At the Ahus and Andra sites, finfish assessments focused on three habitats (back reefs, lagoon reefs and outer reefs), while back reefs and outer reefs only were examined at Onetah. Three replicate 50 m transects were surveyed in each habitat at each station, resulting in 6 transects per habitat at each site (Appendix 1). Each transect was completed by two SCUBA divers who recorded the species name, abundance and length of all fish observed (Appendix 2). The distance of the fish from the transect line was also recorded (Figure 11). Two distance measurements were recorded for a school of fish belonging to the same species and size (D1 and D2; Figure 11), while for individual fish only one distance was recorded (D1). Every effort was made to ensure that the survey took place under the same tidal state and moon phase as the baseline survey. Regular review of identification books and cross-checks between divers after the dive ensured that accurate and consistent data were collected. Following collection, all data were reviewed. Data considered unreliable were removed from the dataset prior to analysis.

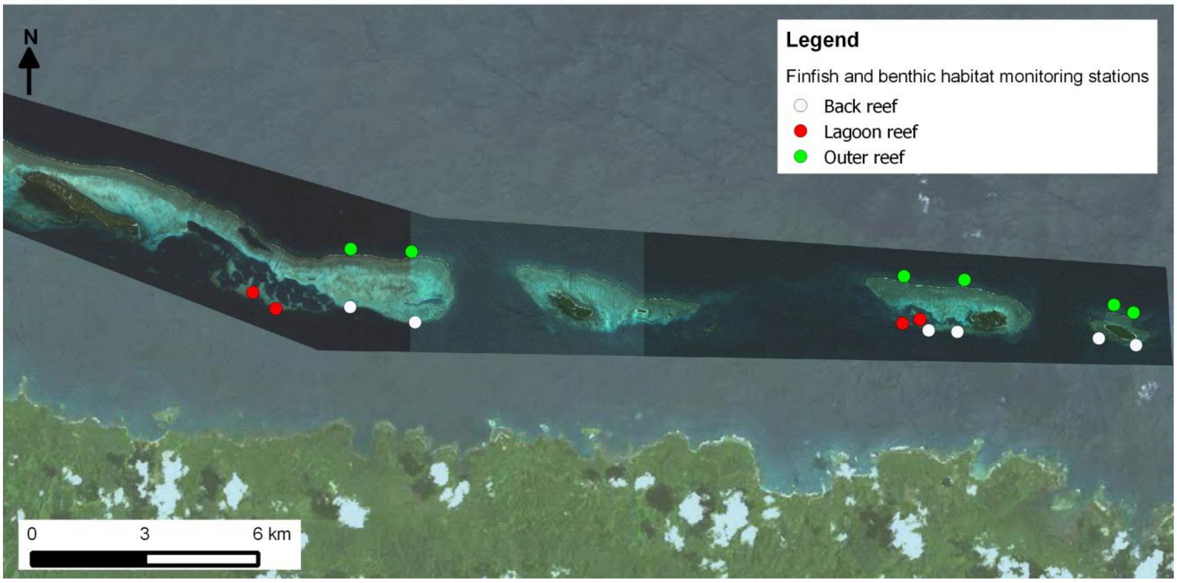


Figure 10 Location of finfish and benthic habitat assessment stations at the study site. Note three replicate transects were surveyed in the vicinity of each point. A list of GPS coordinates for each transect is presented as Appendix 1.

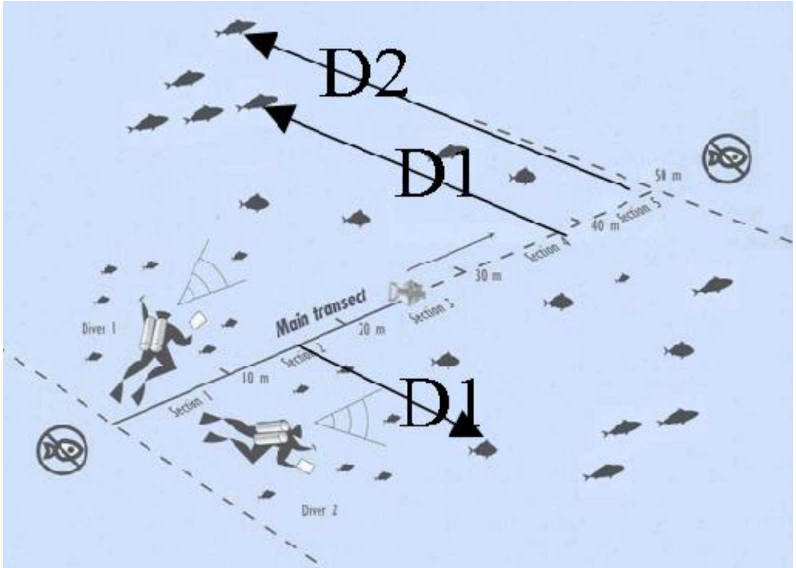


Figure 11 Diagrammatic portrayal of the D-UVC method.

Habitats supporting finfish[1]

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

The substrate types were grouped into the following six categories:

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

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

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

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

Data processing and analysis

Finfish surveys

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

1) richness – the number of families, genera and species counted in D-UVC transects;
2) diversity – mean number of species observed per transect (± SE);
3) mean density (fish/100 m^2) and mean biomass (g/m^2) – estimated from fish abundance in D-UVC, calculated at a total, functional group, family and individual species level.

Indicator families and assignment of functional groups

While all observed finfish species were recorded, including both commercial and non-commercial species, for the purposes of this report analyses at a family level are based on data for 18 selected families, namely Acanthuridae, Balistidae, Chaetodontidae, Ephippidae, Haemulidae, Holocentridae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Mullidae, Nemipteridae, Pomacanthidae, Pomacentridae, Scaridae, Serranidae, Siganidae and Zanclidae. These families were selected as they comprise the dominant finfish families of tropical reefs (and are thus most likely to indicate changes where they occur), and constitute species with a wide variety of trophic and habitat requirements. Other families abundant on reefs, such as Blennidae and Gobiidae, were not analysed due to the difficulties in enumerating these cryptic species.

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

1) Macro-carnivores / Piscivores (feed predominantly on mobile benthic organisms and fish) (e.g. some members of the Lethrinidae, Lutjanidae, Serranidae);
2) Micro-carnivores (feed predominantly on small benthic organisms and ecto-parasites) (e.g. some members of the Labridae, Chaetodontidae);
3) Corallivores (feed predominantly on coral polyps) (e.g. Chaetodontidae);
4) Planktivores (feed predominantly on macro- and micro-zooplankton, including both diurnal and nocturnal species) (e.g. some members of the families Acanthuridae, Apogonidae, Chaetodontidae, Holocentridae, Pomacentridae and Serranidae);
5) Scraping / excavating herbivores (roving herbivores that feed on turf algae, and remove reef substratum as they feed. Members of this group play a key role in coral reef resilience by limiting the establishment of macroalgae, intensely grazing turf algae and providing areas of clean substratum for coral recruitment) (e.g. members of the Scaridae);
6) Detritivores / Grazing herbivores (roving herbivores that feed on turf algae, but do not scrape or excavate the reef substrate as they feed) (e.g. some members of the families Acanthuridae, all Siganidae except *Siganus canaliculatus*);

7) Browsing herbivores (roving herbivore that tends to bite or 'crop' algae leaving the basal portions and substrate intact. Browsers play an important role in reef resilience by reducing coral overgrowth and shading by macroalgae, and can play a key role in reversing coral-algal regime shifts) (e.g. some members of the Acanthuridae, *Siganus canaliculatus*); and
8) Territorial / farming herbivores (feed predominantly on algae within small territories. Considered to have a negative influence on coral recruitment by allowing algae to grow and out-compete coral recruits for space) (e.g. some members of the Pomacentridae).

To account for differences in visibility among sites and habitats, only fish recorded within five metres of the transect line were included in the analysis. Summary graphs of mean density and mean biomass (±SE) for each site were generated to further explore patterns in total mean density and mean density of the 18 indicator families and eight functional groups by habitat and survey year. To test for differences among surveys, sites and habitats, total, family-specific and functional group-specific density and biomass data for each individual transect were ln(x+1) transformed to reduce heterogeneity of variances and analysed by a series of two-way permutational multivariate analysis of variance (PERMANOVA) at $P = 0.05$, using Primer 6.1.13, with site+survey year (e.g. Ahus 2012, Ahus 2014) and habitat (back reef, lagoon reef and outer reef) as fixed factors in the analysis. This procedure uses permutations to test for significant differences among factors and therefore does not assume data normality or homogeneity of variances (Anderson et al. 2008). PERMANOVA analyses were based on Euclidean distances and an unrestricted number of permutations of the data.

Results

Ahus monitoring site

Finfish assemblages within the Ahus site have been monitored at three habitats to date. Back and outer reef habitats were surveyed in both 2012 and 2014, while the finfish assemblages of lagoon reef habitats were surveyed for the first time in 2014 (Appendix 1).

Finfish diversity within the Ahus site was higher during the 2014 survey relative to 2012 for all habitats examined (Table 9). The consistency of this result across all habitats and sites (see also the results for Andra below) suggests this increase potentially reflects greater experience within the survey team rather than a true increase in diversity. In terms of functional groups, browsing herbivores were absent on back reef transects in the 2012 survey, while all habitats showed high functional group diversity in 2014, with all functional groups represented (Table 9).

Table 9 Total number of families, genera and species, and diversity of finfish observed at back, lagoon and outer reef habitats of the Ahus site, 2012 and 2014.

Parameter	Back-reef		Lagoon-reef		Outer-reef	
	2012	2014	2012	2014	2012	2014
No. of families	20	24	-	17	16	26
No. of genera	53	70	-	58	43	73
No. of species	114	172	-	158	84	189
Diversity	46.2±3.3	77.0±6.1	-	62.0±9.5	36.0±1.8	79.7±8.0
Functional groups	7/8	8/8	-	8/8	8/8	8/8

At Ahus, mean total density and biomass of finfish on back reef transects was similar in 2014 to that observed in 2012 (Figure 12; Figure 13). On the outer reef, both mean total density and mean total biomass appeared significantly higher in 2014 relative to 2012 (Figure 12; Figure 13, Appendix 4).

Back reefs

Finfish communities on the back reef transects of the Ahus site were characterised predominantly by Pomacentridae (damselfishes), Acanthuridae (surgeonfishes), Scaridae (parrotfishes) and Labridae (wrasses) in both the 2012 and 2014 surveys (Figure 14–Figure 19). Few differences were observed in density or biomass of the 18 key finfish families on back reef transects at Ahus amongst surveys, with densities and biomass of the families Acanthuridae, Ephippidae (batfish), Haemulidae (sweetlips), Holocentridae (soldierfish and squirrelfish), Kyphosidae (drummers), Labridae, Lethrinidae (emperors), Lutjanidae (snappers), Mullidae (goatfish), Nemipteridae (coral breams), Pomacanthidae (angelfish), Pomacentridae, Serranidae (groupers), Siganidae (rabbitfish) and Zanclidae (Moorish Idol) all appearing similar in 2012 and 2014 (Figure 16; Figure 17). Both mean density and mean biomass of Balistidae (triggerfish) and Scaridae, and density of butterflyfish (Chaetodontidae), were slightly, yet significantly, higher in 2014 than 2012 (Figure 16; Figure 17; Appendix 4). Accordingly, at a functional group level, density and biomass of scraping herbivores, and densities of corallivores and micro-carnivores, appeared higher in 2014 than 2012 (Figure 20; Figure 21; Appendix 4).

Lagoon reefs

Lagoon (patch) reefs at the Ahus site were monitored for the first time in 2014. Finfish communities appeared similar to back reef habitats, and were characterised predominantly by the families Pomacentridae, Acanthuridae, Scaridae and Labridae (Figure 16; Figure 17).

Outer reefs

In contrast to back reefs, a number of differences were observed in density and/or biomass of the 18 key finfish families on outer reef transects. Both mean density and mean biomass of Acanthuridae, Mullidae, Pomacentridae and Scaridae appeared higher in 2014 relative to 2012 (Appendix 4). Mean density of Balistidae and Lutjanidae, and mean biomass of Holocentridae, Labridae, Nemipteridae, Pomacanthidae, and Zanclidae all appeared higher in 2014 than 2012 (Figure 16; Figure 17; Appendix 4). No differences were observed in either mean density or mean biomass of the families Chaetodontidae, Ephippidae, Haemulidae, Kyphosidae, Lethrinidae, Serranidae or Siganidae on the outer reef habitats at Ahus among surveys (Figure 16; Figure 17). At a functional group level, mean densities of detritivores, macro-carnivores, micro-carnivores, planktivores and scraping herbivores, and mean biomass of all eight functional groups, were higher in 2014 than 2012 (Figure 18; Figure 19; Appendix 4).

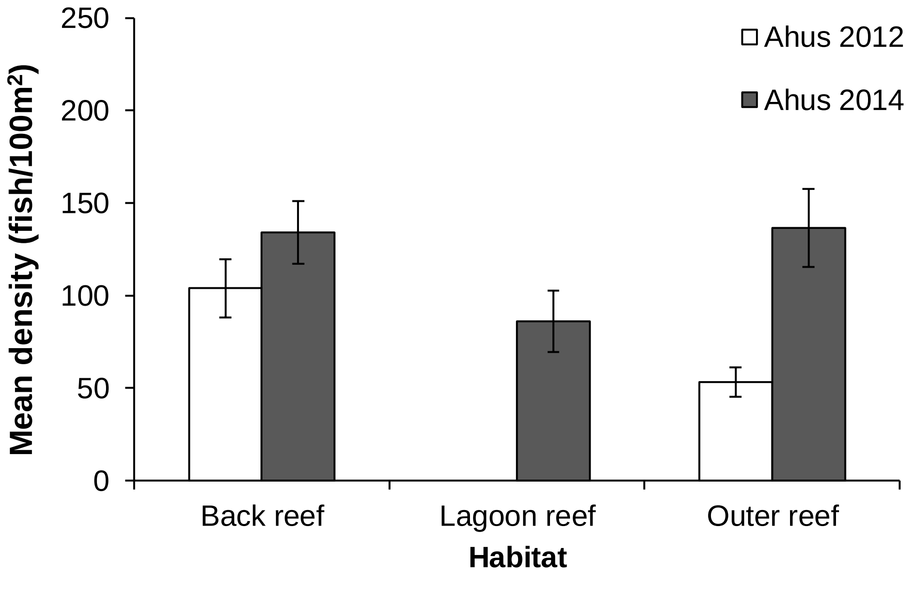


Figure 12 Mean total density of finfish (±SE) on back, lagoon and outer reef transects within the Ahus monitoring site, 2012 and 2014.

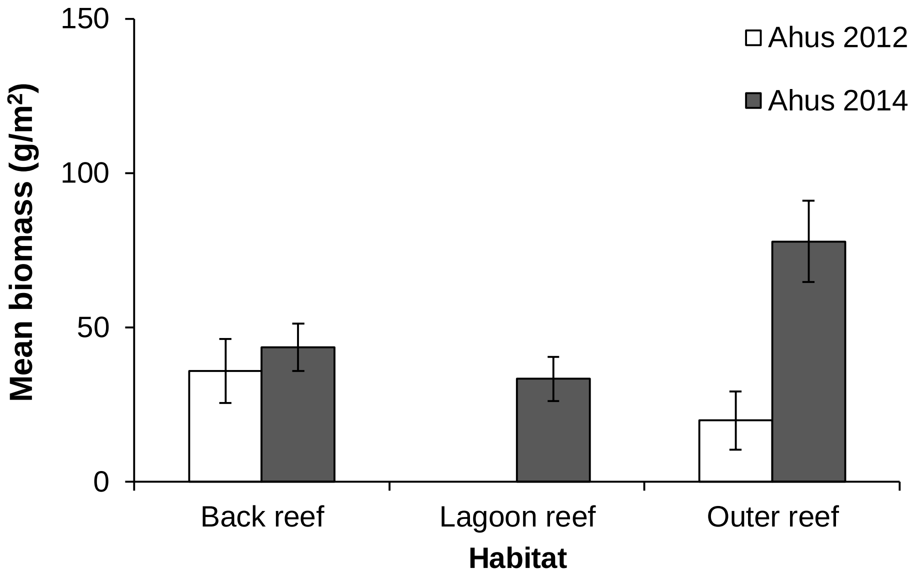


Figure 13 Mean total biomass of finfish (±SE) on back, lagoon and outer reef transects within the Ahus monitoring site, 2012 and 2014.

Figure 14 Wrasses such as *Halichoeres hortulanus* were a common sight on the back reefs of the Ahus site.

Figure 15 Striped monocle breams (*Scolopsis lineatus*) and brushtail tangs (*Zebrasoma scopas*) on the back reef of the Ahus site.

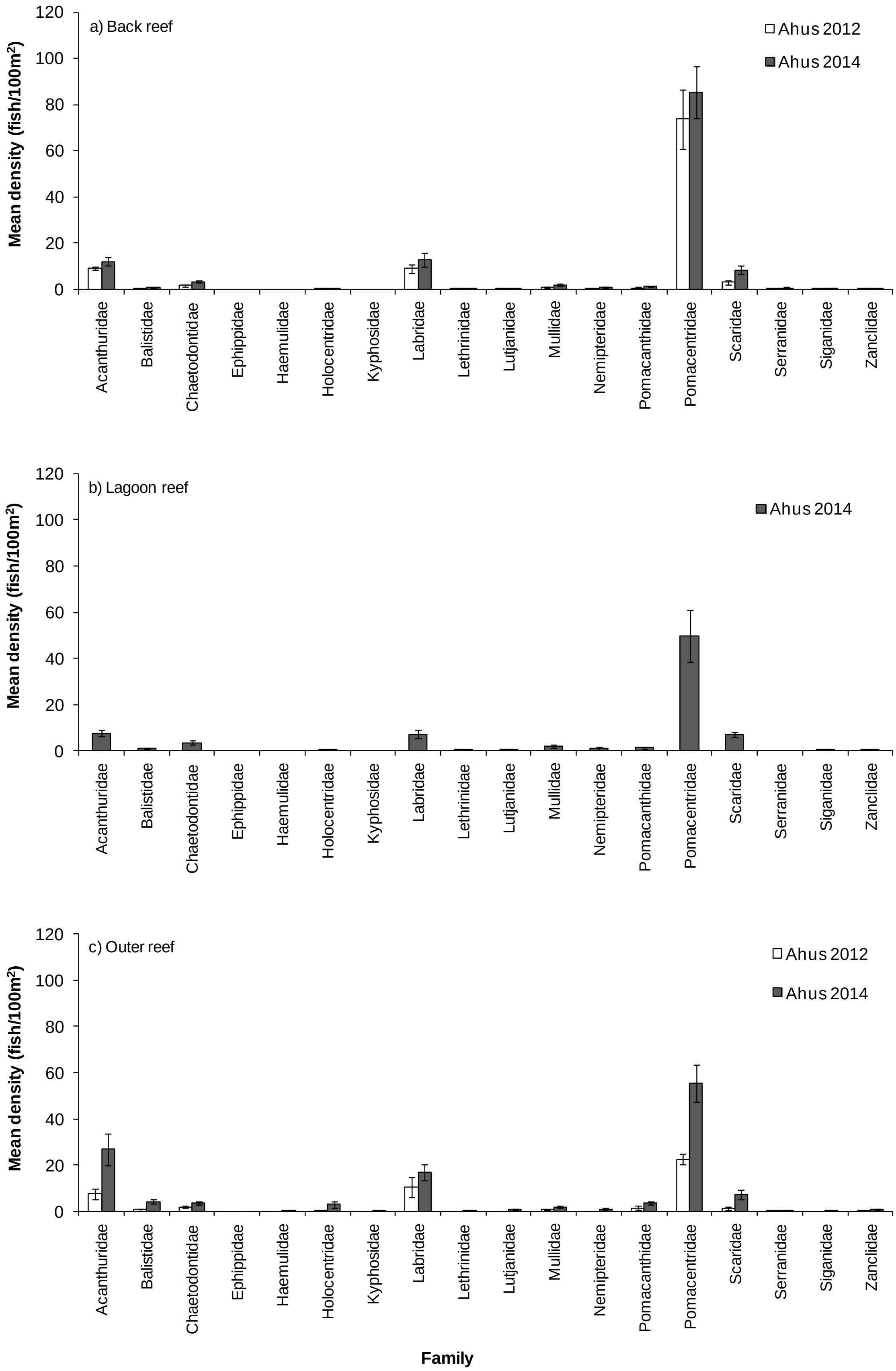


Figure 16 Mean density (±SE) of 18 indicator finfish families among a) back, b) lagoon and c) outer reef habitats of the Ahus site during the 2012 and 2014 surveys.

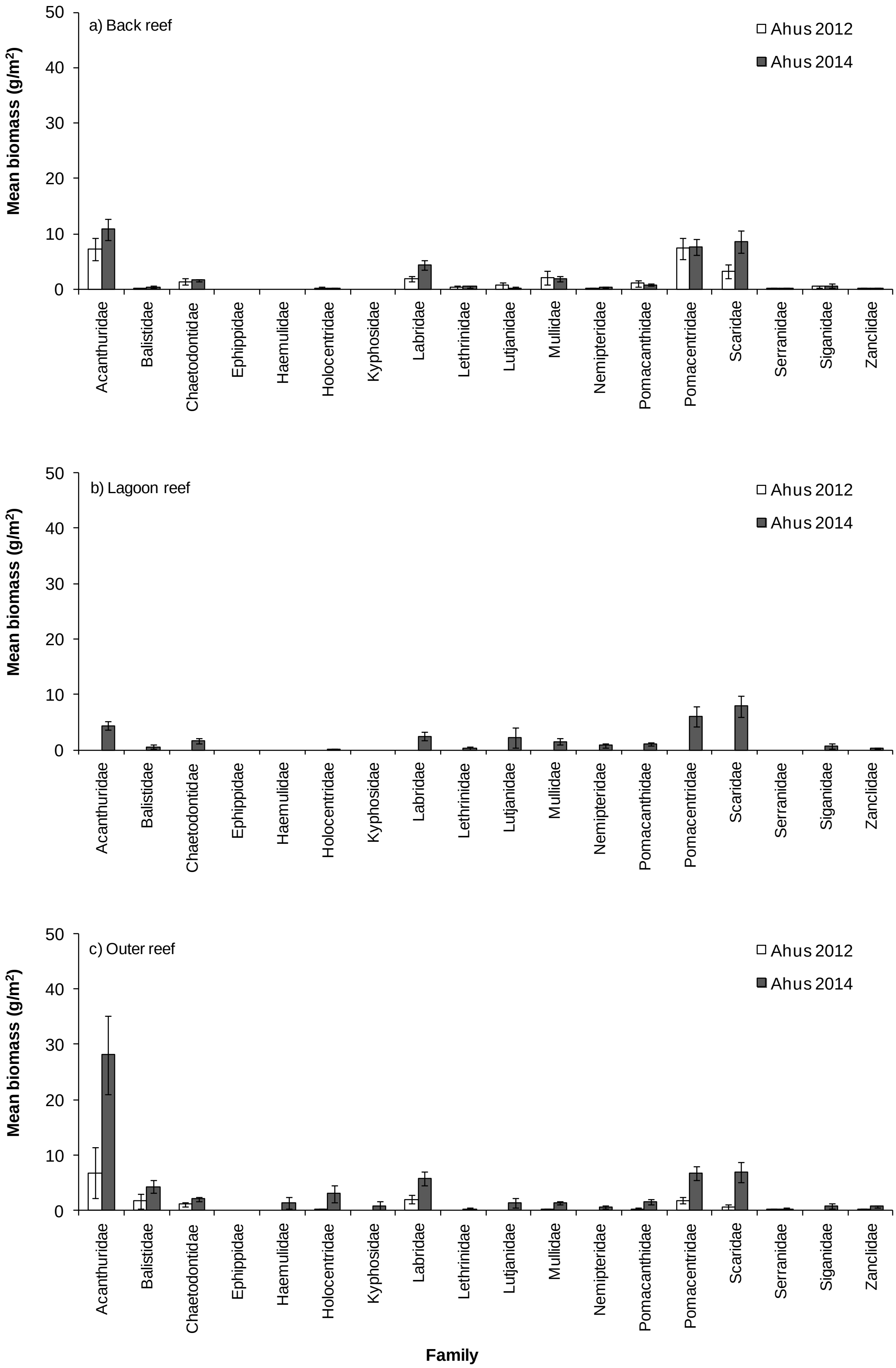


Figure 17 Mean biomass (±SE) of 18 indicator finfish families among a) back, b) lagoon and c) outer reef habitats of the Ahus site during the 2012 and 2014 surveys.

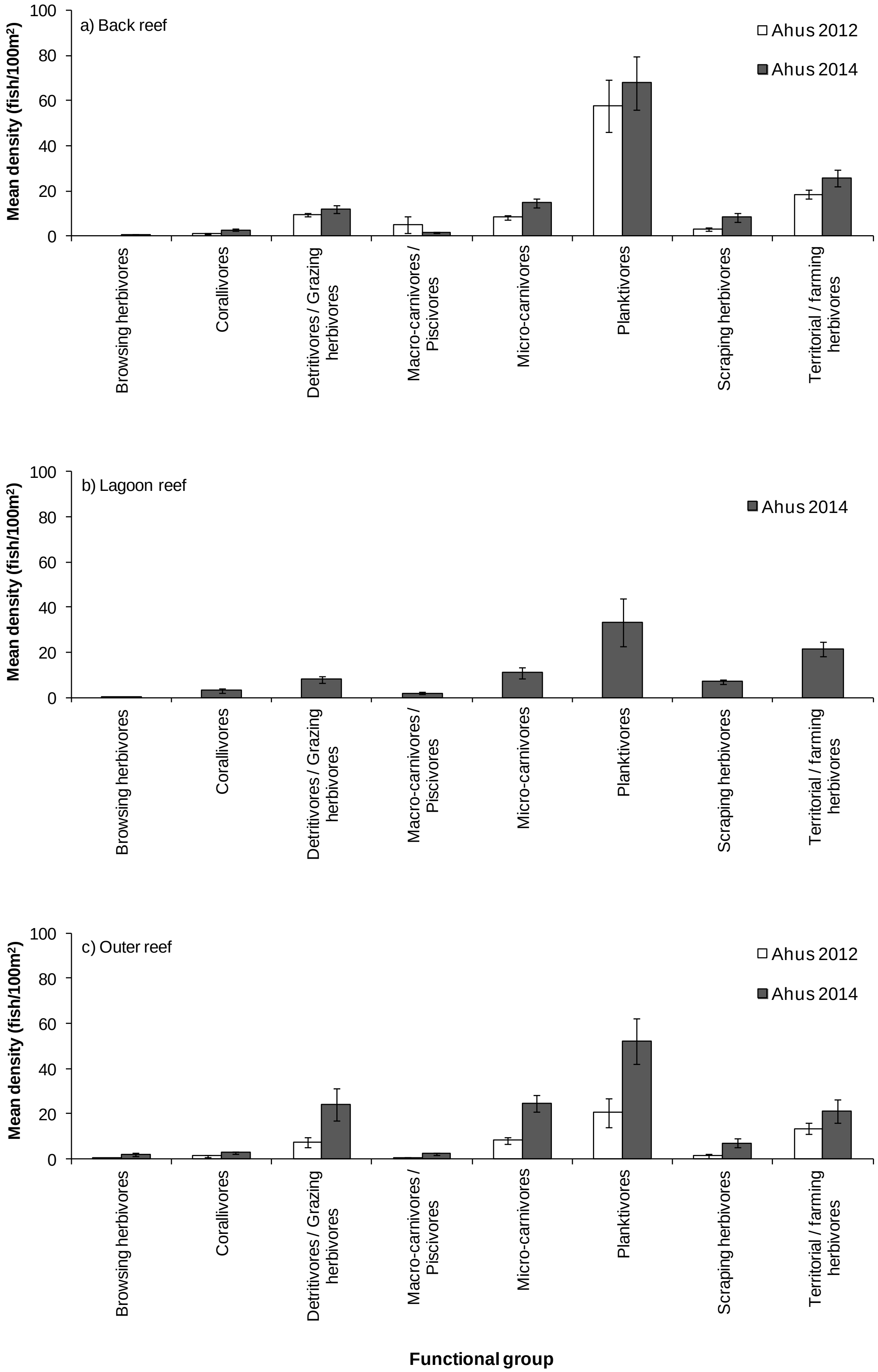


Figure 18 Mean density (±SE) of the eight functional groups among a) back, b) lagoon and c) outer reef habitats of the Ahus site during the 2012 and 2014 surveys.

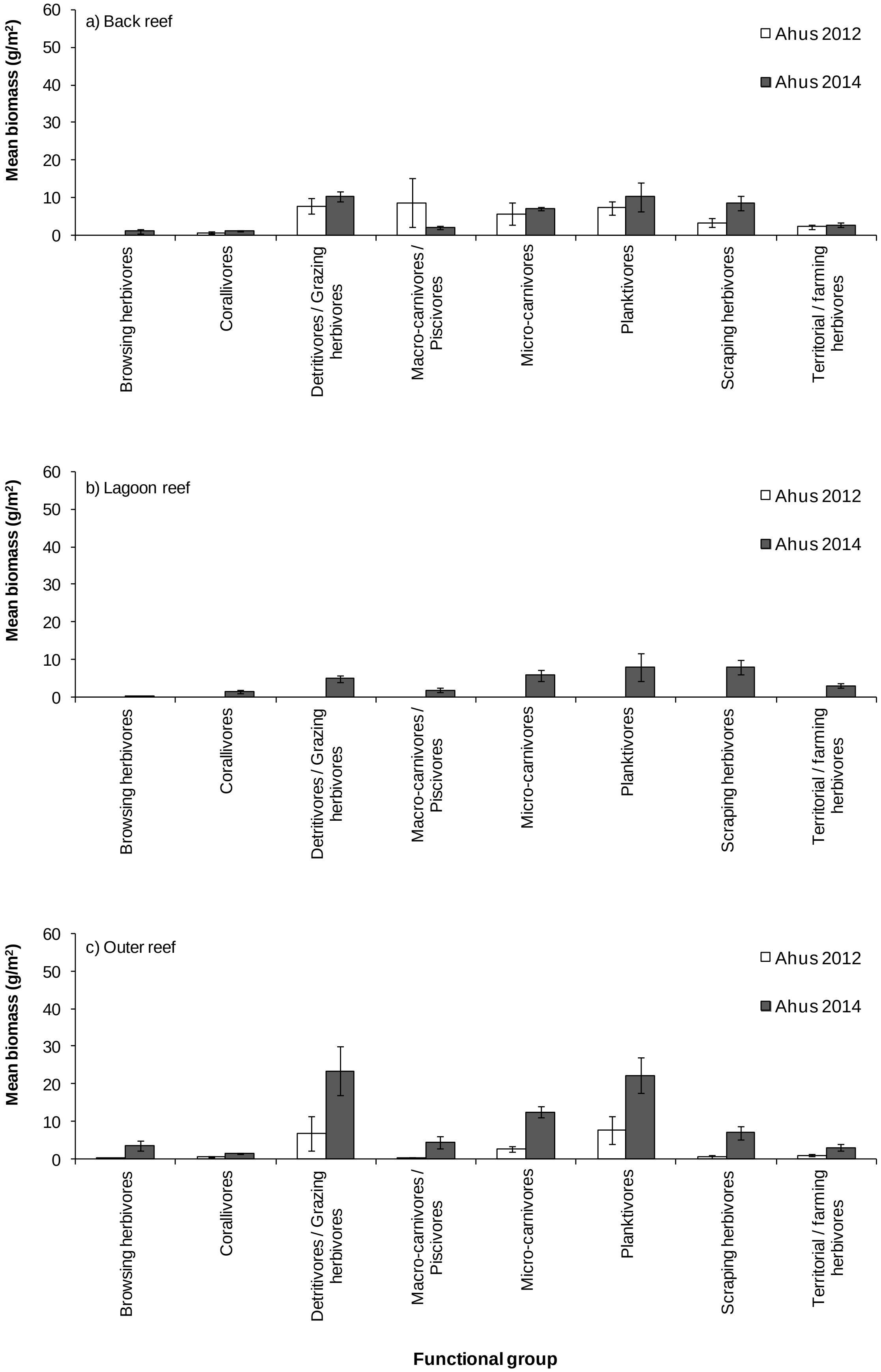


Figure 19 Mean biomass (±SE) of the eight functional groups among a) back, b) lagoon and c) outer reef habitats of the Ahus site during the 2012 and 2014 surveys.

Andra monitoring site

Finfish assemblages of the Andra site have been monitored at three habitats to date, with back reef, lagoon reef and outer reef habitats surveyed in both the 2012 and 2014 surveys (Appendix 1).

As with Ahus, finfish diversity within the Andra site was higher during the 2014 survey relative to 2012 for all habitats examined (Table 10). Browsing herbivores were absent from back reef and outer reef transects in 2012. In 2014 all habitats showed high functional group diversity, with all functional groups represented (Table 9).

Table 10 Total number of families, genera and species, and diversity of finfish observed at back, lagoon and outer reef habitats of the Andra site, 2012 and 2014.

Parameter	Back-reef		Lagoon-reef		Outer-reef	
	2012	2014	2012	2014	2012	2014
No. of families	20	25	23	22	19	28
No. of genera	53	66	54	60	52	80
No. of species	114	182	121	160	106	192
Diversity	51.8±3.8	83.0±7.7	45.8±4.0	64.3±6.2	44.3±4.4	81.0±7.8
Functional groups	7/8	8/8	8/8	8/8	7/8	8/8

Back reefs

Mean total density and biomass of finfish on back reef transects of the Andra site in 2014 was similar to that observed in 2012 (Figure 20; Figure 21). Few differences were observed in density or biomass of the 18 key finfish families on back reef transects at Ahus amongst surveys, with densities and biomass of the families Acanthuridae, Ephippidae, Haemulidae, Holocentridae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Nemipteridae, Pomacentridae, Scaridae and Zanclidae all appearing similar in 2012 and 2014 (Figure 22; Figure 23). Both mean density and mean biomass of Balistidae, Chaetodontidae and Siganidae were significantly higher in 2014 than 2012 (Figure 22; Figure 23; Appendix 4). Densities of Pomacanthidae and Serranidae, and biomass of Mullidae, appeared slightly higher in 2014 than 2012 (Figure 22; Figure 23; Appendix 4). In terms of functional groups, densities and biomass of corallivores appeared higher in 2014 than 2012, while all other functional groups appeared similar amongst surveys (Figure 24; Figure 25).

Lagoon reefs

As with back reef habitats, mean total density and biomass of finfish resources on lagoon reef transects was similar in 2014 to that observed in 2012 (Figure 12; Figure 13). No differences were detected in the density or biomass of any of the 18 indicator families or eight functional groups (Figure 22–Figure 25). Pomacentridae, Acanthuridae and Scaridae were the dominant families in terms of both density and biomass on these transects.

Outer reefs

On the outer reef, both mean total density and mean total biomass appeared significantly higher in 2014 relative to 2012 (Figure 12; Figure 13). Consistent with other habitats, few differences were observed in the density or biomass of the 18 indicator finfish families on the outer reef transects at the Andra site. Both mean density and mean biomass of Nemipteridae, Pomacanthidae, Pomacentridae and Scaridae were significantly higher in 2014 relative to 2012. In terms of functional groups, both mean density and mean biomass of browsing herbivores, corallivores, micro-carnivores, planktivores and scraping herbivores appeared significantly higher on outer reef transects in 2014 compared to those in 2012 (Figure 24; Figure 25; Appendix 4).

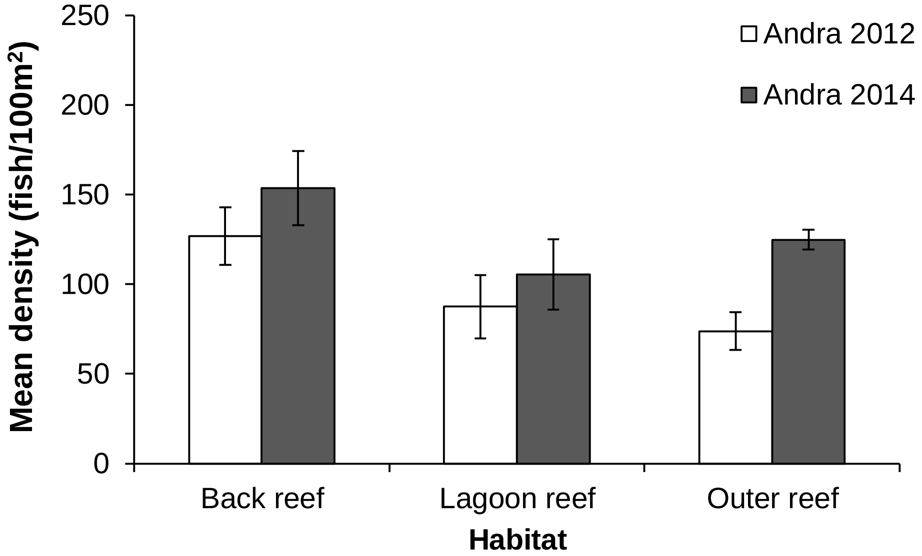


Figure 20 Overall mean density of finfish (±SE) within reef flat, back, lagoon and outer reef habitats within the Andra monitoring site, 2012 and 2014.

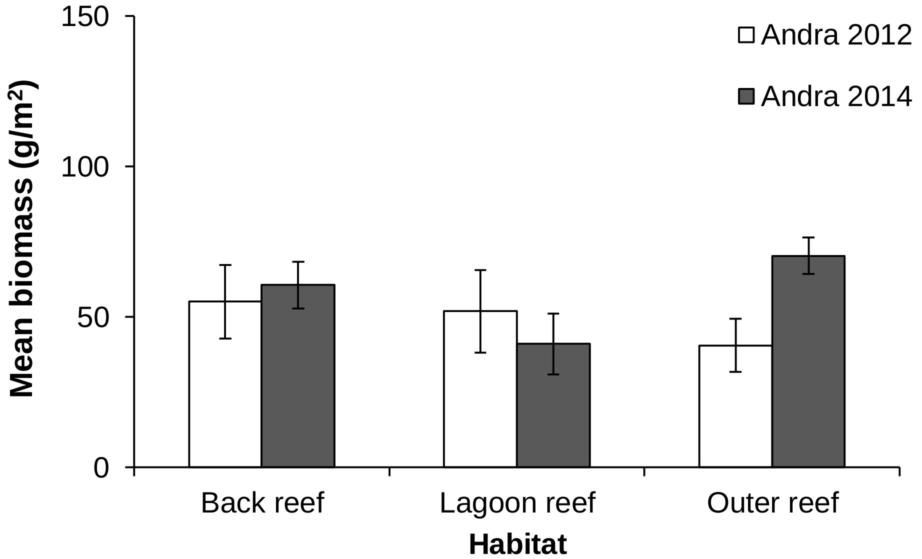


Figure 21 Overall mean biomass of finfish (±SE) within back, lagoon and outer-reef habitats within the Andra monitoring site, 2012 and 2014.

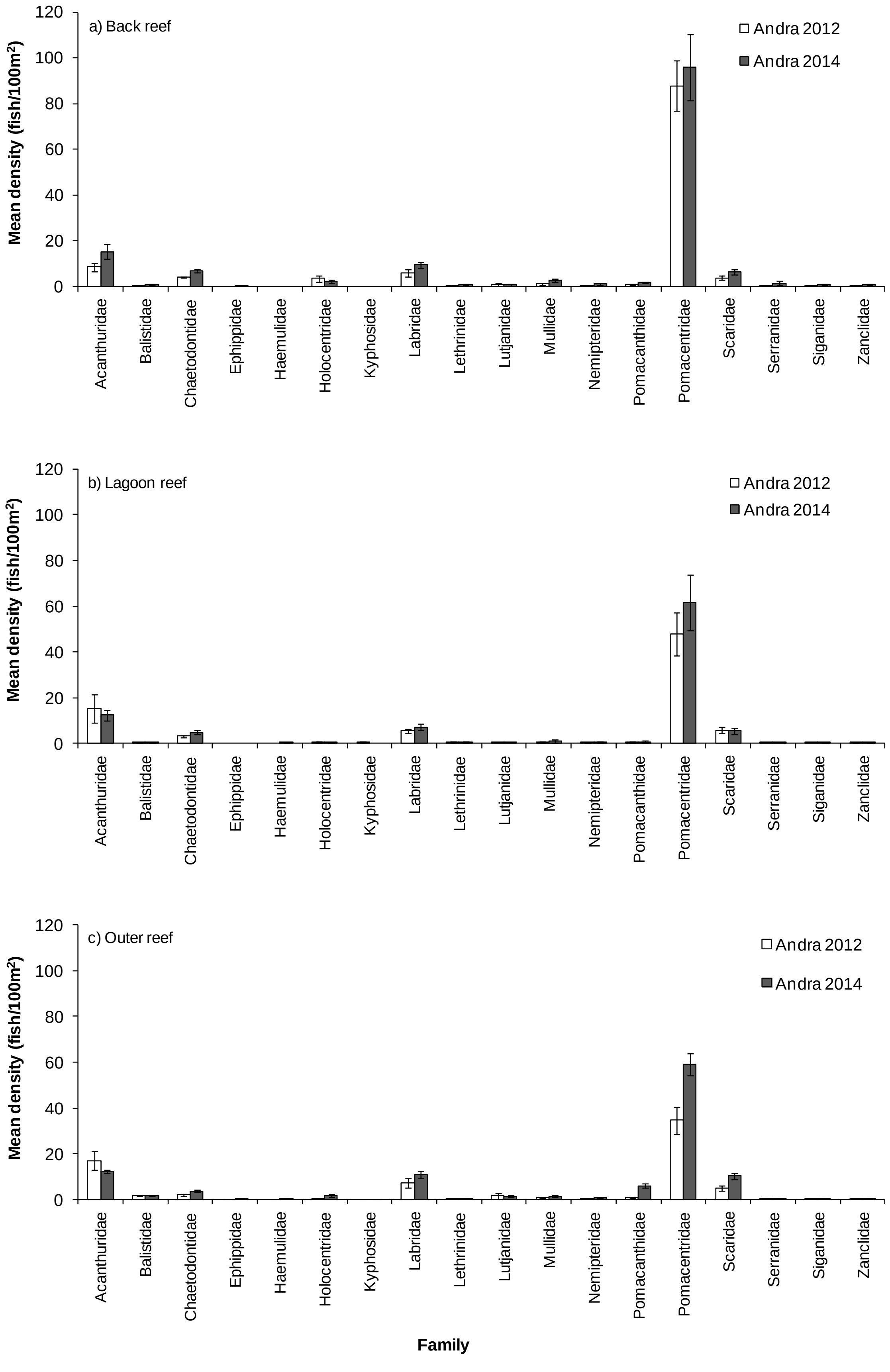


Figure 22 Mean density (±SE) of 18 indicator finfish families among a) back, b) lagoon and c) outer reef habitats of the Andra site during the 2012 and 2014 surveys**.**

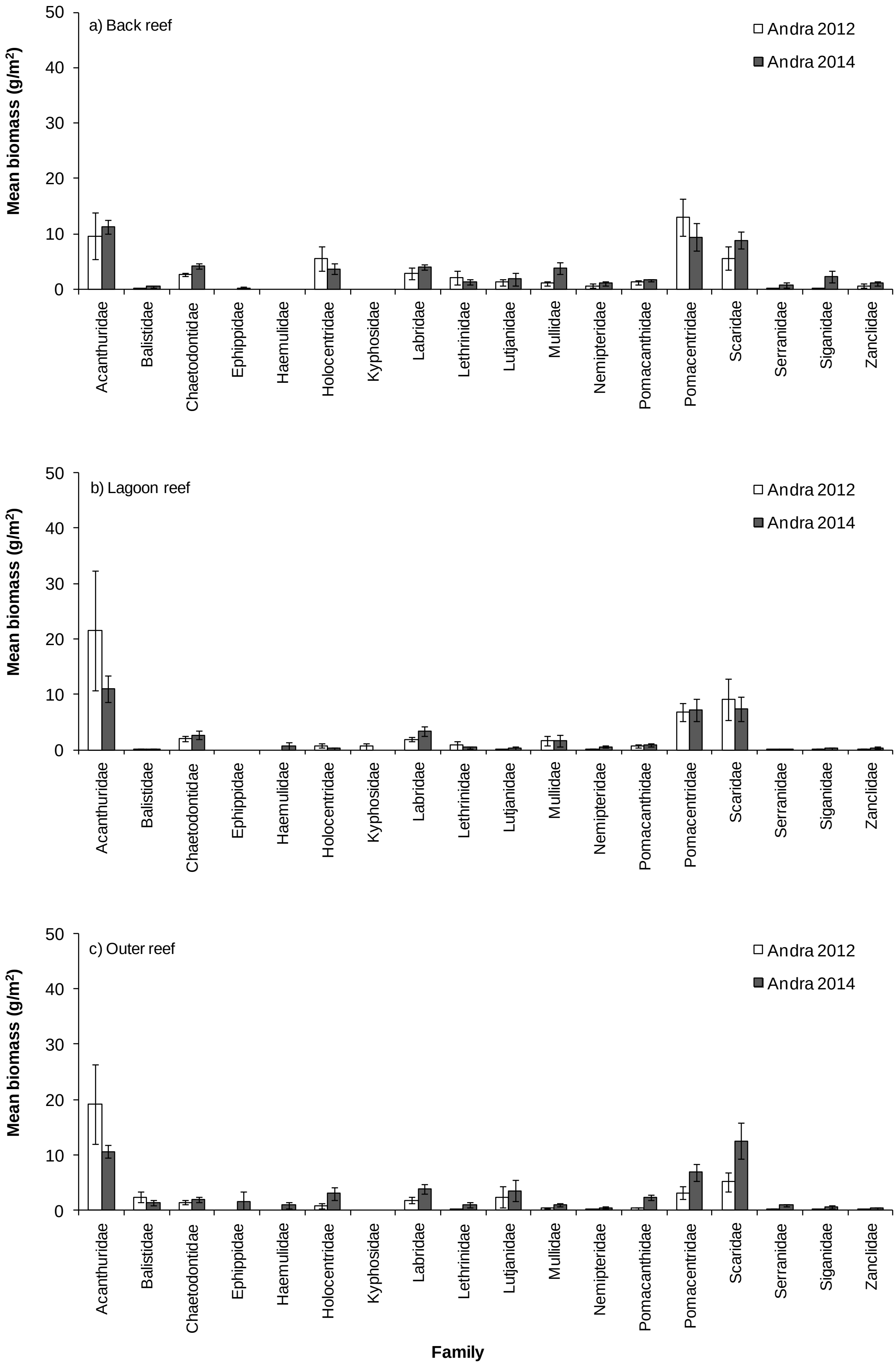


Figure 23 Mean biomass (±SE) of 18 indicator finfish families among a) back, b) lagoon and c) outer reef habitats of the Andra site during the 2012 and 2014 surveys**.**

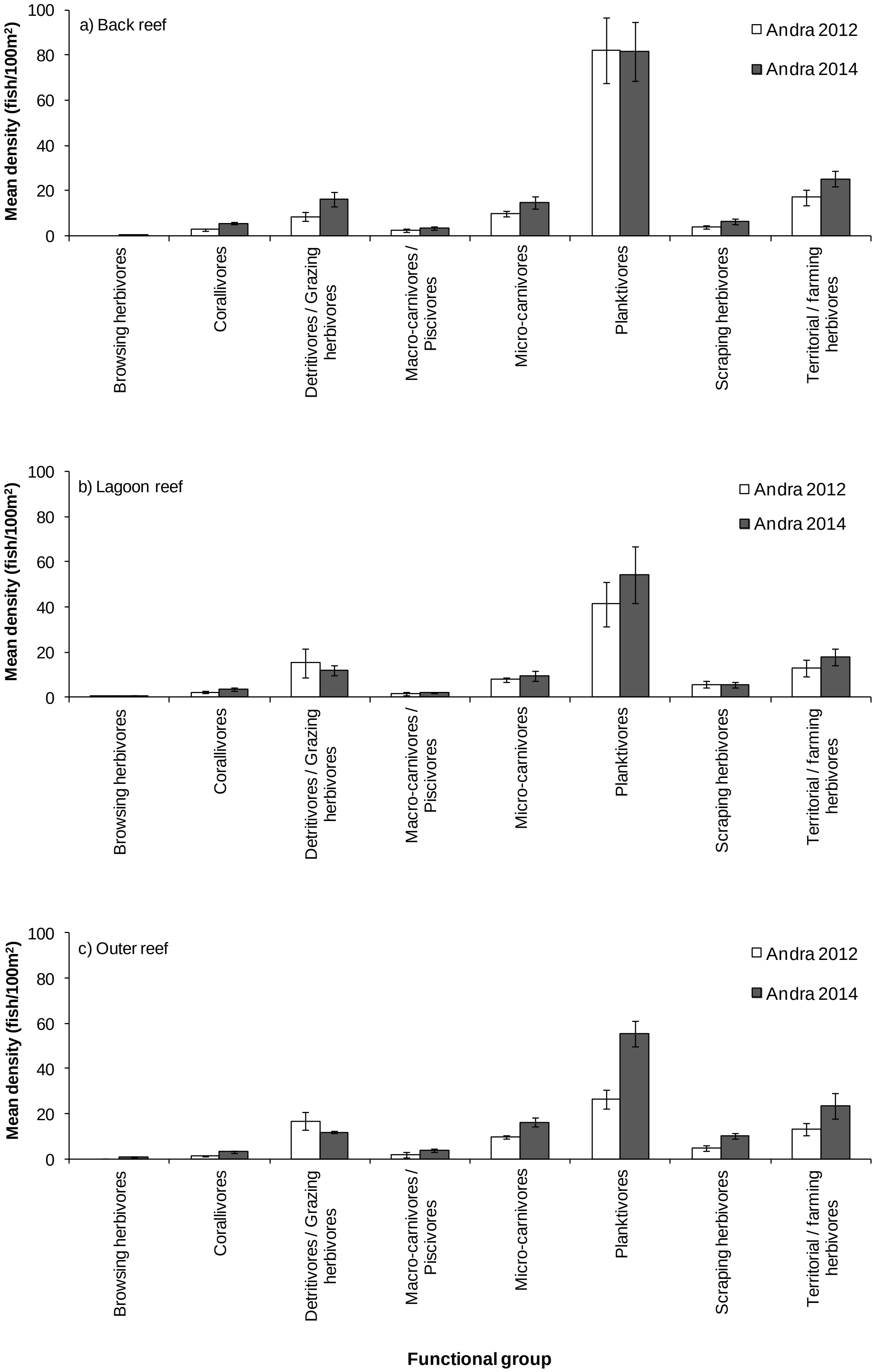


Figure 24 Mean density (±SE) of the eight functional groups among a) back, b) lagoon and c) outer reef habitats of the Andra site during the 2012 and 2014 surveys.

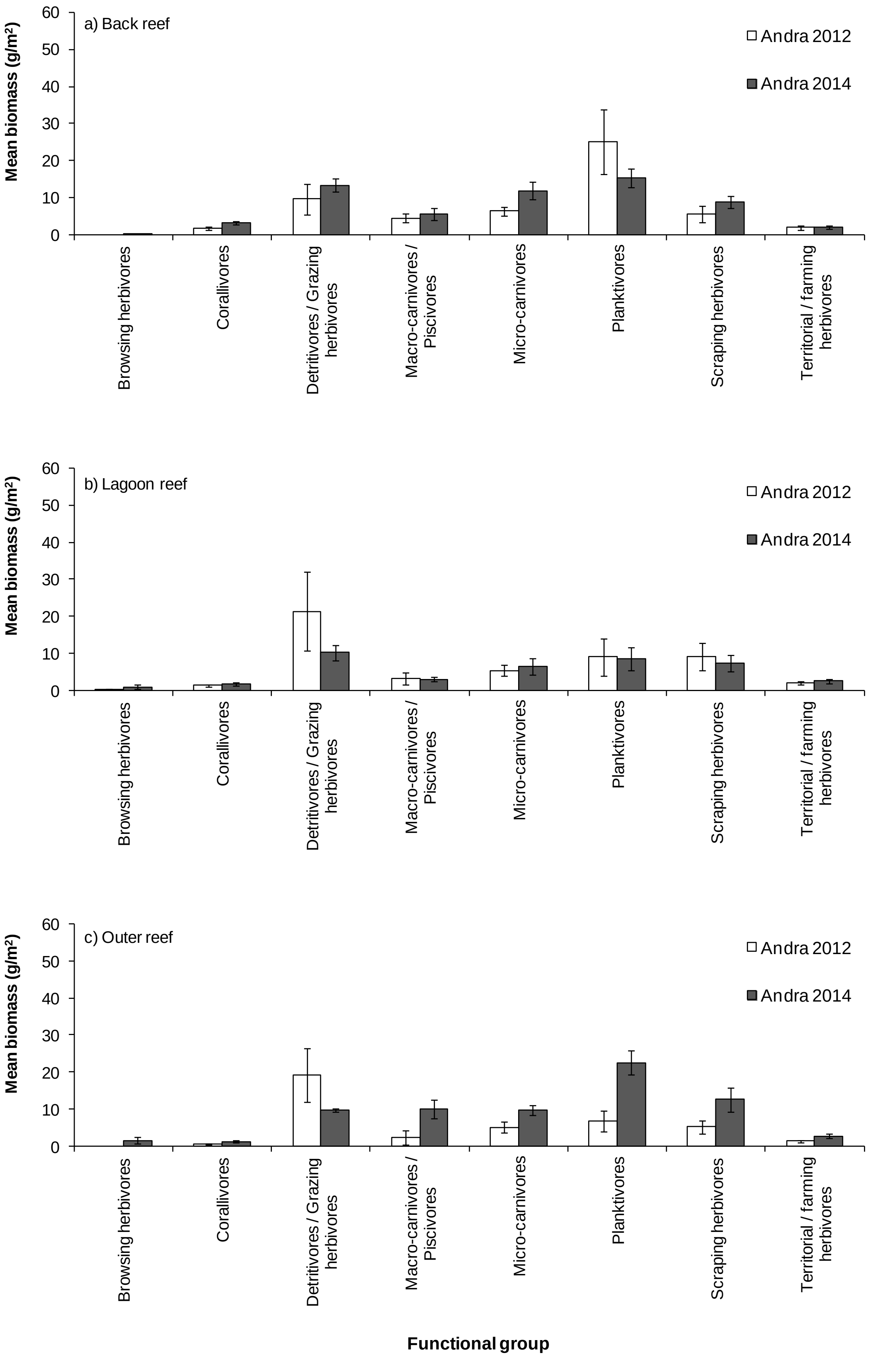


Figure 25 Mean biomass (±SE) of the eight functional groups among a) back, b) lagoon and c) outer reef habitats of the Andra site during the 2012 and 2014 surveys.

Onetah monitoring site

Finfish assemblages at Onetah Island were surveyed for this first time in 2014. Six 50 m transects were completed along both the back and outer reefs (Appendix 1). No lagoon reef habitats were available for survey within this site.

Finfish diversity at Onetah in 2014 was high, with a total 172 and 190 species observed on the back and outer reefs, respectively, yet was not significantly different to the Ahus and Andra sites (Table 11). Functional group diversity was similarly high, with all functional groups represented at both habitats (Table 11).

Table 11 Total number of families, genera and species, and diversity of finfish observed at back and outer reef habitats among the Ahus, Andra and Onetah monitoring sites, 2014.

Parameter	**Back reef**			**Outer-reef**		
	Ahus	**Andra**	**Onetah**	**Ahus**	**Andra**	**Onetah**
No. of families	24	25	24	26	28	28
No. of genera	70	66	70	73	80	73
No. of species	172	182	172	189	192	190
Diversity	77.0±6.1	83.0±7.7	70.1±7.6	79.7±8.0	81.0±7.8	90.5±6.6
Functional groups	8/8	8/8	8/8	8/8	8/8	8/8

Back reefs

Mean total density of finfish was significantly lower on back reef transects at Onetah than those at Ahus or Andra, while mean total biomass on back reefs was lower compared to those at Andra only (Figure 27). At a family level, finfish communities of the back reefs of Onetah appeared similar to those of Ahus or Andra, and were dominated by members of the Pomacentridae, Acanthuridae, Labridae and Scaridae (Figure 28; Figure 29). Back reefs of Onetah supported significantly lower densities of Pomacentridae compared to both Ahus and Andra, and significantly lower densities and biomass of Chaetodontidae and Holocentridae than those at Andra (Figure 28; Figure 29).

Outer reefs

No significant differences were observed between Onetah and Ahus or Andra in mean total density or mean total biomass of finfish on outer reef habitats (Figure 28). Outer reefs at Onetah supported significantly higher densities of Lutjanidae and significantly lower densities of Labridae compared to Ahus, and significantly higher biomass of Holocentridae compared to those at both Ahus and Andra (Figure 28; Figure 29).

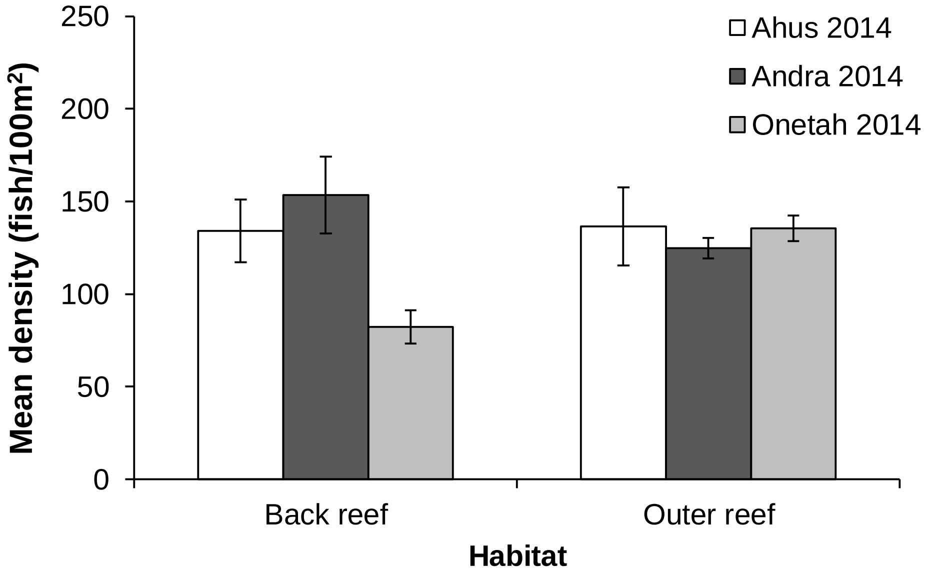


Figure 26 Overall mean density of finfish (±SE) within back and outer reef habitats among the Ahus, Andra and Onetah monitoring site, 2014.

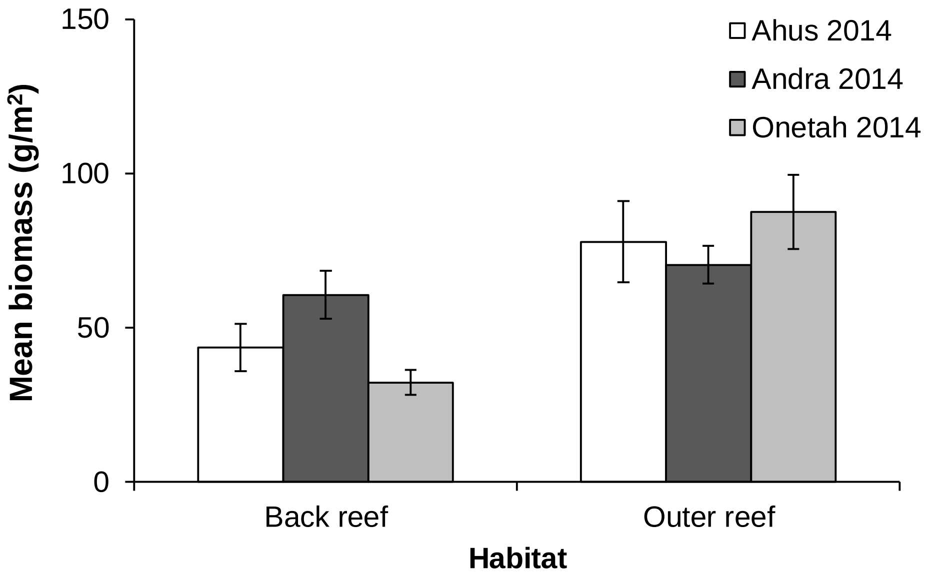


Figure 27 Overall mean biomass of finfish (±SE) within back and outer reef habitats among the Ahus, Andra and Onetah monitoring site, 2014.

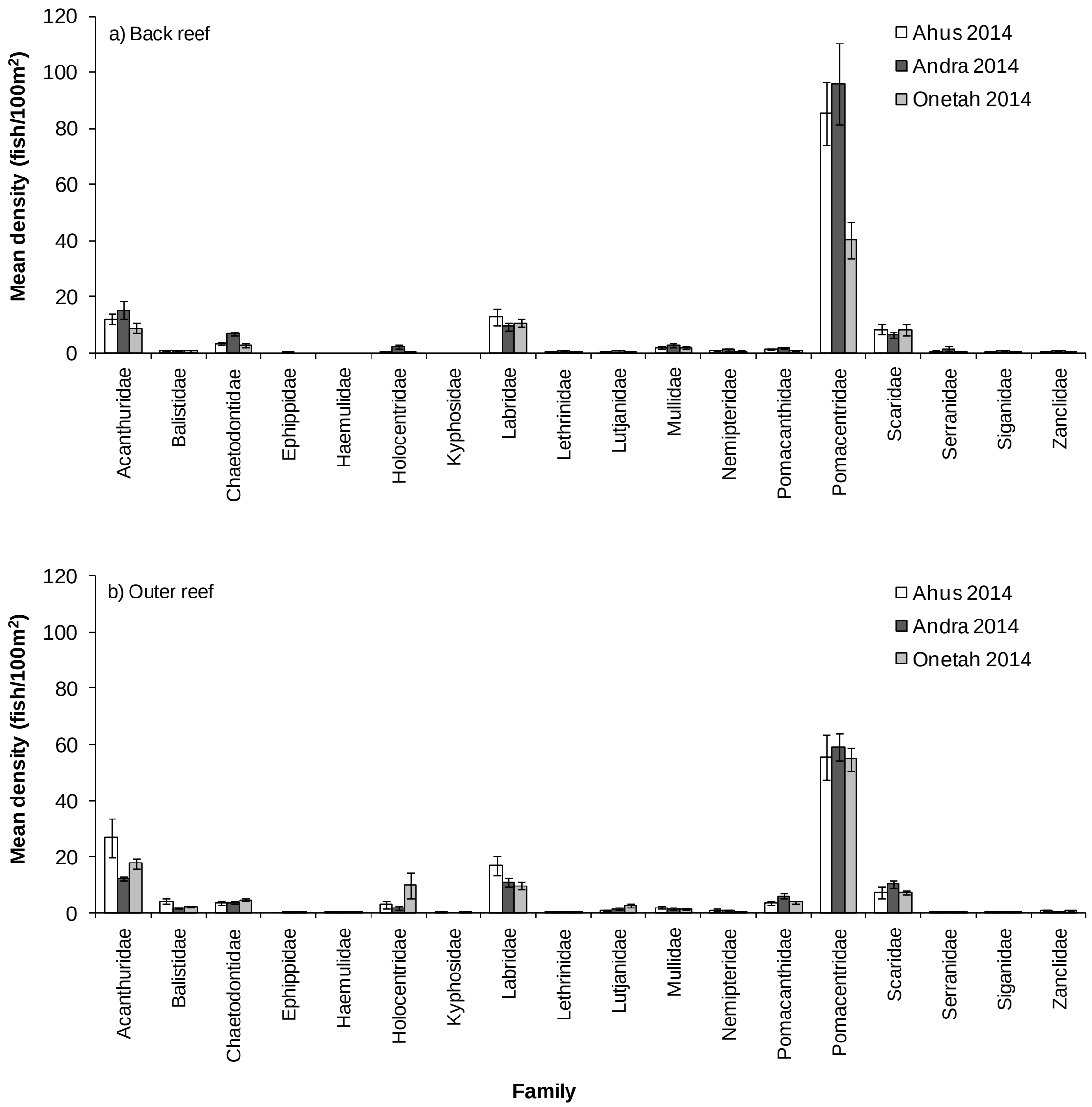


Figure 28 Mean density (±SE) of 18 indicator finfish families among a) back and b) outer reef habitats of the Ahus, Andra and Onetah sites during the 2014 survey.

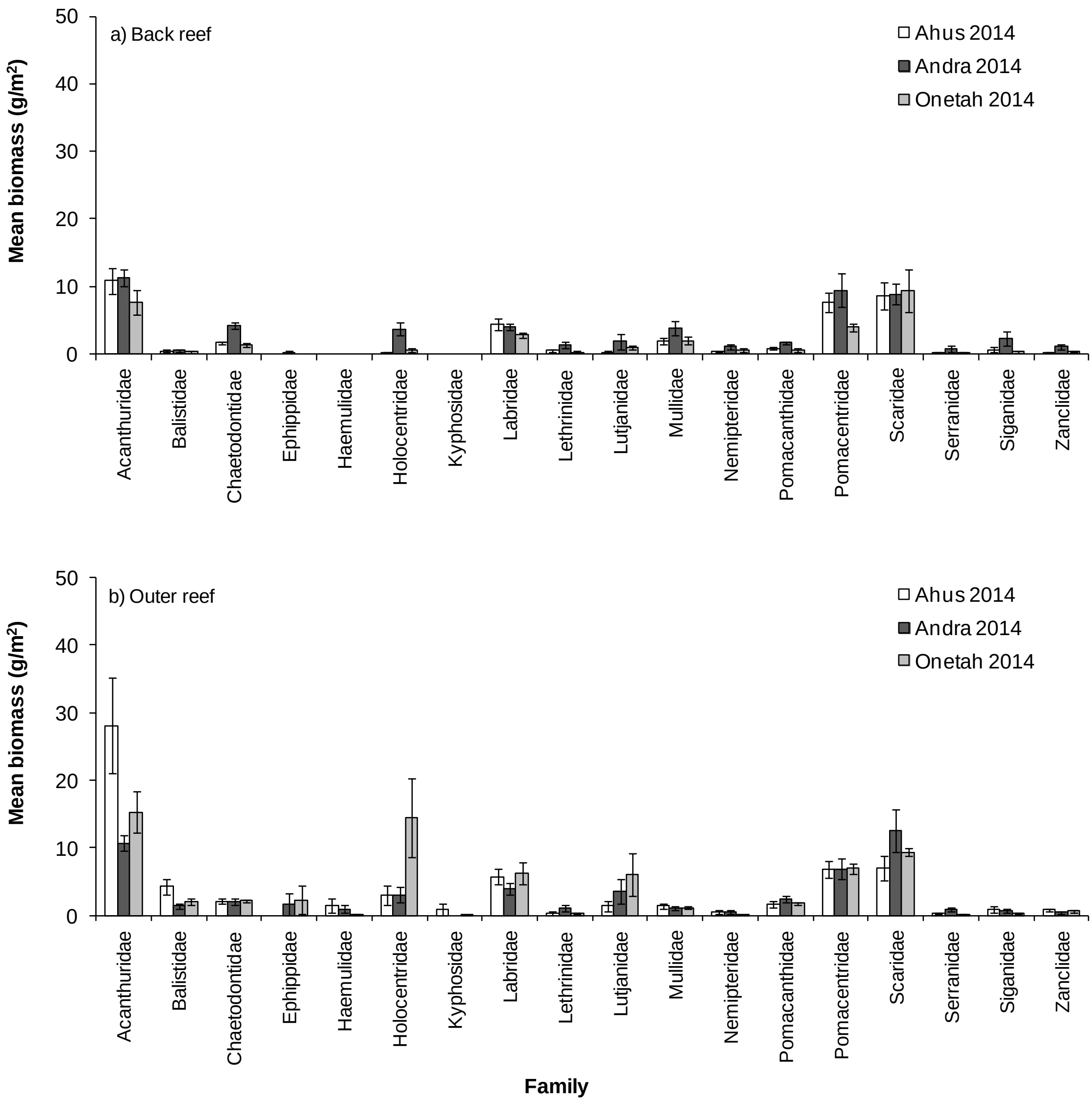


Figure 29 Mean biomass (±SE) of 18 indicator finfish families among a) back and b) outer reef habitats of the Ahus, Andra and Onetah sites during the 2014 survey.

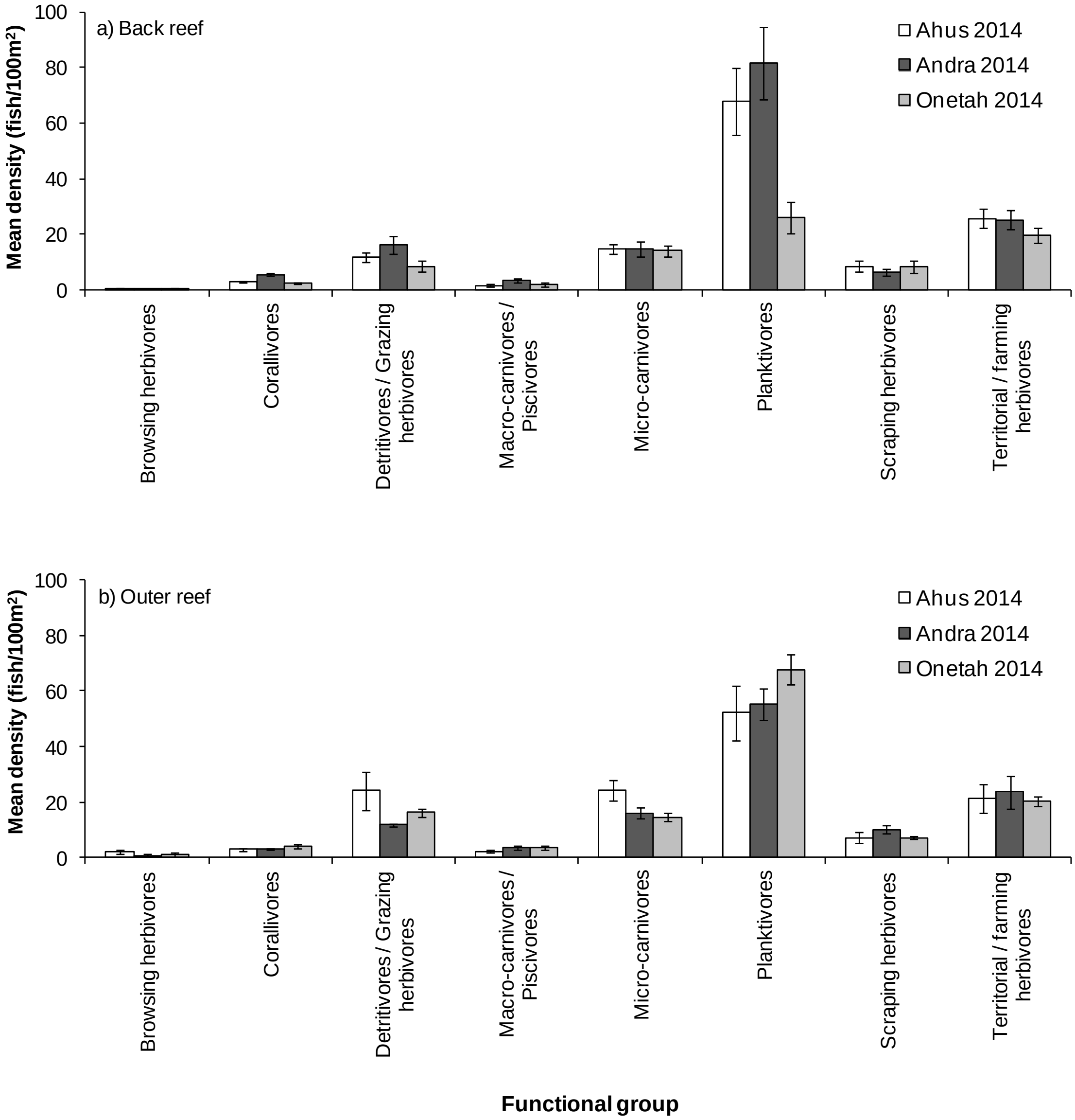


Figure 30 Mean density (±SE) of eight functional groups among a) back and b) outer reef habitats of the Ahus, Andra and Onetah sites during the 2014 survey.

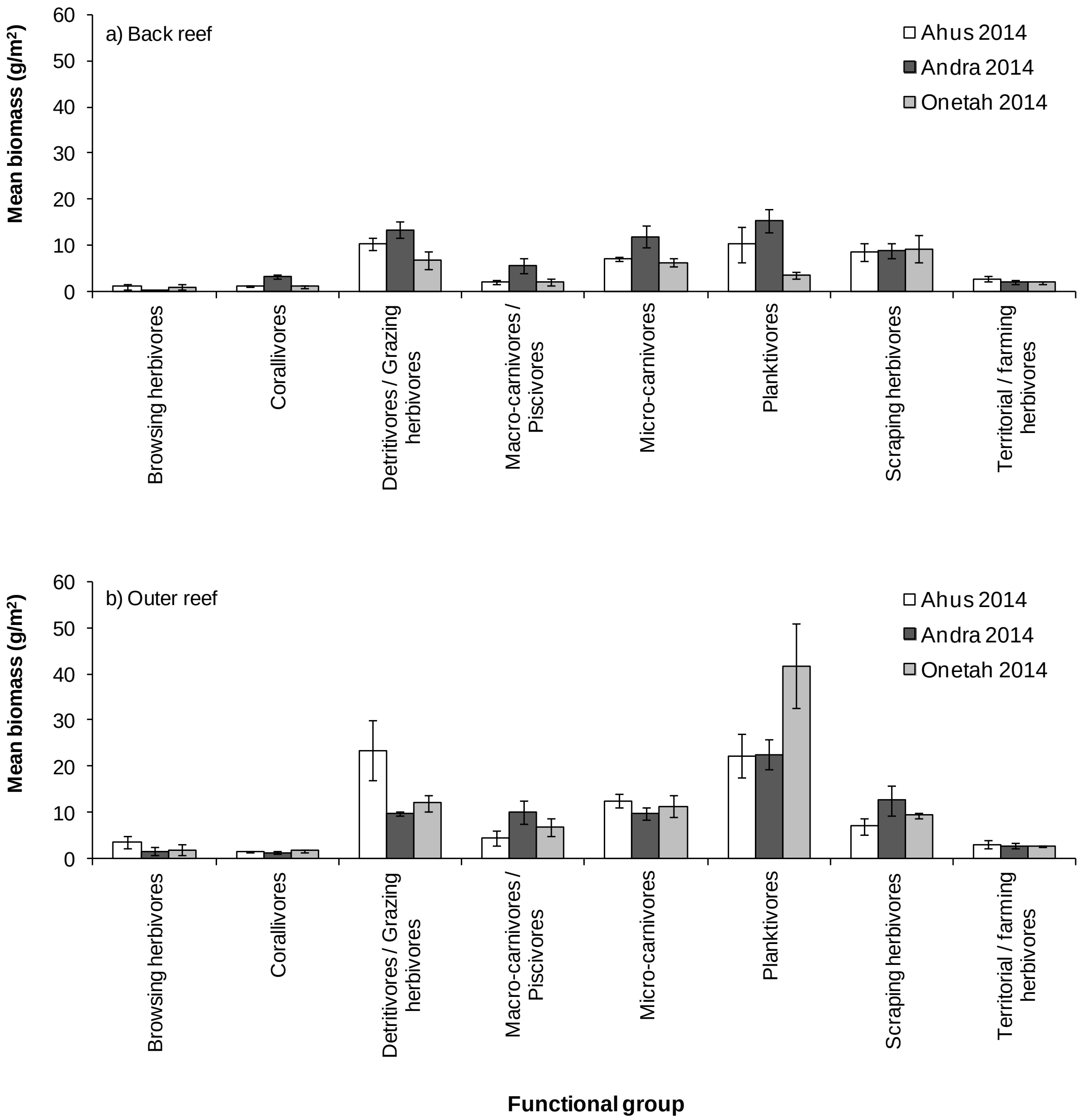


Figure 31 Mean biomass (±SE) of eight functional groups among a) back and b) outer reef habitats of the Ahus, Andra and Onetah sites during the 2014 survey.

4. Benthic Habitat Assessments

Methods

Broad-scale assessments

Data collection

Broad-scale assessments of the benthic habitats of the study region were assessed using manta tow. Here, a surveyor was towed on a manta board behind a boat at a speed of approximately 3-4 km/h. Manta tows were conducted along the back and outer reefs of the Andra, Ahus and Onetah sites. The surveyor recorded percent cover of substrate types, including live coral, dead coral, bleached coral, rubble, coralline algae (e.g. *Halimeda*) and other macroalgae within a 300 m long x 2 m wide transect. Transect lengths were determined using the odometer function within the trip computer option of a Garmin Etrex GPS, and transects were typically conducted at depths of 1–6 metres. Six 300 m manta tow replicates were conducted within each site, with GPS positions recorded at the start and end of each transect to an accuracy of within ten meters.

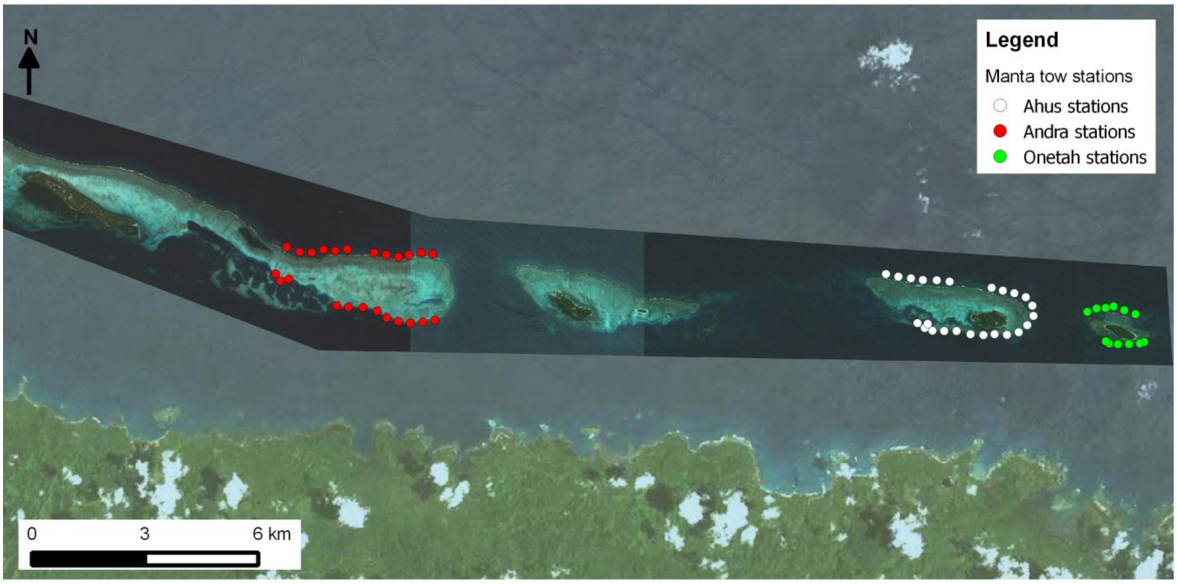


Figure 32 Location of broad-scale (manta tow) benthic habitat monitoring transects within the study region. Each point represents a single 300 m replicate transect.

Data analysis

To explore whether significant differences in cover occurred among sites and habitat, summary graphs of mean percentage cover (± SE) of each substrate type, based on cover of each individual 300 m x 2m transect, were generated for each site (Ahus, Andra and Onetah), habitat (back reef, outer reef) and survey year (2012 and 2014).

Fine-scale assessments

Fine-scale benthic habitat assessments were conducted using a photoquadrat approach at the same locations and transects as the finfish assessments (Figure 10), and were conducted immediately after the finfish surveys. Up to 50 photographs of the benthos were taken per transect (with one photo taken approximately every metre) using a housed underwater camera and a quadrat frame measuring an area of 0.25 m^2. Transects were laid parallel to the reef. A GPS position was recorded at the beginning of each transect.

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

1. Hard coral – sum of the different types of hard coral, identified to genus level[2];
2. Other invertebrates – sum of invertebrate types including *Anemones*, *Ascidians*, *Cup sponge*, *Discosoma*, *Dysidea sponge*, *Gorgonians*, *Olive sponge*, *Terpios sponge*, *Other sponges*, *Soft coral*, *Zoanthids*, and *Other invertebrates* (other invertebrates not included in this list);
3. Macroalgae – sum of different types of macroalgae *Asparagopsis*, *Blue-green algae*, *Boodlea*, *Bryopsis*, *Chlorodesmis*, *Caulerpa*, *Dictyota*, *Dictosphyrea*, *Galaxura*, *Halimeda*, *Liagora*, *Lobophora*, *Mastophora*, *Microdictyton*, *Neomeris*, *Padina*, *Sargassum*, *Schizothrix*, *Turbinaria*, *Tydemania*, *Ulva* and *Other macroalgae* (other macroalgae not included in this list);
4. Branching coralline algae – *Amphiroa*, *Jania*, *Branching coralline general*;
5. Crustose coralline algae (growing on fixed substrate);
6. Fleshy coralline algae (growing on fixed substrate, e.g. *Peyssonnelia*);
7. Turf algae (growing on fixed substrate);
8. Seagrass – sum of seagrass genera *Enhalus*, *Halodule*, *Halophila*, *Syringodium*, *Thalassia*, *Thalassodendron*;
9. Sand / silt – 0.1 mm < hard particles < 30 mm, including that covering other categories;
10. Rubble – carbonated structures of heterogeneous sizes, broken and removed from their original locations; and
11. Pavement.

In addition, the status of corals (live, recently dead or bleached) was noted for each coral genera data point. Recently dead coral was defined as coral with newly exposed white skeletons with visible corallites and no polyps present, while bleached coral was defined as white coral with polyps still present. All data processing and identifications were checked by an experienced surveyor. Resulting data were extracted to MS Excel and summarized as percentages. Summary graphs of mean percentage cover (± SE) for each site were generated to visualise patterns of each major substrate category by habitat and survey year.

To explore whether significant differences in cover occurred among sites and habitats, coverage data of each major benthic category in each individual transect were log(x+1) transformed to reduce heterogeneity of variances and analysed by a two-way permutational multivariate analysis of variance (PERMANOVA) at P = 0.05, using Primer 6.1.13, with site+survey year (e.g. Ahus 2014) and habitat (back reef, lagoon reef and outer reef) as fixed factors in the analysis. PERMANOVA analyses were based on Euclidean distances and 999 permutations of the data.

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

Results

Broad-scale assessments

Ahus

Few differences in cover of benthic categories were evident from the broadscale surveys on the inner reef transects of the Ahus site amongst 2012 and 2014 surveys (Figure 33). Similarly, on the outer reef, little difference was observed in the cover of live coral, rubble, coralline algae or other macroalgae amongst surveys (Figure 33). The cover of dead coral appeared slightly lower, while cover of bleached coral appeared slightly higher, in 2014 compared to 2012 (Figure 33). Ongoing monitoring is warranted to track changes in habitat condition over time.

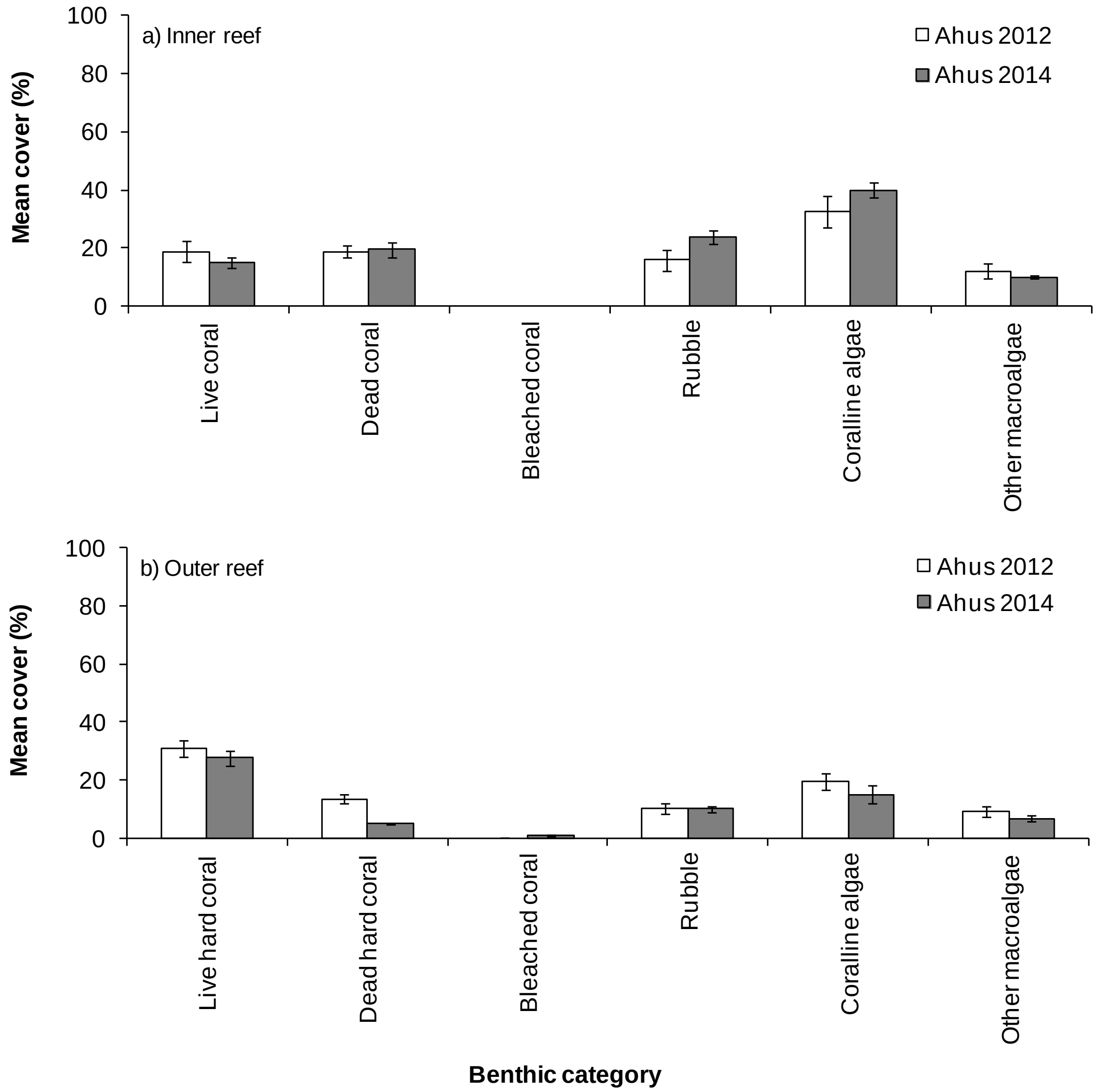


Figure 33 Mean percent cover (±SE) of coral, rubble and algae categories observed on a) inner reef and b) outer reef transects of the Ahus site during broadscale assessments by manta tow, 2012 and 2014.

Andra

Significant declines in the cover of live and dead hard coral were evident during broadscale surveys of the inner reefs of the Andra site between the 2012 and 2014 monitoring events (Figure 34). In contrast, little change was evident from broadscale surveys on the outer reef of the Andra site, with only a slight decrease in cover of coralline algae evident amongst surveys, and little difference evident in cover of live hard coral, dead hard coral, bleached coral, rubble or other macroalgae (Figure 34).

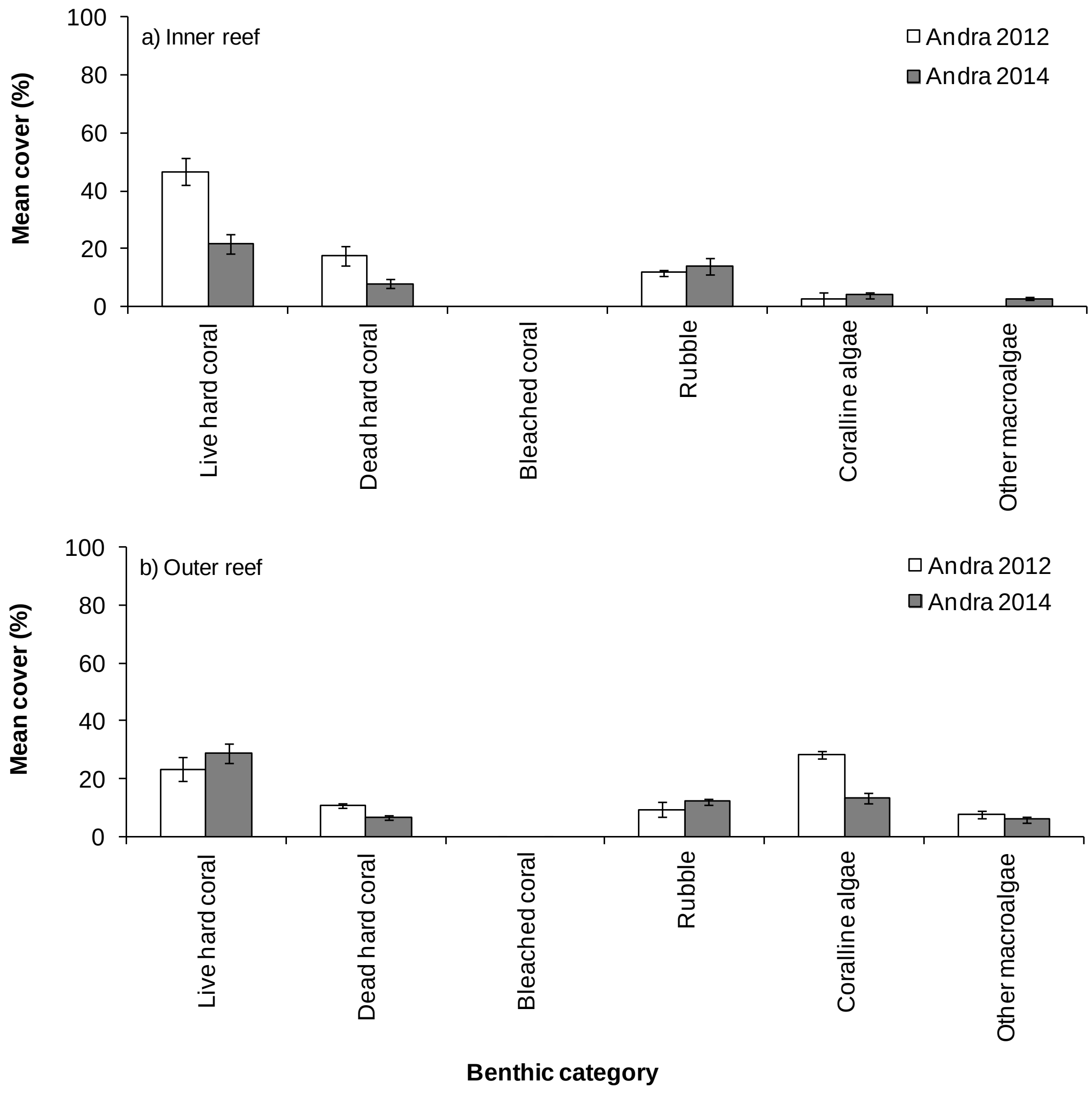


Figure 34 Mean percent cover (±SE) of coral, rubble and algae categories observed on a) inner reef and b) outer reef transects of the Andra site during broadscale assessments by manta tow, 2012 and 2014.

Onetah

A broadscale assessment of the condition of reef habitats of the Onetah site was conducted for the first time in 2014. Benthic habitats of the inner reef transects at Onetah had higher cover of live coral and lower cover of dead coral and rubble than those that the neighbouring Ahus site (Figure 35). Similarly, live coral cover was higher on the outer transects of the Onetah site than those at Ahus or Andra (Figure 35).

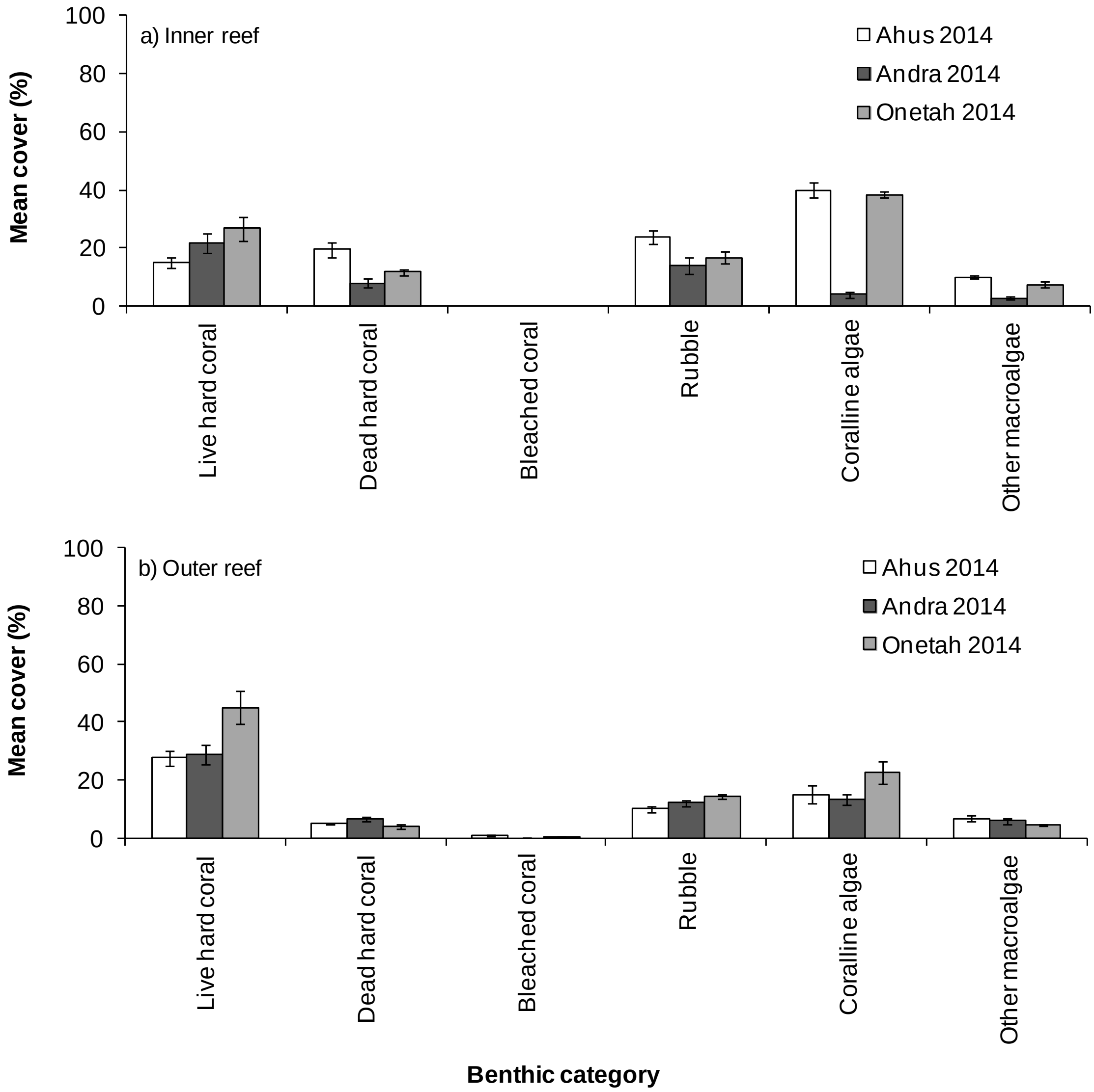


Figure 35 Mean percent cover (±SE) of coral, rubble and algae categories observed on a) inner reef and b) outer reef transects of the Ahus, Andra and Onetah sites in 2014 during broadscale assessments by manta tow.

Fine-scale assessments

Ahus monitoring site

Benthic communities of the Ahus site have been monitored at three habitats during the project. Back reef and outer reef habitats were surveyed in both 2012 and 2014, while benthic habitats of lagoon reef habitats were surveyed for the first time in 2014 (Appendix 1).

No significant differences were evident in benthic community composition of back reef habitats at Ahus among the 2012 and 2014 surveys. As with the baseline assessment, in 2014 benthic communities of the back reefs of the Ahus site were dominated by macroalgae (32.04±4.07% cover), with lower cover of live hard coral (19.22±3.81%), soft coral (12.77±2.04%) and rubble (16.98±1.43%) (Figure 36; Figure 37). The cover of macroalgae was considerably higher on the back reefs of Ahus than those of the Andra site (32.04±4.07% vs. 3.76±1.87%).

Lagoon reefs of the Ahus site were characterised by sand / silt and macroalgae, and to a lesser extent live hard coral, soft coral and rubble (Figure 36; Figure 39). The cover of macroalgae was significantly higher on the lagoon reefs of Ahus than those at the Andra site (22.42±6.18% vs. 1.57±0.99 in 2014).

Few differences were evident in benthic community composition of outer reef habitats of the Ahus site among the 2012 and 2014 surveys. The cover of turf algae was slightly, yet significantly, lower in 2014 relative to 2012 (1.42±0.59% in 2014 vs. 5.68±0.77% in 2012) (Appendix 5). Benthic communities of the outer reefs of the Ahus site were generally dominated by live hard coral (in particular the genera *Acropora*, *Porites*, *Montipora* and *Stylophora*), macroalgae, and crustose coralline algae, with lower cover of sand / silt and rubble (Figure 36; Figure 40).

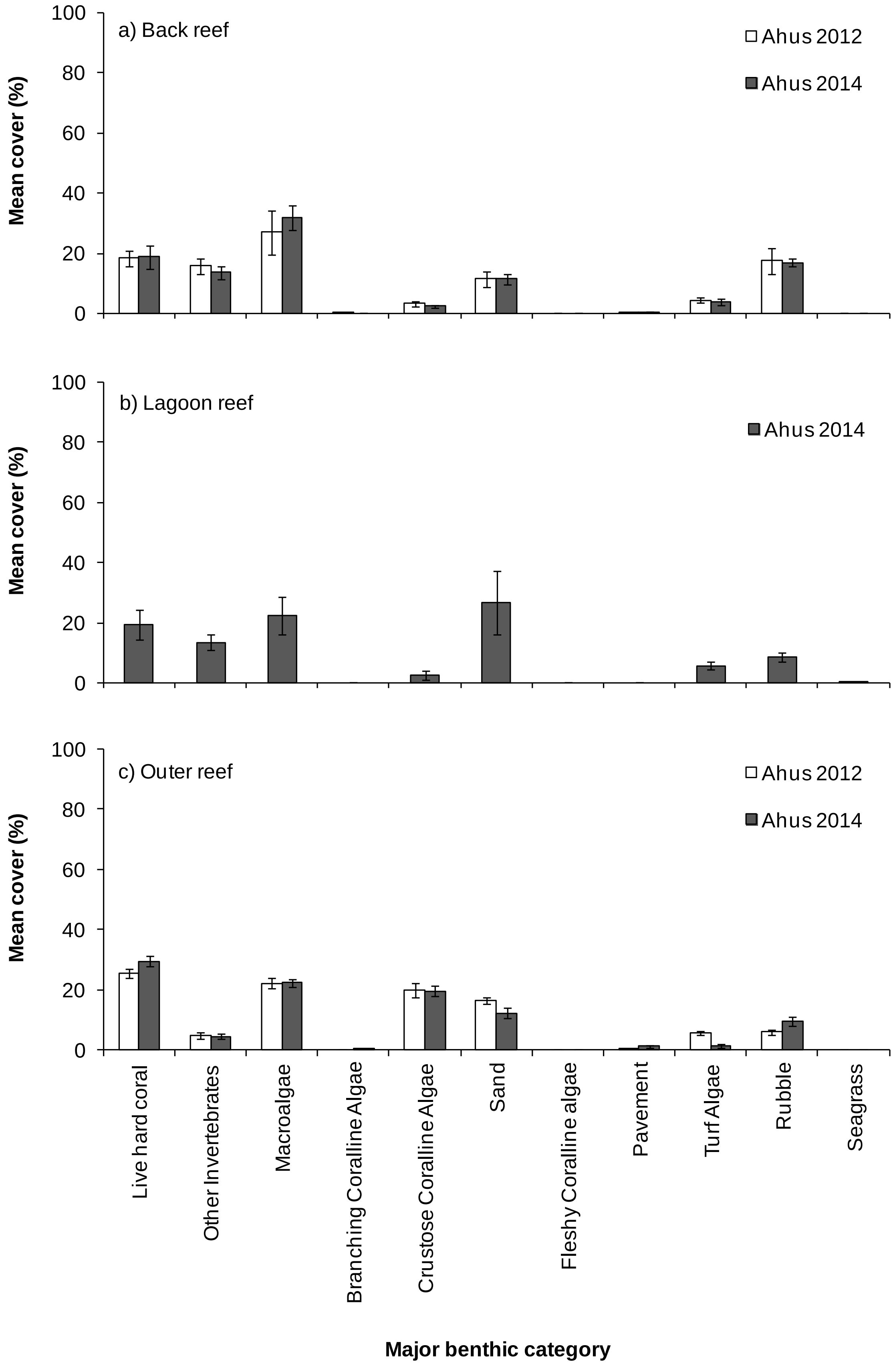


Figure 36 Percent cover of major benthic categories at a) back reef, b) lagoon reef and c) outer reef transects of the Ahus monitoring site during the 2012 and 2014 surveys.

Figure 37 Back reef habitats of the Ahus monitoring site were characterised by low coral cover and high cover of rubble and algae (typically *Halimeda* spp. and cyanobacteria (blue-green algae)).

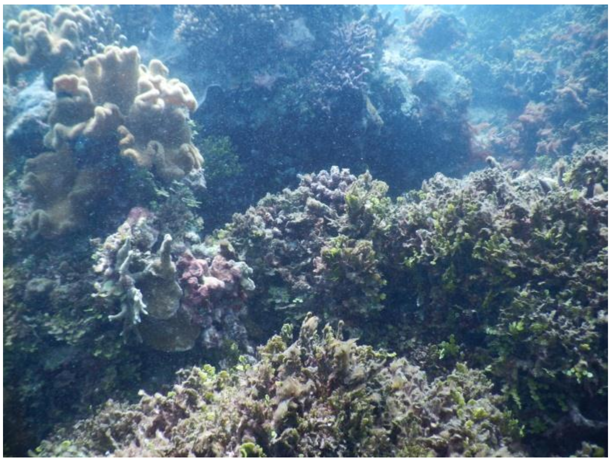
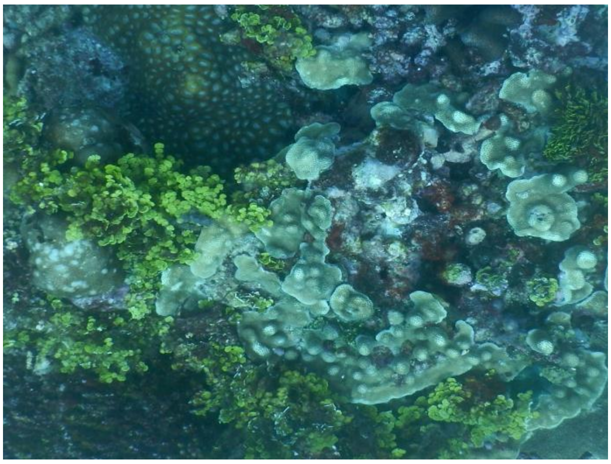


Figure 38 High cover of algae (primarily *Halimeda* spp.) on the back reef of Ahus.

Figure 39 Lagoon reef habitats of the Ahus monitoring site had a moderate cover of moderate cover of macroalgae (predominantly *Halimeda*) and sand / silt.

Figure 40 Outer reef habitats of the Ahus monitoring site had a moderate cover of live coral (in particular *Acropora*, *Porites, Montipora* and *Stylophora*), crustose coralline algae and macroalgae (predominantly *Halimeda).*



Andra monitoring site

Few differences were evident in benthic community composition of back reef habitats of the Andra site among the 2012 and 2014 surveys. While no difference were observed in the cover of live hard coral, other invertebrates (including soft coral), macroalgae or rubble, the cover of turf algae was lower in 2014 relative to 2012 (2.02±0.70% in 2014 vs. 8.96±1.65% in 2012), and the cover of sand / silt slightly higher in 2014 than 2012 (32.51±3.41% in 2014 vs. 23.90±2.43% in 2012) (Figure 41; Appendix 5). Benthic communities of the back reefs of the Andra site were dominated by sand / silt, live hard coral (in particular *Porites*, *Diploastrea*, *Echinopora* and *Turbinaria*), other invertebrates (in particular soft corals and sea fans) and rubble Figure 41; Figure 42; Figure 43). The cover of live hard coral on the back reefs of the Andra site was higher, and cover of macroalgae lower, than those at the Ahus or Onetah sites (Figure 37; Figure 41).

Lagoon reef habitats of the Andra monitoring had a moderate cover of live coral (including *Turbinaria*), soft coral, sand/silt and rubble (Figure 41; Figure 44). Cover of turf algae in 2014 was significantly lower than that observed in 2012 (Figure 41; Appendix 5). Relative to the lagoon reefs of Ahus, those at the Andra site appeared in better health, with higher cover of hard and soft corals and lower cover of algae Figure 36; Figure 41).

Consistent with other habitats, few differences were evident in benthic community composition of outer reef transects of the Andra site among the 2012 and 2014 surveys. No differences were observed in the cover of major categories of live hard coral, other invertebrates, crustose coralline algae, sand, turf, or bleached and recently dead corals. The cover of macroalgae decreased slightly, largely due to a decline in the cover of *Halimeda* (from 20.33±1.43% cover in 2012 to 11.76±1.61% in 2014) (Figure 41; Appendix 5). In general, benthic communities of the outer reef transects at the Andra site were comprised of live hard coral, macroalgae, crustose coralline algae, sand / silt and rubble (Figure 41; Figure 45).

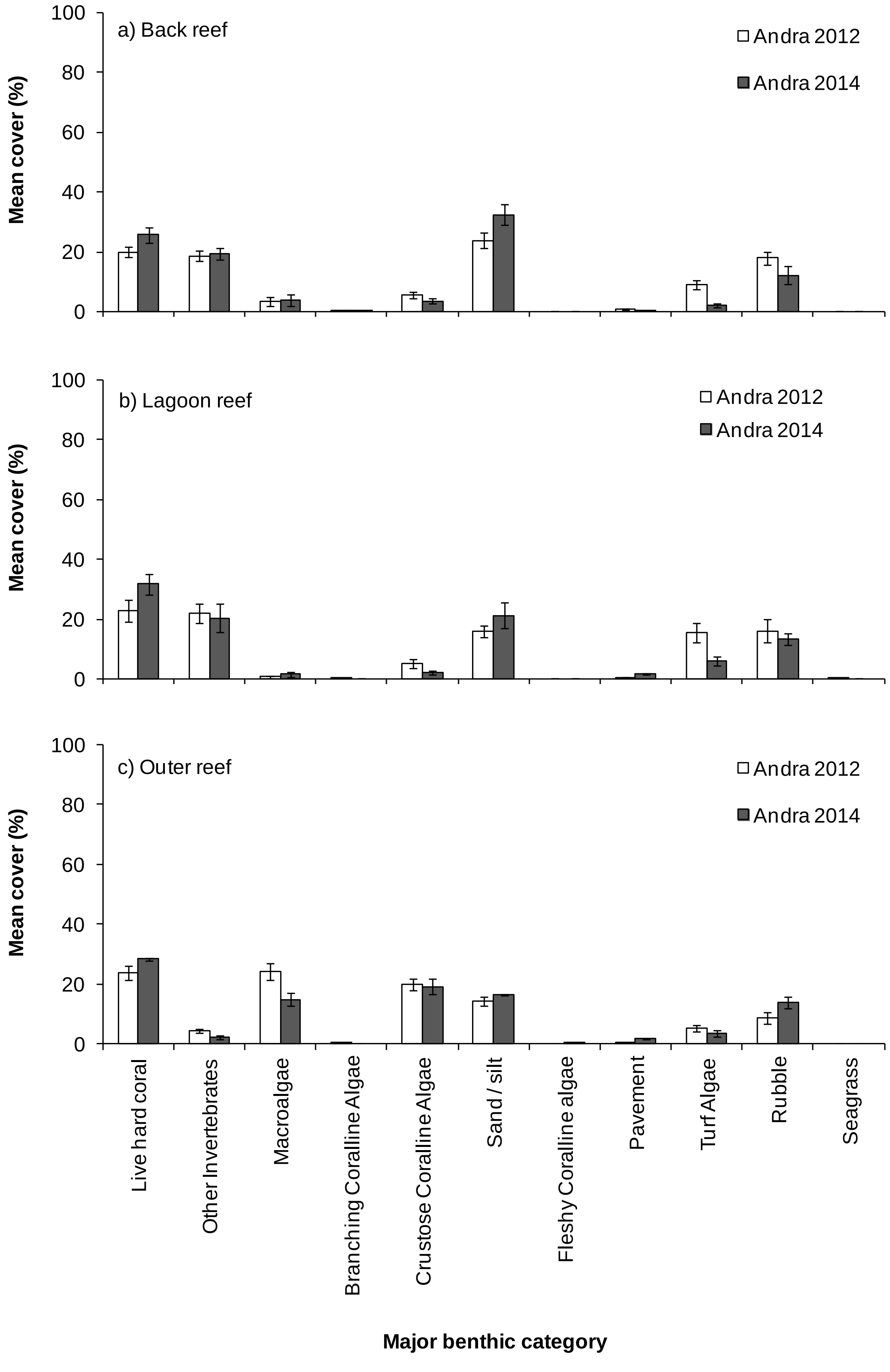


Figure 41 Percent cover of major benthic categories at a) back reef, b) lagoon reef and c) outer reef transects of the Andra monitoring site during the 2012 and 2014 surveys.

Figure 42 Back reef habitats of the Andra site were characterised by low cover of macroalgae, moderate cover of live hard coral and high cover of sand/silt.

Figure 43 A large gorgonian fan along the back reef of the Andra site.

Figure 44 Lagoon reef habitats of the Andra monitoring had a moderate cover of live coral (including *Turbinaria*), soft coral, sand/silt and rubble.

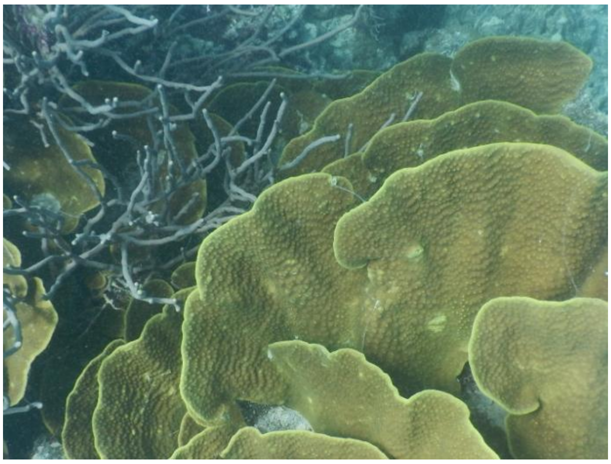


Figure 45 Outer reef habitats of the Andra monitoring site had a moderate cover of live coral (in particular *Acropora* spp.), *Halimeda* spp. and crustose coralline algae.

Onetah monitoring site

Benthic habitats around Onetah Island were surveyed for the first time in 2014. Monitoring focused on back and outer reef habitats (Figure 46). Back reefs of the Onetah Island site were characterised by high cover of live hard coral (28.14±4.13% cover) and macroalgae (32.27±5.79% cover) (Figure 47; Figure 50). Common coral genera at this site were *Acropora*, *Porites* and *Turbinaria*. Common algae genera were *Halimeda* and *Caulerpa*. Coral diversity was highest at this site, with 32 genera observed, compared to 19 and 27 genera for the back reefs of the Ahus and Andra sites, respectively.

Outer reefs of the Onetah monitoring site were characterised by high complexity and rugosity, a high cover of live hard coral and moderate cover of macroalgae and crustose coralline algae (Figure 48; Figure 49). The cover of live hard was significantly higher than outer reef transects of both the Ahus and Andra sites (Figure 50). Hard coral diversity was also high at this site, with 25 genera observed in 2014 (compared to 22 for outer reef transects of the neighbouring Ahus site). The most common coral genera were *Acropora*, *Stylophora*, *Porites*, *Montipora* and *Pocillopora*.

Figure 46 Back reef of the Onetah monitoring site.

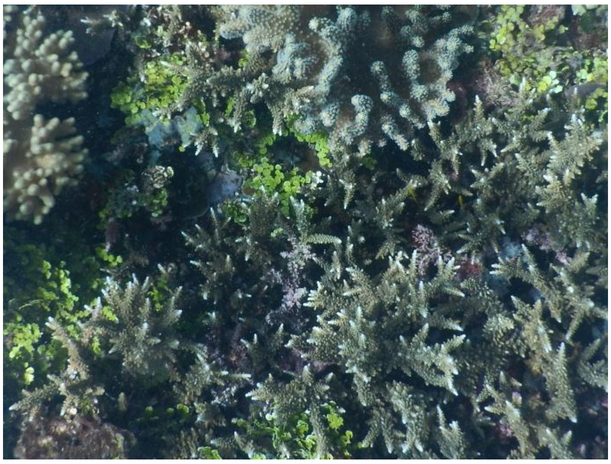


Figure 47 Back reefs of the Onetah site were characterised by moderate live coral cover (in particular branching corals of the genera *Acropora* and *Porites*) and macroalgae (in particular *Halimeda* spp.).

Figure 48 Outer reef habitats of the Onetah monitoring site had high complexity.

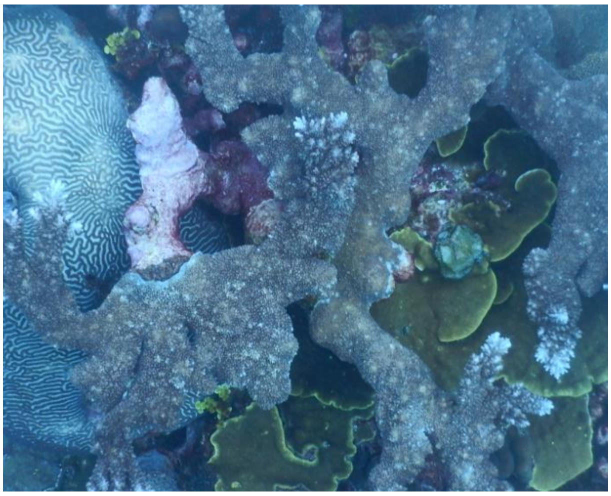


Figure 49 Coral cover and diversity was high on outer reef transects at the Onetah site.).

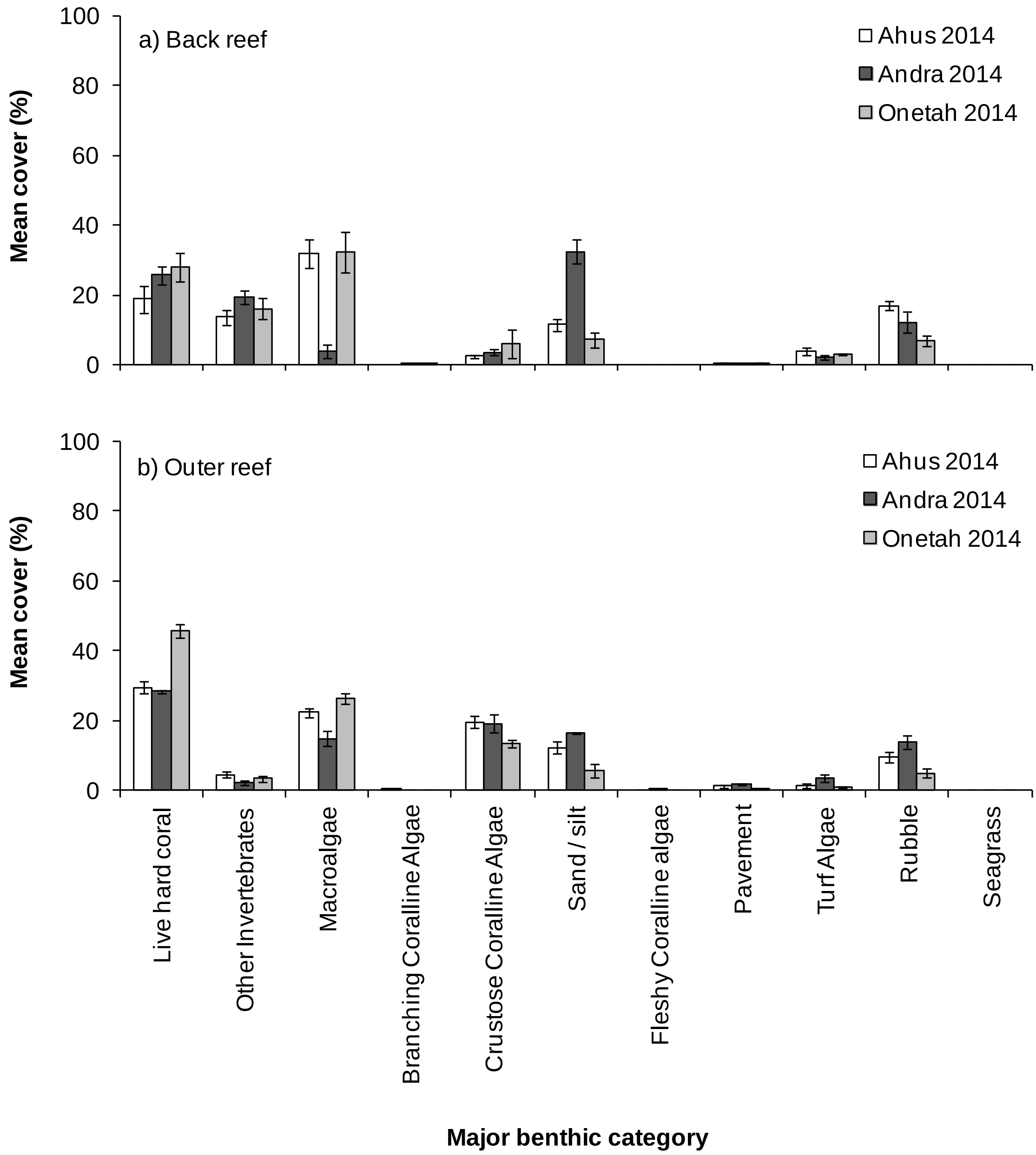


Figure 50 Percent cover of major benthic categories at a) back reef and b) outer reef transects of the Ahus, Andra and Onetah monitoring sites during 2014 survey.

5. Invertebrate Surveys

Methods

Data collection

Two survey methods were used to assess the abundance, size and condition of reef-associated invertebrate resources of the study region. Manta tows were used to provide a broad-scale assessment of invertebrate resources associated with reef areas, and followed the same path used in the broadscale habitat assessments (Figure 32). In this assessment, a snorkeler was towed behind a boat with a manta board for recording the abundance of large sedentary invertebrates (e.g. sea cucumbers) at an average speed of approximately 4 km/hour (Figure 51; Table 12). The snorkeler's observation belt was two metres wide and tows were conducted in depths typically ranging from one to ten metres. Each tow replicate was 300 m in length and was calibrated using the odometer function within the trip computer option of a Garmin 76Map GPS. Six 300 m manta tow replicates were conducted within each station, with the start and end GPS positions of each tow recorded to an accuracy of less than ten meters.

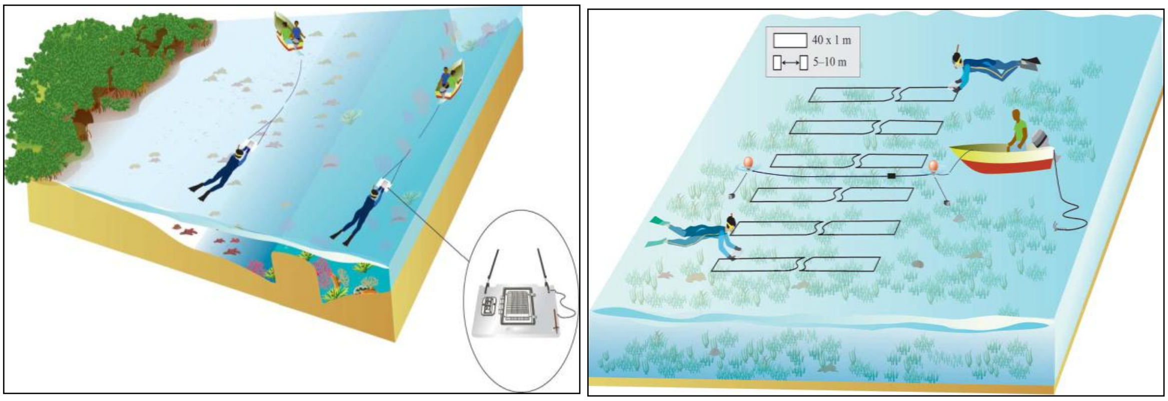


Figure 51 Diagrammatic representation of the two invertebrate survey methods used at the study region during the 2012 and 2014 surveys: manta tow (left) and reef benthos transects (right). GPS coordinates for the manta and RBt stations are provided as Appendices 7 and 8, respectively.

To assess the abundance, size and condition of invertebrate resources at finer-spatial scales, reef benthos transects (RBt) were conducted. RBt stations were established around the back reef and reef flat areas of the Ahus, Andra and Onetah monitoring sites (Figure 52). Each station was surveyed by a minimum of two surveyors equipped with measuring instruments attached to their record boards (slates) for recording the abundance and size of invertebrate species. For some species, such as sea urchins, only abundance was recorded due to difficulty in measuring the size of these organisms. Each transect was 40 meters long with a one meter wide observation belt, conducted in depths ranging from one to three meters. The two snorkellers conducted three transects each, totalling six 40 m x 1 m transects for each station (Figure 51). The GPS position of each station was recorded in the centre of the station.

Data analysis

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

1) richness – the number of genera and species observed in each survey method (for RBt stations only);
2) diversity – total number of observed species per site divided by the number of stations at that site (for RBt stations only); and
3) mean density per station (individuals/ha).

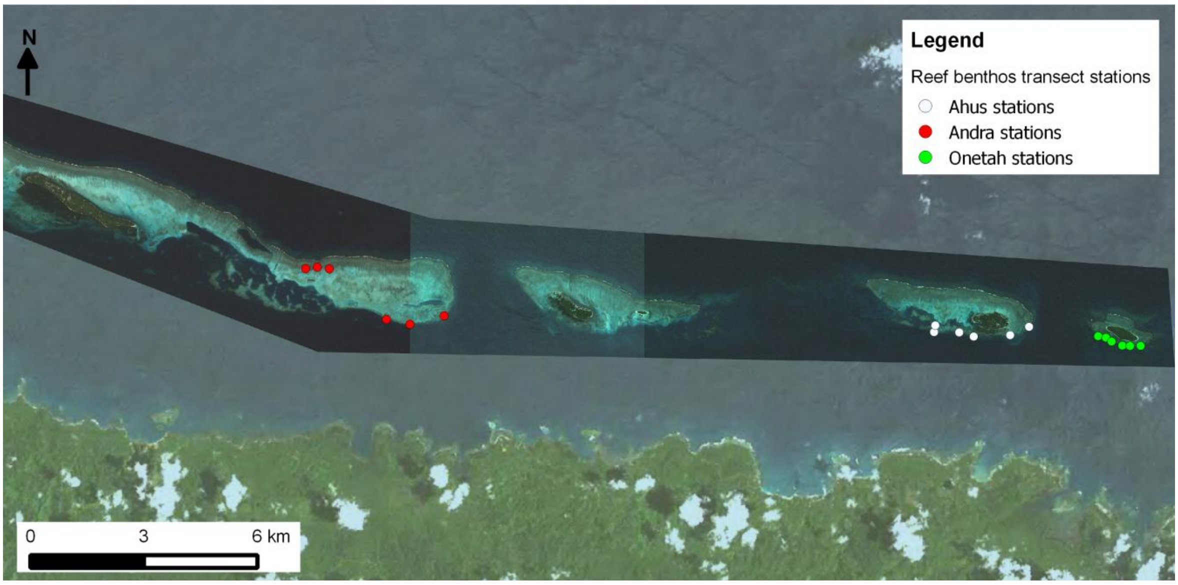


Figure 52 Map of the study region showing approximate positions of reef benthos transect (RBt) stations.

Summary graphs of mean density by site and survey year were generated to explore spatial and temporal patterns in invertebrate assemblages from the manta tow and RBt stations. Data was analysed on an individual species level except for gastropods, which were pooled at a genus level, and urchins, which were pooled to the family level, due to uncertainties in species identification of these organisms, particularly during the baseline assessment. To test for differences in invertebrate densities observed during RBts amongst surveys and sites, density data within each station were ln(x+1) transformed to reduce heterogeneity of variances and analysed by a series of one-way PERMANOVAs at P = 0.05, using Primer 6.1.13, with site+survey year (e.g. Ahus 2014) as a fixed factors in the analysis. PERMANOVA analyses were based on Euclidean distances and an unrestricted number of permutations of the data. Due to low numbers of invertebrates observed on the outer reefs, only back reef transects were used in the analyses of manta tow data. Due to low number of station replicates (resulting from small reef areas), no higher statistics were performed on the manta tow data.

Table 12 Species analysed in manta tow assessments (where present).

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

Results

Manta tow

Few differences in species density were observed amongst manta tow surveys at either the Ahus or Andra sites (Figure 53; Figure 54). At Ahus, densities of flowerfish (*Pearsonothuria graeffei*) increased significantly amongst surveys, with 29.17±1.39 individuals/ha observed in 2014 and no individuals observed in 2012 (Figure 53).

Reef benthos transects

Invertebrate diversity at the RBt stations was higher in 2012 than 2014 for both the Ahus and Andra sites (Table 13). In 2014, diversity at Onetah was slightly higher than that at Ahus and Andra, with a total of 48 species recorded from 6 stations (Table 13).

The sea cucumber assemblage of RBt stations was relatively speciose, with fourteen species observed across the three sites (Table 14). While this study was not designed to be a dedicated stock assessment survey, none of the fourteen species were observed in densities exceeding minimum recommended densities for harvest proposed by Pakoa et al. (2014) (Table 14). While individual species' densities appeared highly variable amongst survey, few significant differences in density were observed, largely owing to high between-station variability for individual species and sites (Figure 58). At Ahus, densities of the brittle star *Ophiomastix janualis* appeared significantly higher in 2014 (none were recorded in 2012), while at Andra densities of the cushion star *Culcita novaeguineae* were significantly higher in 2014 compared to 2012 (Figure 56; Figure 57).

Several significant differences were observed in densities of individual invertebrate species amongst Onetah and the Ahus and Andra sites. Most noticeably, Onetah supported significantly higher densities of the gastropods of the genera *Cypraea* (in particular *C. annulus* and *C. tigris*) and *Tectus* (in particular trochus, *T. niloticus*) and *Turbo* (in particular *Turbo argyrostomus*), and the urchins *Diadema setosum* and *Echinometra mathaei* (Figure 58).

Table 13 Number of genera and species, and diversity of invertebrates observed during reef-benthos transects at the Ahus, Andra and Onetah monitoring sites during the 2012 and 2014 surveys.

Parameter	Site and year				
	Ahus 2012	**Ahus 2014**	**Andra 2012**	**Andra 2014**	**Onetah 2014**
Number of genera	20	28	17	33	36
Number of species	23	36	26	46	48
Diversity	3.83	6.0	4.3	7.7	8.0

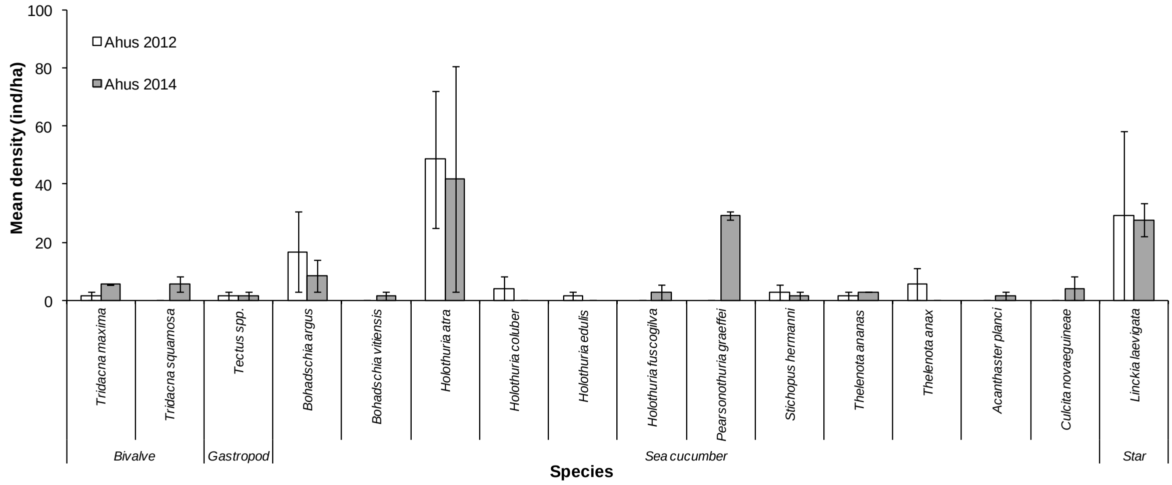


Figure 53 Overall mean densities (±SE) of invertebrate species observed during manta tow surveys at the Ahus monitoring site, 2012 and 2014.

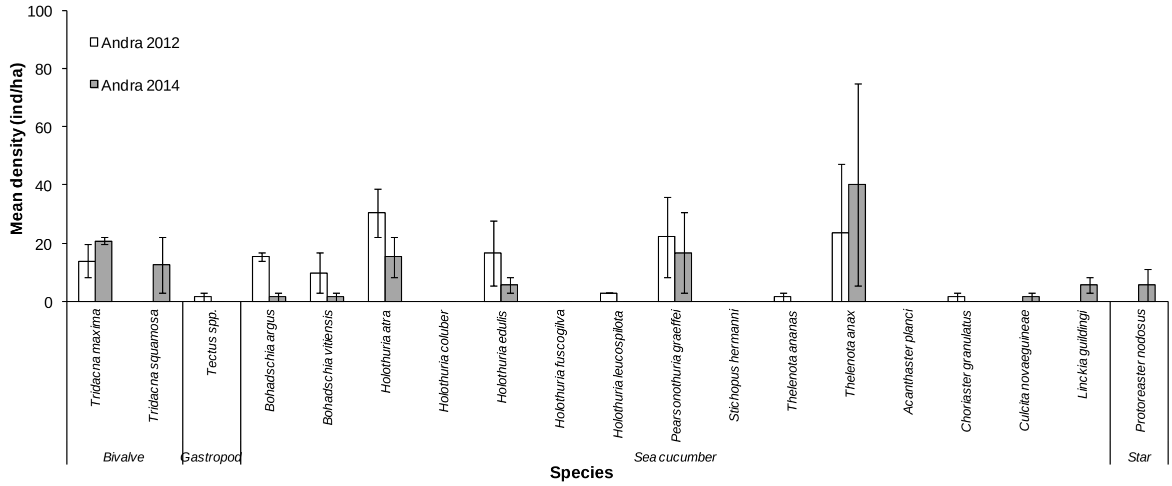


Figure 54 Overall mean densities (±SE) of invertebrate species observed during manta tow surveys at the Andra monitoring site, 2012 and 2014. Not shown: *Linckia laevigata* – 2012 density = 159.72±45.82 individuals/ha, 2014 density = 65.27±9.72 individuals/ha.

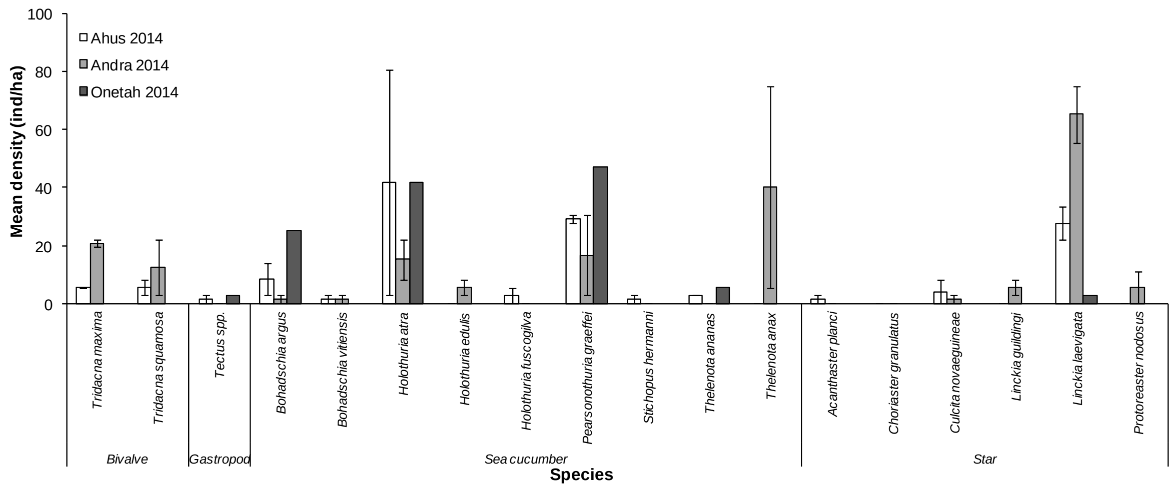


Figure 55 Overall mean densities (±SE) of invertebrate species observed during manta tow surveys at the Ahus, Andra and Onetah monitoring sites, 2014.

Table 14 Mean overall densities (±SE) of sea cucumber species at RBt stations in 2012 and 2014. The regional reference density for healthily stocks (RBt sites) is provided in the last column (from Pakoa et al. 2014).

Species	Ahus 2012	Ahus 2014	Andra 2012	Andra 2014	Onetah 2014	RBt reference density
Actinopyga lecanora	0.00±0.00	0.00±0.00	0.00±0.00	4.17±4.17	0.00±0.00	10
Actinopyga mauritiana	0.00±0.00	0.00±0.00	0.00±0.00	0.56±0.37	0.69±0.69	200
Bohadschia argus	13.89±8.78	10.00±8.26	6.94±6.94	21.11±9.25	18.75±10.77	120
Bohadschia vitiensis	0.00±0.00	0.28±0.28	6.94±6.94	0.28±0.28	0.00±0.00	100
Holothuria atra	41.67±18.63	17.50±8.80	263.89±125.31	76.11±29.82	26.39±10.85	5600
Holothuria coluber	41.67±26.35	0.00±0.00	55.56±47.71	33.33±29.00	0.00±0.00	1100
Holothuria edulis	0.00±0.00	0.00±0.00	27.78±17.57	9.72±8.22	0.00±0.00	260
Holothuria fuscogilva	0.00±0.00	0.56±0.56	0.00±0.00	0.00±0.00	0.00±0.00	20
Holothuria leucospilota	0.00±0.00	0.00±0.00	13.89±13.89	0.00±0.00	0.00±0.00	-
Pearsonothuria graeffei	6.94±6.94	43.33±21.14	13.89±8.78	20.00±12.61	53.13±25.69	100
Stichopus chloronotus	0.00±0.00	0.00±0.00	0.00±0.00	12.50±8.89	0.00±0.00	3500
Stichopus hermanni	0.00±0.00	0.28±0.28	0.00±0.00	0.00±0.00	0.00±0.00	100
Thelenota ananas	0.00±0.00	0.56±0.37	0.00±0.00	0.00±0.00	1.39±0.91	30
Thelenota anax	0.00±0.00	0.00±0.00	0.00±0.00	8.06±7.46	0.00±0.00	-

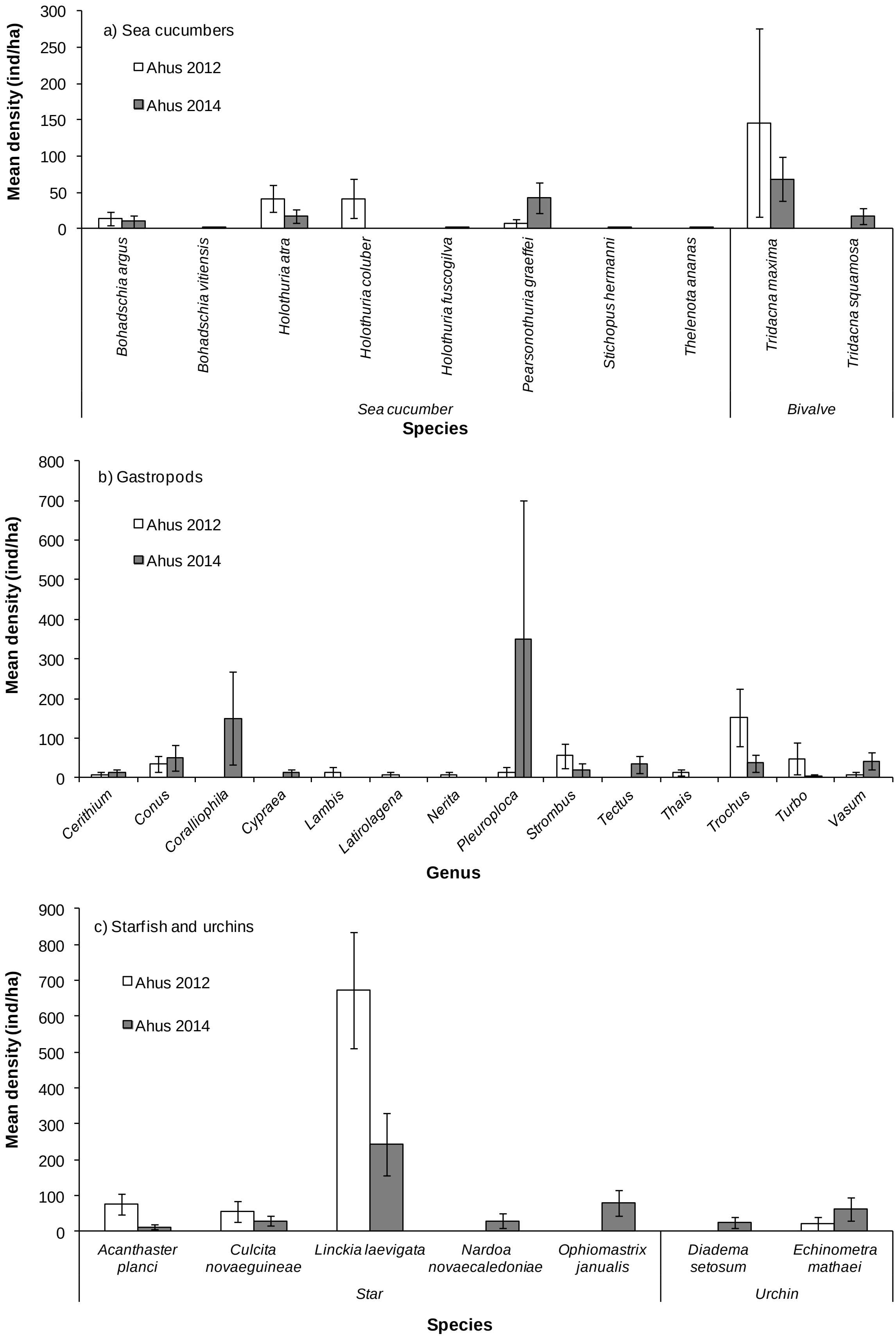


Figure 56 Overall mean densities (±SE) of a) sea cucumbers and bivalves, b) gastropods and c) starfish and urchins at RBt stations at Ahus site, 2012 and 2014.

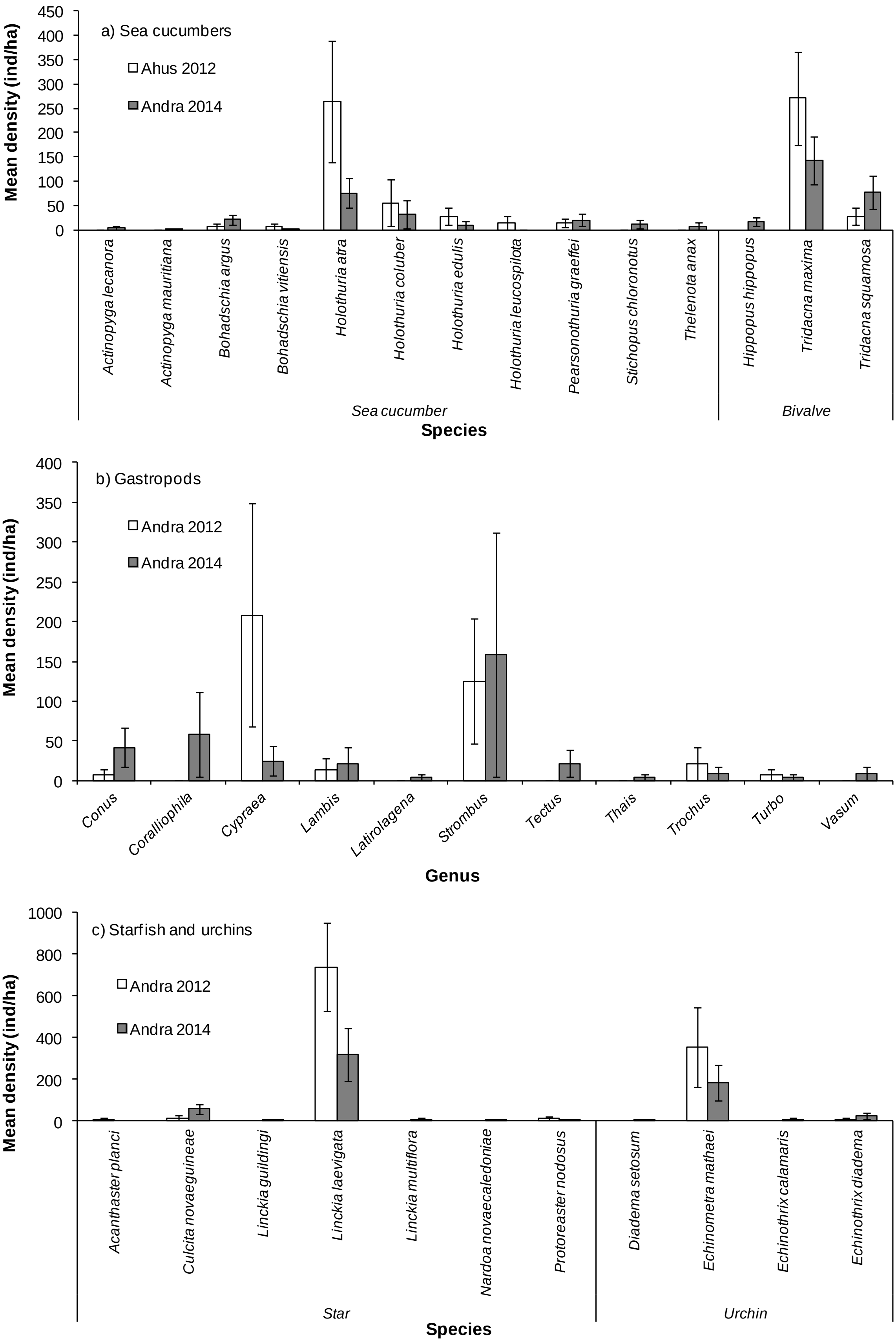


Figure 57 Overall mean densities (±SE) of a) sea cucumbers and bivalves, b) gastropods and c) starfish and urchins at RBt stations at the Andra site, 2012 and 2014.

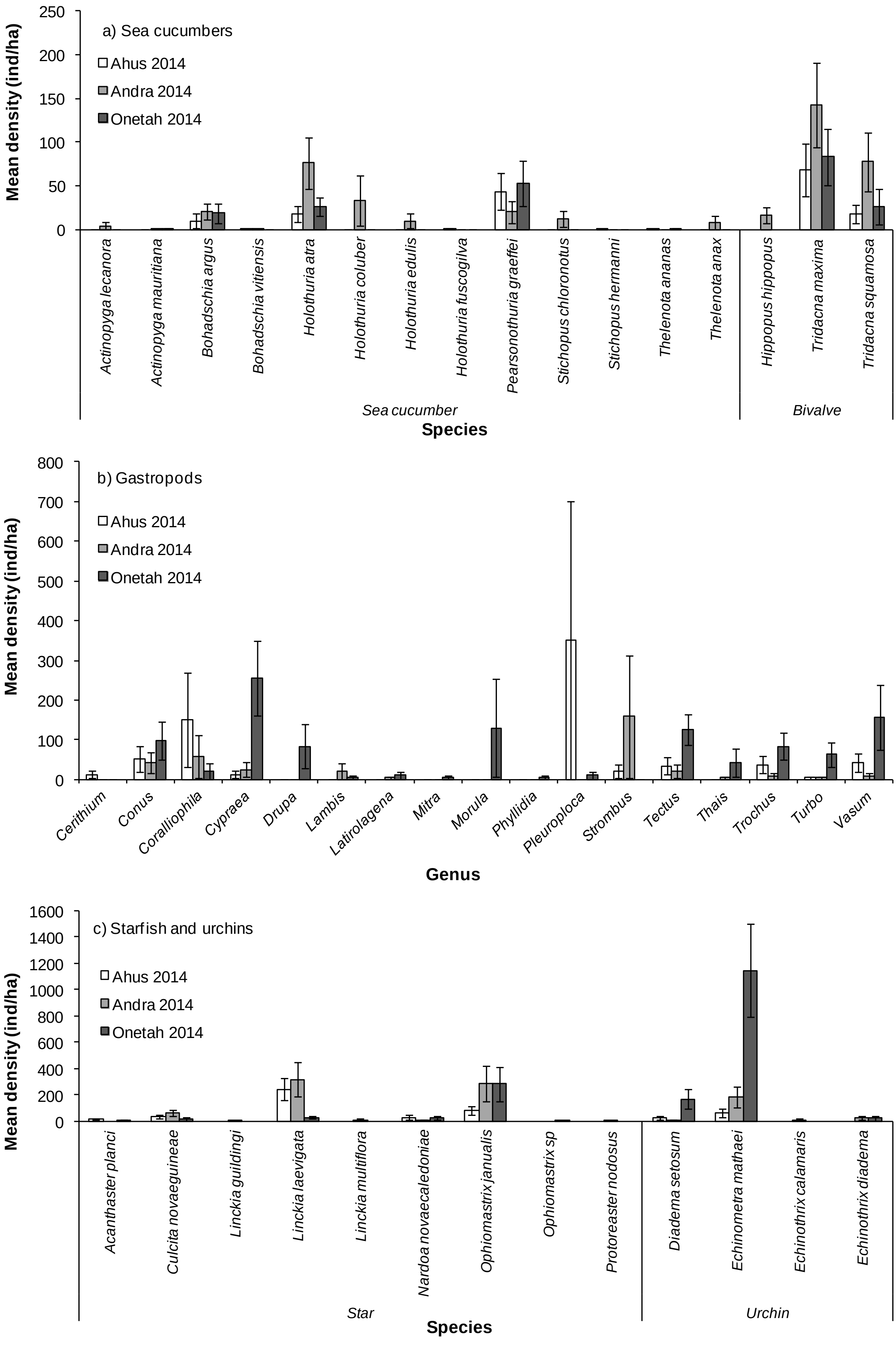


Figure 58 Overall mean densities (±SE) of a) sea cucumbers and bivalves, b) gastropods and c) starfish and urchins at RBt stations at the Ahus, Andra and Onetah sites, 2014.

6. Creel surveys

Methods

Creel surveys at the study region focused on fishers of Andra Island. The creel surveys had the following objectives:

1) Document fisher demographics and fishing behavior (e.g. locations fished, distances travelled);
2) Provide a 'snapshot' of species composition of each fishery;
3) Document catch (including length and weight of all individuals caught), effort (including trip duration, time spent fishing and gears used) and catch-per-unit-effort (CPUE) for monitoring purposes.
4) Document fisher's perceptions of the status of fisheries resources.

During the survey the lead fisher was asked questions relating to the fishing trip, including the number of fishers that took part in the fishing trip, the fishing method(s) used, locations fished, distance travelled, and costs involved. Their historical fishing patterns, and perceptions of the state of resources, were also documented. Perceptions were documented once only for each lead fisher, regardless of how many times that fisher was surveyed. All finfish caught were identified to species, measured to the nearest mm and weighed to the nearest 10 g unless damaged. Shells were measured to the nearest mm, and octopus measured to the nearest mm and weighed the nearest 10 g, following methods of Pakoa et al. (2014). A copy of the survey form used in the creel surveys is included as Appendix 9.

Data analysis

Summary statistics, including mean number of fishers per trip, mean trip duration, mean catch (individual fish and kg) were compiled for each fishing method. Where weight data were not recorded (i.e. when a fish was damaged), weights were estimated from length-weight relationships in FishBase (Froese and Pauly 2013). Length-frequency plots were established for key target species and were compared against lengths-at-maturity (where known) to estimate the percentage of immature individuals in the catch. Catch-per-unit-effort was calculated for each fishing method, and was based on number of fish and weight of fish caught per fisher per hour. The number of surveys required to detect a change in CPUE by abundance at a level of precision of 0.2 was calculated for each fishing method using the formula:

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

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

Figure 59 Members of the survey team undertaking a creel survey on Andra Island.

Results

A total of 63 creel surveys were completed, covering a wide variety of fishing methods. Below is a brief synopsis of the most commonly encountered fishing practices, including details of fishing patterns and behaviours and catch dynamics.

Bottom fishing

Bottom fishing activities were encountered on 12 landings. Each trip consisted of a single fisher, who spent approximately 3.83±0.54 hours fishing. The average catch per trip was 10.79±1.99 kg, or 17.17±3.20 individuals caught. Catch-per-unit-effort was 5.51±1.45 fish/fisher/hour, or 3.64±1.04 kg/fisher/hour. Bottom fishing took place mainly along the outer reef of Andra, the passages between Andra, Ponam and Ahus Reefs and on the patch reefs (termed *mocho*) in the lagoon between Andra and the mainland. The average distance travelled was 2.43±0.32 km. The catch was dominated by members of the families Lutjanidae (snappers), Carangidae (trevallies), Lethrinidae (emperors) and Serranidae (groupers) and Sphyraenidae (barracudas) in terms of both individuals and weight (Figure 60). Thirty-eight species were observed in the bottom fishing catch (Appendix 10), with 206 individuals weighing an estimated 130 kg recorded. The most common species observed in the handline catch were *Lutjanus gibbus* (representing 26% of the total catch by abundance and 17% of the total catch by weight), *Caranx sexfasciatus* (16% of the total catch by abundance and 23% of the total catch by weight), *Lutjanus timorensis* (6% of the total catch by abundance and 16% of the total catch by weight) and *Lutjanus vitta* (5% of the total catch by abundance and 1% of the total catch by weight) (Appendix 10).

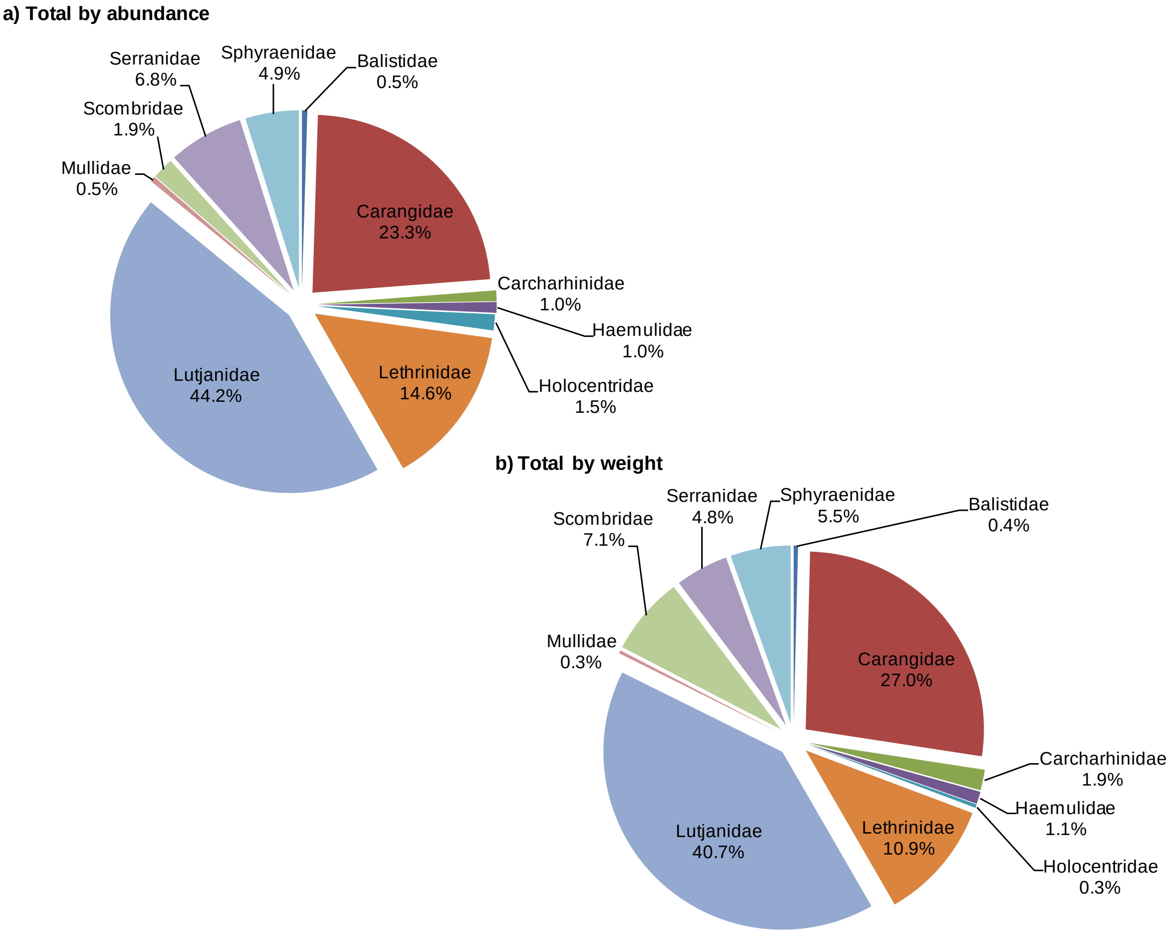


Figure 60 Percent contribution by abundance (top) and weight (bottom) of families caught by bottom fishing, Andra Island, May–June 2014.

Drop-stone lining

Drop-stone handling was encountered in six landings. This technique predominantly targets the oceanic triggerfish, *Canthidermis maculata*, but catches other species as well (Figure 61). The drop-stone lining trips surveys typically involved a single fisher (encountered on all but one trip, which had six fishers), which each fisher spending an average on 3.33±0.95 hours fishing (Table 15). The average catch per trip was 9.80±4.33 kg, or 11.50±5.35 individual fish. Catch-per-unit-effort was 2.37±0.82 fish/fisher/hour, or 2.06±0.71 kg/fisher/hour (Table 15). Drop-stone lining was exclusively practiced from drifting canoes along the northern outer reef slope.

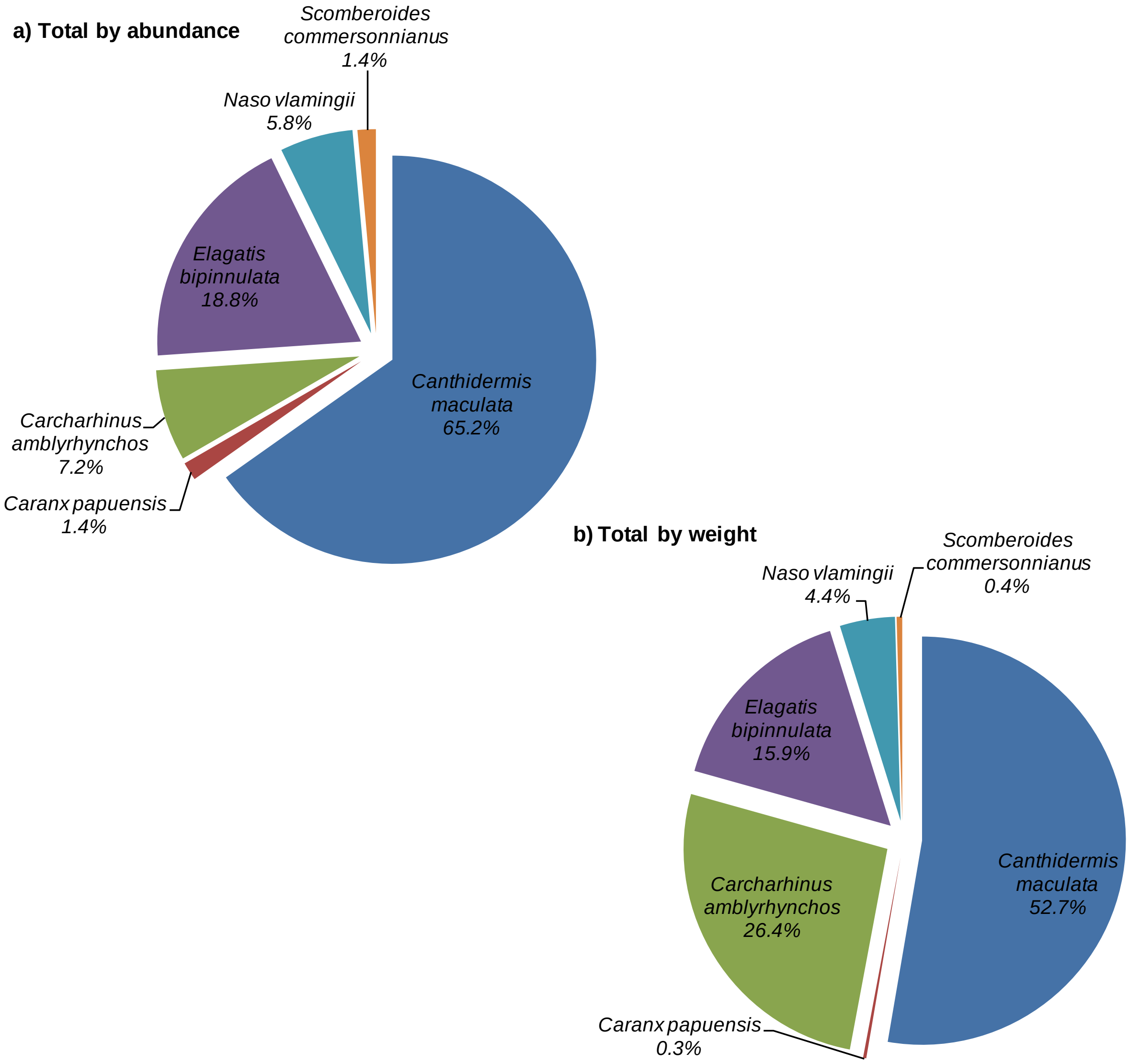


Figure 61 Percent contribution by abundance (top) and weight (bottom) of species caught by drop-stone lining, Andra Island, May–June 2014.

Day spearfishing

Six landings of day spearfishing trips were surveyed. Trips involved 1–2 fishers and lasted a mean duration of 2.50±0.68 hours (Table 15). The average catch per trip was 6.26±2.00 kg, or 12.00±3.30 individual fish. Catch-per-unit-effort was 4.31±0.69 fish/fisher/hour, or 2.30±0.72 kg/fisher/hour (Table 15). The average distance travelled per trip was 1.68±0.56 km. A total of 72 individuals were observed from the night spearfishing catch. Twenty-eight species from 13 families were observed (Appendix 10), with members of the Acanthuridae (surgeonfishes), Scaridae (parrotfishes), and Haemulidae (sweetlips) dominating the total catch by both abundance and weight (Figure 62). The most common finfish species caught included the surgeonfish *Acanthurus nigricans*, *A. lineatus*, *A. nigricauda* and *A. nigrofuscus*, the drummer *Kyphosus vaigiensis* and the sweetlip *Plectorhinchus lineatus* (Appendix 10).

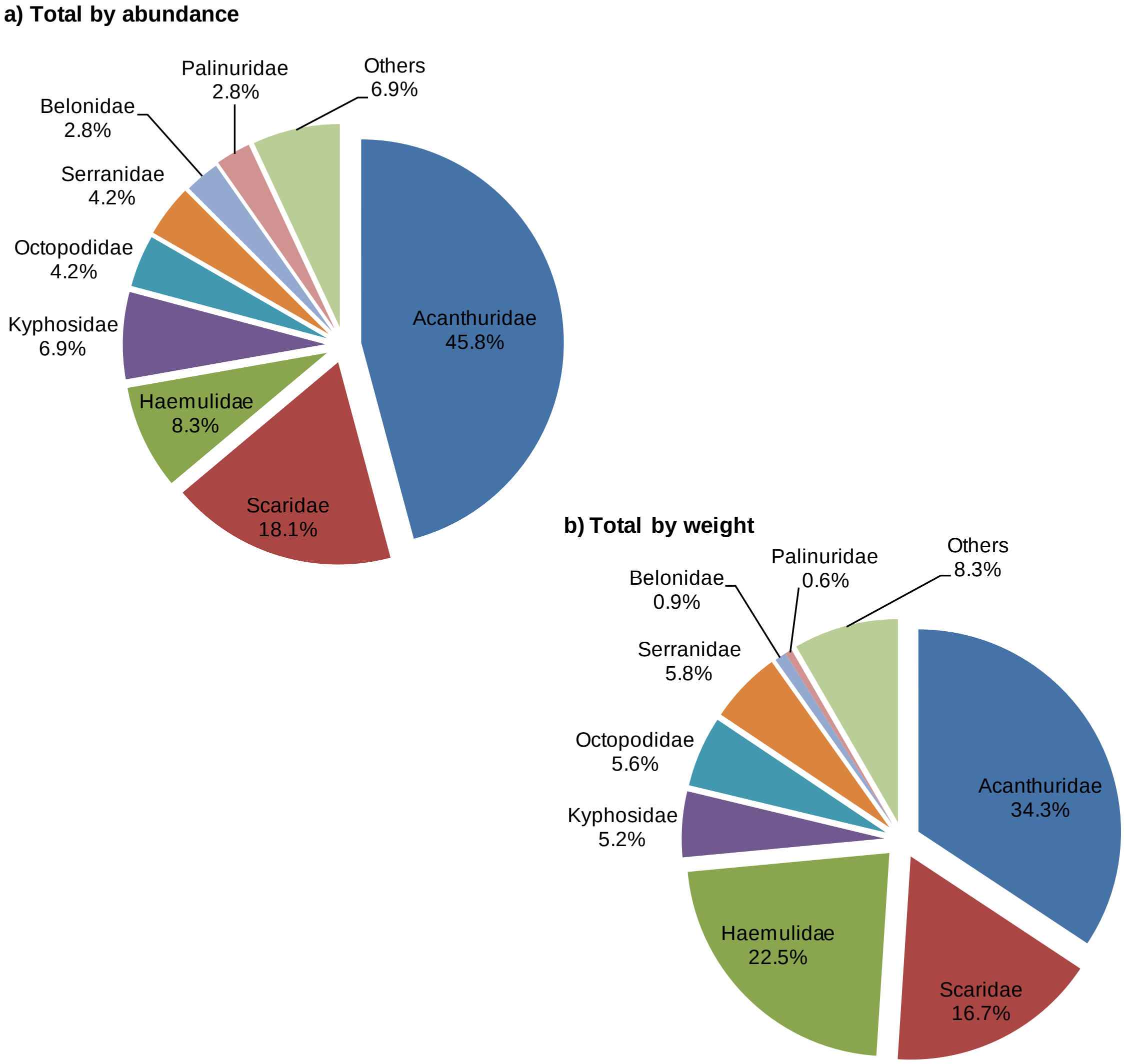


Figure 62 Percent contribution by abundance (top) and weight (bottom) of families caught by day spearfishing, Andra Island, May–June 2014.

Night spearfishing

Nine surveys of night spearfishing trips were completed. Each trip consisted of a single fisher and lasted a mean duration of 3.24±0.55 hours (Table 15). The average catch per trip was 15.30±1.70 kg, or 52.11±6.66 individual fish. Catch-per-unit-effort was 19.90±4.42 fish/fisher/hour, or 5.86±1.05 kg/fisher/hour (Table 15). Spearfishing trips took place mainly at Ponam (Cholioh) Reef and along the outer reef and passes of Andra. The average distance travelled per trip was 2.67±00.36 km. A total of 469 individual fishes were observed from the night spearfishing catch. Seventy-nine species from 17 families were observed (Appendix 10), with members of the Scaridae (parrotfishes), Acanthuridae (surgeonfishes), Mullidae (goatfishes) and Siganidae (rabbitfishes) dominating the total catch by both abundance and weight (Appendix 10). The most common finfish species caught included the goatfish *Parupeneus barberinus* (representing 14.5% of the total catch by abundance and 10.8% of the total catch by weight), the surgeonfish *Acanthurus lineatus* (7.5% of the total catch by abundance and 4% of the total catch by weight), the rabbitfish *Siganus spinus* (4.3% of the total catch by abundance and 2.8% of the total catch by weight) and the parrotfishes *Scarus globiceps* and *Hipposcarus longiceps* (4.3% and 3.2% of the total catch by abundance and 3.7% and 3.6% of the total catch by weight, respectively) (Appendix 10).

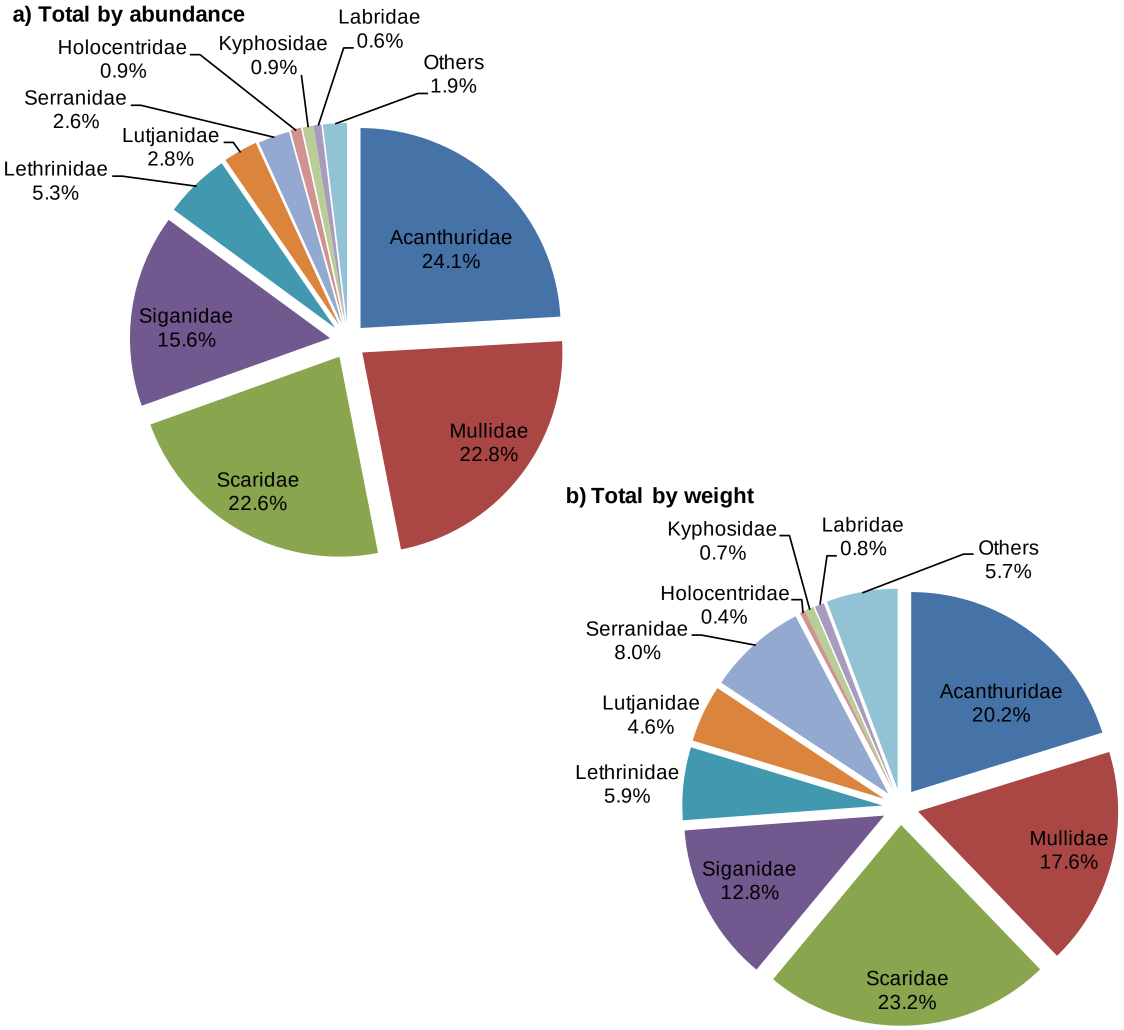


Figure 63 Percent contribution by abundance (top) and weight (bottom) of families caught by night spearfishing, Andra Island, May–June 2014.

Mixed reef gleaning

Fourteen surveys of reef gleaning trips were completed. Reef gleaning typically involved one to all of the following activities: handlining for reef fishes, shell collecting on snorkel, and hand spearing for reef fishes and octopus, and was exclusively a female affair. In a 'typical' trip, a fisher would spend on average just under 1 hour handlining, 1 hour 15 minutes collecting shells and 1 hour 10 minutes spearing for octopus. Mixed reef gleaning targeted a wide range of species (Figure 64). Fishing took place in various habitats across the Andra reef flat platform (collectively termed *lomat*), but most commonly occurred around Papi Island at the eastern end of the reef flat.

Figure 64 A typical mixed reef gleaning catch, consisting of *Octopus cyanea* (top right), *Acanthurus triostegus*, *Arothron manilensis*, *Cypraea tigris*, *Stombus luhuanus*, *S. thersites* and *Lambis* spp.

Handlining was observed in five mixed gleaning trips, with a single fisher involved in each trip (Table 15). Handlining typically entailed casting a baited hook from an anchored or drifting canoe within the reef flat (a practice termed *yai lomat*). A variety of fishes were caught by handlining on these trips, with seventeen species from seven families observed in the catch (Appendix 10). Catches were typically small (Table 15), with just enough fish for daily meals taken. Catch-per-unit effort was 5.06±0.67 fish/fisher/hour, or 0.91±0.13 kg/fisher/hour.

Shell collecting on snorkel was observed in 11 gleaning trips, again with a single fisher involved in each trip. On average fishers spent 2.45±0.83 hours collecting. A total of 1865 individual shells were identified and weighed during the surveys, form 14 species. The catch was dominated by *Strombus luhuanus*, which encompassed 95% of the catch (Appendix 10). Catch-per-unit-effort was 95.64±19.47 individuals/fisher/hour (Table 15). Catch-per-unit effort of *S. luhuanus* was 90.85±19.55 individuals/fisher/hour. The bulk of *S. luhuanus* collected were between 3.5 and 6 cm total length (Figure 65), with an average observed total length of 4.77±0.03 cm.

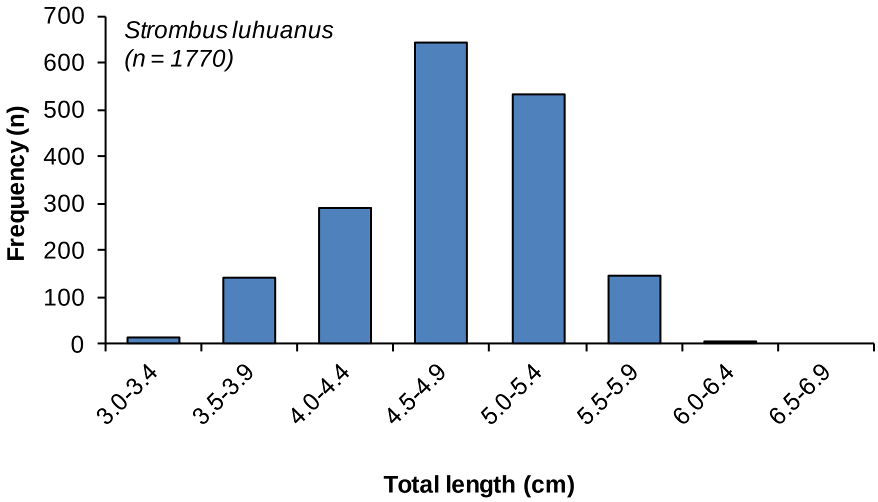


Figure 65 Length frequency of *Strombus luhuanus* observed in mixed gleaning catches.

Hand spearing by female fishers was observed in 11 of the 14 mixed reef gleaning trips. A wide variety of species were harvested through this method, with 22 species from 12 families observed. Catches were typically dominated by the acanthurid *Acanthurus triostegus* (which represented 40% of the catch by abundance) and *Octopus cyanea* (which represented 23% of the total catch by abundance) (Table 15). Catch-per-unit effort was 7.31±1.40 individuals/fisher/hour (Table 15).

Trolling

Eighteen trolling trips were surveyed. On average, trolling trips involved 1.5±0.29 fishers, with fishers spending 3.42±0.26 hours fishing (Table 15). The average catch per trip was 7.60±1.81 kg, or 15.22±2.12 individual fish. Catch-per-unit-effort was 3.72±0.57 fish/fisher/hour, or 1.58±0.20 kg/fisher/hour (Table 15). The main species caught during the survey period were striped bonito, *Sarda orientalis*, and skipjack, *Katsuwonus pelamis* (Figure 66) (Appendix 10). In all cases trolling took place in the deep ocean waters north of the Andra reef platform (these deep waters are called *ndras arawan* when near the reef and *ndras mahun* when farther away). Length frequency analysis revealed the majority of *S. orientalis* were between 28 and 35 cm FL (Figure 67), with an average size of 31.1±0.1 cm FL.

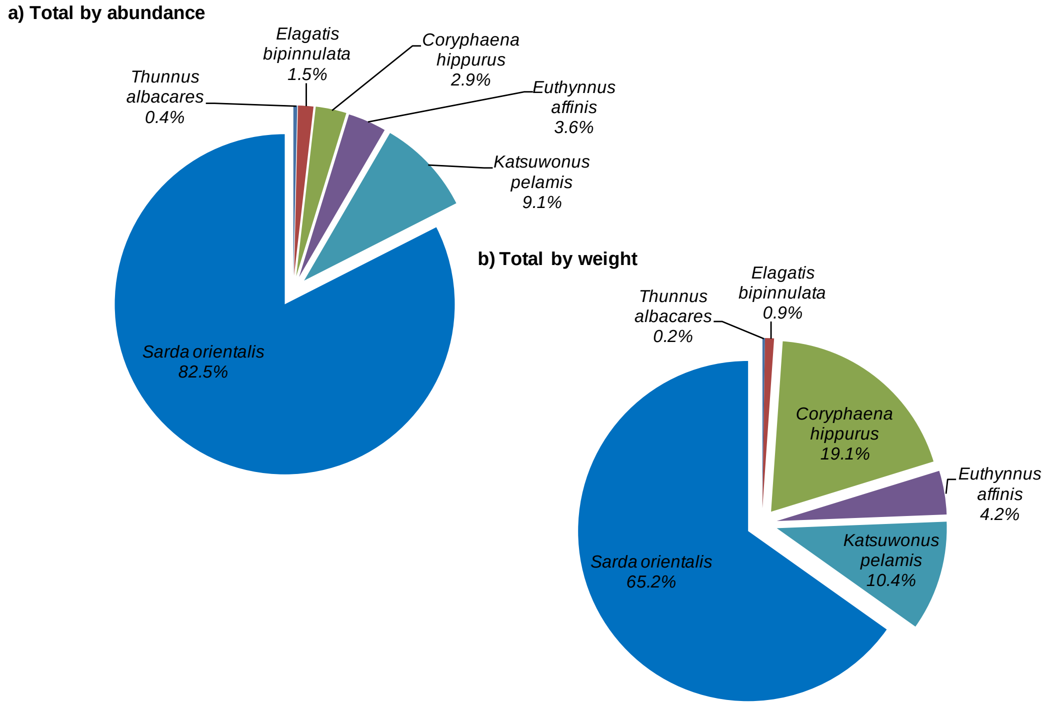


Figure 66 Percent contribution by abundance (top) and weight (bottom) of species caught by trolling, Andra Island, May–June 2014.

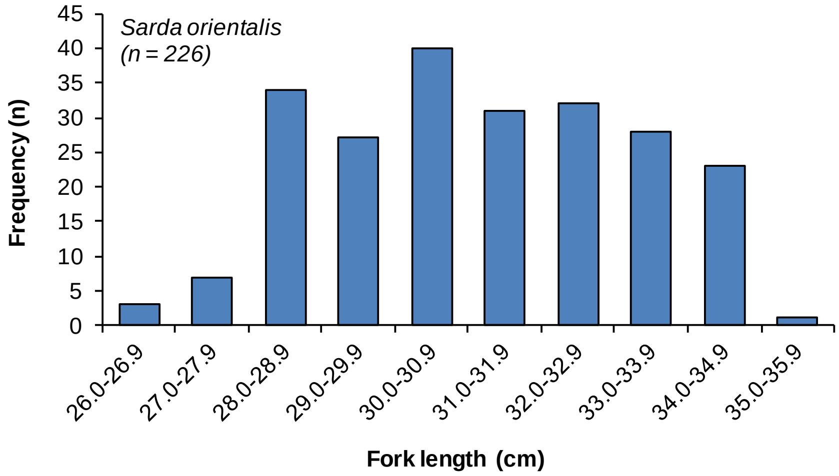


Figure 67 Length frequency of *Sarda orientalis* observed in trolling catches.

Table 15 Data summary of creel surveys conducted at Andra Island, May–June 2014.

Fishing method	**Bottom fishing**	**Drop-stone lining**	**Day spearfishing**	**Night spearfishing**	**Mixed reef gleaning**			**Trolling**
					Handlining	**Shell collecting**	**Spearing**	
No. surveys where method observed	12	6	6	9	5	11	11	18
Total number of fishers surveyed	12	11	8	9	5	12	11	27
Mean time spent fishing (hrs)	3.83±0.54	3.33±0.95	2.50±0.68	3.24±0.55	2.45±0.83	1.64±0.29	1.54±0.34	3.42±0.26
Mean no. of fishers per trip	1.00±0.00	1.83±0.83	1.33±0.21	1.00±0.00	1.00±0.00	1.09±0.09	1.00±0.00	1.50±0.29
Average catch (number of fish) per trip	17.17±3.20	11.50±5.35	12.00±3.30	52.11±6.66	12.00±3.42	169.45±39.27	12.45±3.68	15.22±2.12
Average catch (kg) per trip	10.79±1.99	9.80±4.33	6.26±2.00	15.30±1.70	2.18±0.69	-	2.92±0.80	7.60±1.81
Average CPUE by abundance (no. fish / fisher / hour)	5.51±1.45	2.37±0.82	4.31±0.69	19.90±4.42	5.06±0.67	95.64±19.47	7.31±1.40	3.72±0.57
Average CPUE by weight (kg / fisher / hour)	3.64±1.04	2.06±0.71	2.30±0.72	5.86±1.05	0.91±0.13	-	1.77±0.44	1.58±0.20
No. of landings needed to survey to detect change in CPUE by abundance at precision of 0.2 (to 1 sig. fig.)	21	18	4	11	2	11	10	11
No. of landings needed to survey to detect change in CPUE by weight at precision of 0.2 (to 1 sig. fig.)	25	18	15	7	2	-	17	7
No. of landings needed to survey to detect change in CPUE by abundance at precision of 0.3 (to 1 sig. fig.)	9	8	2	5	2	5	4	5
No. of landings needed to survey to detect change in CPUE by weight at precision of 0.3 (to 1 sig. fig.)	11	8	7	3	2	-	8	3

Fisher perceptions

Fisher perceptions were collected during 38 surveys[3]. The majority of fishers surveyed indicated that they had seen changes in the fishery in the last few years, with 66% of all respondents claiming they considered their catches had decreased compared to five years ago, and 61% of all respondents claiming sizes of fish had decreased compared to those five years ago (Figure 68). Variations in perceptions were observed amongst fishers operating in different fisheries and amongst genders. Of the fishers returning from nearshore/oceanic fishing trips (drop-stone lining and trolling), only 50% of respondents felt their catches had decrease in the last 5 years, while only 36% of respondents felt fish sizes had decreased (Figure 68). In contrast, 75% of respondent returning from reef/lagoon fishing activities (bottom fishing, spearfishing, netting, mixed gleaning etc) felt that catches and sizes had decreased (Figure 68). Of fishers returning from reef/lagoon fishing activities, 69.2% of males and 82% of females considered catch quantities had decreased, while 77% of males and 73% of females considered the sizes of individual fish or shellfish had decreased (Figure 68).

During the creel surveys fishers were asked their concerns and suggestions for management. Main concerns were:

- Overfishing;
- Habitat destruction and geophysical changes on the reef;
- Climate change;
- Increased population.

Some of the more common suggestions for management were:

- Night spearfishing (torch fishing) should be prohibited;
- The fish aggregating device (FAD) installed by NFA, which was damaged in 2013, should be repaired and re-deployed. This will bring pelagic fish closer to fishers and help reduce fishing pressure on reef habitats;
- Areas closed to fishing could be established to help protect stocks;
- Coral harvesting for lime production should be reduced, and corals should be replanted to increase fish habitat and complexity.
- Community-based fisheries management practices could be put in place, such as the establishment of permanent 'no-take' areas or local daily catch limits.

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

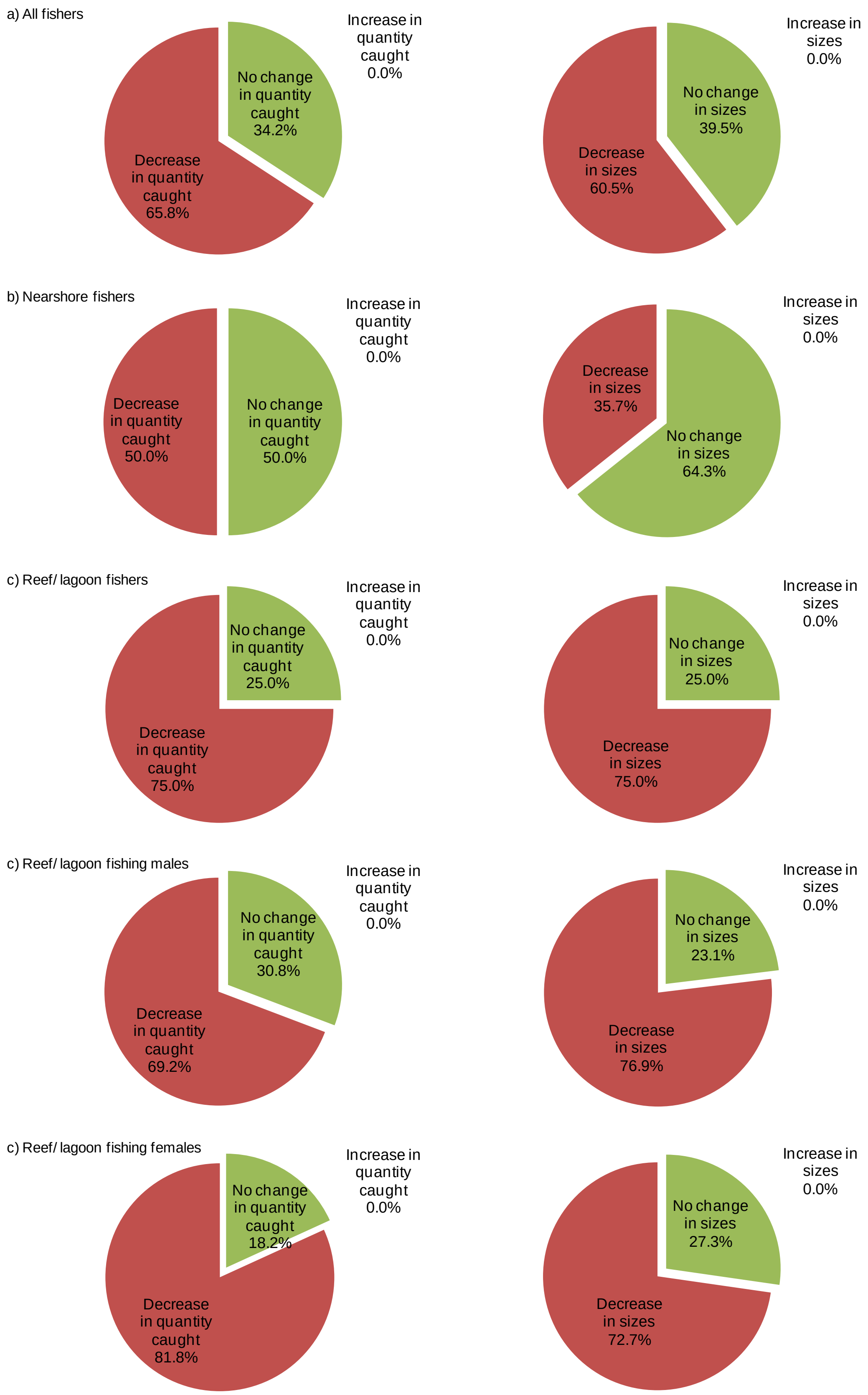


Figure 68 Responses of lead fishers to questions on perceptions on whether catch quantities (left) or fish sizes (right) have changed over the last five years.

7. Biological Monitoring of Selected Reef Fish Species

Methods

Sample collection

Biological monitoring of key reef fish species focused on two harvested species: humpback red snapper (*Lutjanus gibbus*) and orangespine unicornfish (*Naso lituratus*) and two unharvested ('control') species: redfin butterflyfish (*Chaetodon lunulatus*) and striated surgeonfish (*Ctenochaetus striatus*), which were included to control for the effects of fishing. Fish were collected from fishers or by fisheries-independent spearfishing. The fork length (FL) and total length (TL) were measured to the nearest millimetre for each fish collected, unless damaged. Each individual was weighed to the nearest 0.1 g unless damaged or eviscerated. Sex was determined from a macroscopic examination of the gonads. Gonads were weighed to the nearest 0.001 g. Sagittal otoliths (hereafter referred to as otoliths) were removed from all specimens for ageing purposes, cleaned, dried and stored in plastic vials until processing in the laboratory.

Sample processing

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

Otoliths from *C. lunulatus* were prepared using the single ground transverse sectioning method described in Krusic-Golub and Robertson (2014). Briefly, a single otolith from each fish was fixed on the edge of a slide using thermoplastic mounting media (CrystalBond), with the anterior of the otolith hanging over the edge of the slide, and the primordium just inside the slide's edge. The otolith was then ground down to the edge of the slide using 400 and 800 grit wet and dry paper. The slide was then reheated and the otolith removed and placed on a separate slide with CrystalBond, with the ground surface facing down. Once cooled, the otolith was ground horizontally to the grinding surface using varying grades (400, 88, 1200 and 1500 grit) of wet and dry paper and polished with lapping film.

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

Data analysis

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

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

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

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

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

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

Results

Forty-six redfin butterflyfish (*C. lunulatus*) were sampled by fisheries-independent spearfishing from the outer reefs of Ponam and Andra Island, 44 of which have been aged (Table 16). Ages ranged from 2–9 years, with a modal age of 5 years (Figure 69). Growth showed little variation amongst sexes (Figure 69).

Forty-three striated surgeonfish (*C. striatus*) were sampled by fisheries-independent spearfishing from Ponam reef and Andra Island. Of these, 42 have been aged. Estimated ages ranged from 2-16 years, with a modal age of 5 years (Figure 69). Growth showed little variation amongst sexes, although only a small number of females (n=9) were sampled (Figure 69).

Forty-six humpback red snapper (*L. gibbus*) were sampled from the fishers of Andra Island, 45 of which were successfully aged (Table 16). Estimated ages ranged from 2–11 years, with a modal age of 4 years (Figure 69). Growth differed markedly among sexes, with males reaching a greater length at a given age than females (Figure 69). Total (Z) and natural (M) rates of mortality were estimated as 0.381 and 0.262, respectively (Table 17). Fishing mortality was estimated as 0.119, slightly under the recommended optimal fishing mortality rate of 0.131 (Table 17).

Forty-two orangespine unicornfish (*Naso lituratus*) were sampled by fisheries-dependent and fisheries-independent spearfishing at the study region, with 41 of these aged to date (Table 16). Estimated ages ranged from 1–17 years, with a modal age of 2 years (Figure 69). Growth differed markedly among sexes, with males reaching a greater length at a given age than females (Figure 69).Total mortality (Z) and natural mortality were estimated as 0.683 and 0.246, respectively. Fishing mortality was calculated as 0.436, well above the recommended optimal fishing mortality rate of 0.123 (Table 17). As this may be an artefact of small sample sizes, further sampling of this species is required.

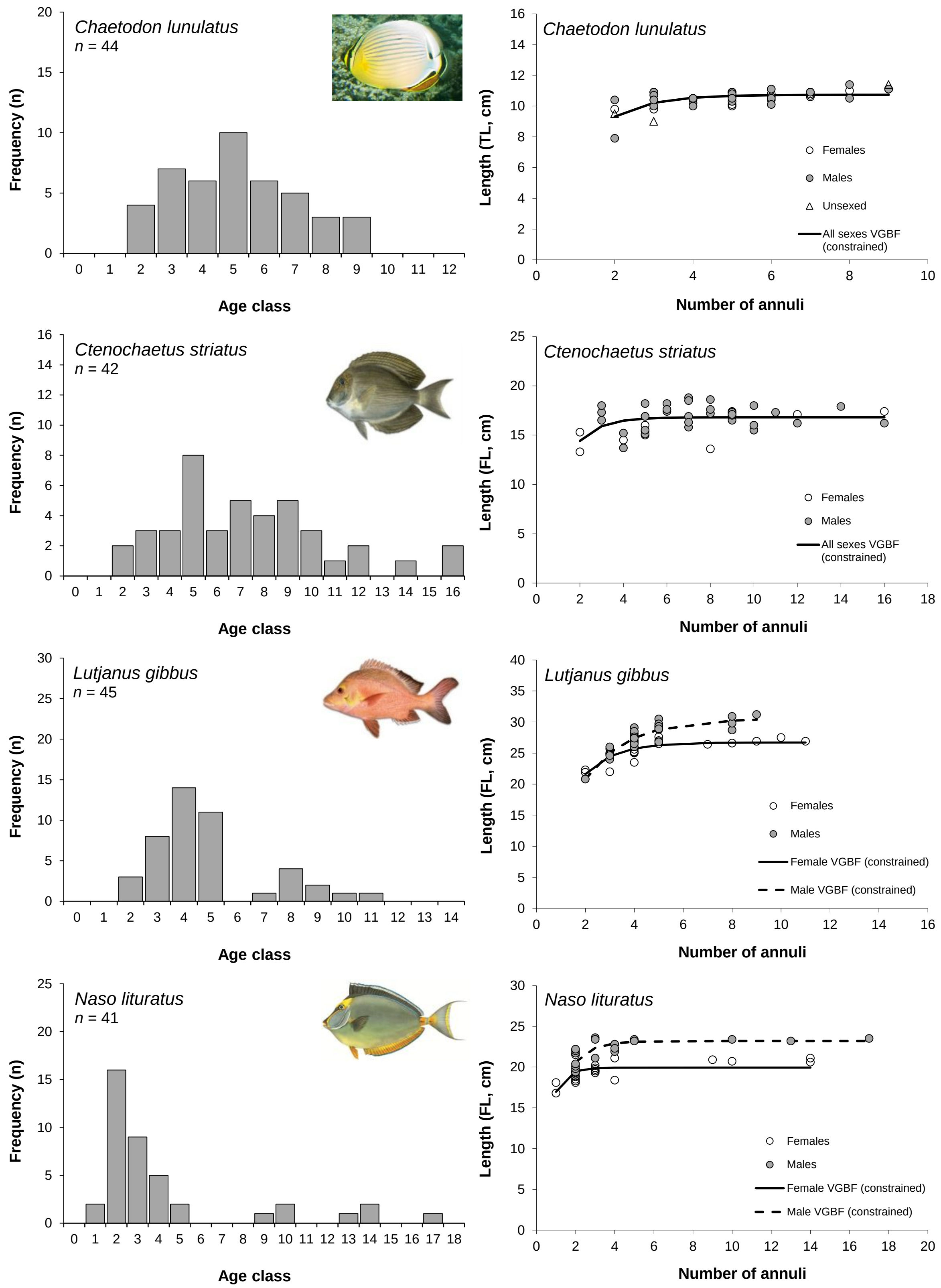


Figure 69 Age class frequencies (left) and von Bertalanffy growth function curves (right) for the four monitored finfish species at Andra Island, April–June 2014.

Table 16 Demographic parameter estimates for selected reef fish species from Andra Island, Papua New Guinea, April–June 2014. VBGF parameters are based on constrained (t_0=0) estimates.

Species	**No. collected**	**No. aged to date**	**Size range (cm)**	**Age range**	**L_∞ (males / females)**[4]	**K (males / females)**
Chaetodon lunulatus	46	44	7.9–11.4	2–9	10.7	1.01
Ctenochaetus striatus	43	42	13.3–18.8	2–16	16.8	0.98
Lutjanus gibbus	46	45	20.8–31.2	2–11	30.5 / 26.7	0.57 / 0.83
Naso lituratus	42	41	16.8–23.6	1–17	23.2 / 19.9	1.10 / 1.92

Table 17 Estimates of mortality for fished species (where n > 40 individuals aged) using catch curve and Hoenig (1983) estimators. Maximum ages used in the equation of Hoenig (1983) and age ranges used for total mortality (Z) calculations are indicated.

Species	**Maximum age (yr)**	**Age range**	**Catch curve (Z)**	**Hoenig (1983)**	**Fishing mortality (F)**	**Fopt**
Lutjanus gibbus	16 (this study)	4–11	0.381	0.262	0.119	0.131
Naso lituratus	17 (this study)	2–5	0.683	0.246	0.436	0.123

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

8. Discussion and Recommendations for Improving the Resilience of Coastal Fisheries of the Study Region

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

1) **Reduce nutrient input by replacing platform toilets with composting systems.** Poor overall health and considerable overgrowth of corals by macroalgae and cyanobacteria is apparent along the back reefs of Ahus and Andra Islands. This finding is suggestive of a widespread coral-algae regime shift in this region. Given their pattern of occurrence towards populated areas, and the lack of differences observed in the density and biomass of key herbivorous fish functional groups amongst populated (e.g. Ahus) and unpopulated sites (e.g. Onetah), the high cover of macroalgae and cyanobacteria likely results from high levels of point-source nutrient input. This hypothesis is supported by studies by Ford et al. (2014), who observed a decrease in O_2 consumption (a proxy for organic matter pollution) and macroalgae and cyanobacteria with increasing distance from the source of discharge, and an increase in live coral with increasing distance from the discharge, with highest live coral cover at control sites without any direct exposure. To prevent further overgrowth, and to promote the re-growth of coral on damaged reefs, it is highly recommended that the current platform toilets be replaced with land-based composting systems. Composting toilets could bring an additional benefit of providing high quality compost that would enrich the nutrient poor soils of the islands, allowing better growth of fruit and vegetables, helping to reduce household costs and increase food security. Toilets would have to be designed carefully to prevent contamination of precious groundwater supplies. An initial trail could be conducted to demonstrate the benefits of such systems. Funding donors should be sought with assistance from the national and provincial governments, and support from the NFA, local NGOs and regional organizations (e.g. SPC). Potential donors could include the Global Environment Facility (GEF; currently funding a regional project to build capacity of Pacific Island countries to manage water resources) or the Australian Department of Foreign Affairs and Trade (DFAT), who are funding a range of projects in Manus Province.

2) **Re-deployment of the Fish Aggregating Device (FAD).** Prior to breaking it's mooring in 2013, the NFA FAD was frequently used by fishers to access pelagic stocks, with many interviewed fishers stating that they preferentially fished on the FAD instead on of the reef while it was in place. We recommend that the FAD be reinstalled urgently to aggregate pelagic fishes closer to communities for ease of capture, thus reducing fishing pressure on reef resources and habitats.

3) **Creation of locally managed Marine Protected Areas.** Locally managed Marine Protected Areas (MPAs) can play a critical role in protecting diversity and managing marine resources. For Ahus, Onetah Island has been flagged to become a locally managed marine area by the Ahus community in a joint program with TNC. Onetah Island is considered an ideal location for the establishment of an MPA, due to its lack of population and subsequent lack of direct organic matter input, relative healthy reefs with high live coral cover and subsequent high structural complexity (in particular the outer reef), and high diversity of corals, finfish and invertebrate species. For Andra, suitable areas include the western-most and eastern-most points of the reef platform, or the northern passage area directly north of Andra Island. This latter area has the added advantage that it is easily visible from the shoreline, allowing for ease of enforcement. At either site, any MPA should be designed to include multiple habitats, such as outer reef areas, channels, reef flats and deeper lagoon areas.

4) **Place restrictions on destructive or highly efficient fishing practices, in particular night-time spearfishing.** Herbivorous fishes play an important role in coral reef resilience by limiting the establishment and growth of algal and thus facilitating settlement and growth of corals (Green and Bellwood 2009). However, such groups are highly vulnerable to night-time spearfishing. We recommend that restrictions be placed on night-time spearfishing at the community level. In conjunction, awareness programs should also be offered to inform communities of the benefits of protecting herbivorous fish stocks (see below), while alternate fishing options (e.g. FAD fishing) need to be established to provide alternate sources of protein for the local population.

5) **Maintain the national closure of sea cucumber fisheries.** A national ban was placed on the harvest of sea cucumbers in 2009 to allow stocks to recover. In 2013 it was decided to extend this closure for a further three years (Pakoa and Bertram 2013). Recently there has been interest to open the fishery. We strongly recommend that this ban is extended until at least such a time when a national assessment of sea cucumber populations is completed to maintain stock recovery and the ecological functioning sea cucumbers provide. It is highly recommended that a full sea cucumber survey be conducted in Manus by NFA with support from regional partners. Data should be collected in a manner consistent with methods outlined in Pakoa et al. (2014) to ensure densities are comparable to regional recommended healthy stock densities.

6) **Protect sharks and other iconic and ecologically-significant species.** Protection should be offered to ecologically significant species, in particular sharks, humphead wrasse, (*Cheilinus undulates*) and bumphead parrotfish (*Bolbometopon muricatum*). Sharks are apex predators that play a key role in maintaining healthy reef ecosystems. Despite extensive time in the water, only a single shark was observed during the surveys. Globally, reef shark populations are plummeting and at risk of ecological extinction over the coming decades as a result of fishing, primarily for the shark fin trade. We recommend that a permanent ban on sale of shark fin be put in place at least at the provincial level, or that a moratium be placed on the shark-fin fishery until such time as a NFA shark-fin management plan is in place. Similarly, the

humphead wrasse and bumphead parrotfish are listed as Endangered and Vulnerable, respectively, on the IUCN Red List in recognition of their slow population turnover and vulnerability to fishing, in particular nighttime spearfishing (Aswani and Hamilton 2004; Dulvy and Polunin 2004; Choat et al. 2006). To conserve these iconic species we recommend that a moratorium be placed on the commercial sale of *C. undulates* and *B. muricatum,* at least at the provincial level, and ideally the national level.

7) **Maintain healthy catchments on mainland Manus.** Due to their close proximity reefs of the northern outer islands of Manus, as elsewhere in the province, are highly susceptible to land-use practices on mainland Manus. Destruction of catchments by unsustainable mining and logging operations will result in increased sediment loads on reefs, resulting in further stress to already strained systems. Mangrove forests in particular should be afforded protection due to both their value as nursery habitats for a large number of fish and invertebrates and their roles as sediment traps.

8) **Strengthen stakeholder awareness programs and exchange of information on coastal fisheries, the marine environment and climate change.** It cannot be expected that outer island communities will be able to access the outcomes of this and other studies of their reefs through normal channels. Accordingly, education and awareness programs promoting responsible reef management practices and incorporating relevant scientific information should be provided to communities. Understanding the processes and effects of climate change will assist the communities to better integrate local and scientific knowledge in management processes and strategies to mitigate their impacts. NFA, with assistance from Manus Provincial Fisheries and other relevant groups (e.g. TNC, WCS offices in Manus) should play a central role in facilitating these programs.

Ultimately, any decision regarding management of reef resources should be done in consultation and collaboration with the communities of Andra and Ahus Islands. To be successful, management decisions will require the support of the entire community. Similarly, increasing resilience of Manus' reefs and decreasing their susceptibility to climate change will require a coordinated and unified commitment within the communities whose lives such habitats support.

Recommendations for Future Monitoring

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

- It is highly recommended that a 'core' monitoring team be established within NFA that can work with and support regional and local partner organisations (e.g. WCS, TNC). The development of a core team of monitoring staff will help maintain and build monitoring capacity, and help reduce surveyor biases that may otherwise preclude the detection of 'real' trends.

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

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

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

- The creel surveys conducted at Andra Island represent a single 'snapshot' of fisher behavior, fishing patterns and catches at the time of survey. Additional creel surveys, including in other locations such as neighbouring islands or the Lorengau port/fish market, are recommended to explore spatial and temporal variations in these parameters. Creel surveys should be conducted initially at least every six months, or better seasonally, and could be scaled back should little temporal variation emerge.

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Appendix 1 GPS positions of finfish and benthic habitat assessment transects

Station ID	Habitat	Transect name	Latitude (S)	Longitude (E)
Ahus 1	Back reef	Rb10	-1.943433	147.086733
	Back reef	Rb11	-1.943900	147.087267
	Back reef	Rb12	-1.944033	147.087967
	Lagoon reef	Rl31	-1.942150	147.080283
	Lagoon reef	Rl32	-1.942200	147.081033
	Lagoon reef	Rl33	-1.942450	147.081850
	Outer reef	Rs1	-1.930817	147.080550
	Outer reef	Rs2	-1.930900	147.081383
	Outer reef	Rs3	-1.931000	147.082333
Ahus 2	Back reef	Rb7	-1.944400	147.095167
	Back reef	Rb8	-1.944250	147.094117
	Back reef	Rb9	-1.944100	147.093550
	Lagoon reef	Rl34	-1.940867	147.084650
	Lagoon reef	Rl35	-1.941283	147.085200
	Lagoon reef	Rl36	-1.941167	147.085783
	Outer reef	Rs4	-1.931767	147.094667
	Outer reef	Rs5	-1.931783	147.095800
	Outer reef	Rs6	-1.931733	147.096450
Andra 1	Back reef	Rb22	-1.938233	146.948567
	Back reef	Rb23	-1.938283	146.949433
	Back reef	Rb24	-1.938333	146.950267
	Lagoon reef	Rl25	-1.934367	146.925867
	Lagoon reef	Rl26	-1.934783	146.926267
	Lagoon reef	Rl27	-1.935250	146.926717
	Outer reef	Rs13	-1.924267	146.948883
	Outer reef	Rs14	-1.924383	146.949583
	Outer reef	Rs15	-1.924283	146.950617
Andra 2	Back reef	Rb19	-1.942067	146.964050
	Back reef	Rb20	-1.941950	146.964917
	Back reef	Rb21	-1.941933	146.965917
	Lagoon reef	Rl28	-1.938083	146.930933
	Lagoon reef	Rl29	-1.938683	146.931733
	Lagoon reef	Rl30	-1.938767	146.932517
	Outer reef	Rs16	-1.925217	146.963083
	Outer reef	Rs17	-1.925017	146.964083
	Outer reef	Rs17	-1.924667	146.965000
Onetah 1	Back reef	Rb37	-1.944950	147.126500
	Back reef	Rb38	-1.945817	147.127817
	Back reef	Rb39	-1.945583	147.128867
	Outer reef	Rs43	-1.937800	147.130283
	Outer reef	Rs44	-1.937783	147.131417
	Outer reef	Rs45	-1.938217	147.132800
Onetah 2	Back reef	Rb40	-1.947267	147.137433
	Back reef	Rb41	-1.947450	147.136683
	Back reef	Rb42	-1.947650	147.135850
	Outer reef	Rs46	-1.939133	147.134917
	Outer reef	Rs47	-1.939650	147.136067
	Outer reef	Rs48	-1.939517	147.137183

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

Fish form UVC PAGE /

Campaign |_______________| Site |___________________________| Diver |__|__| Transect |__|__|__|

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

ST	SCIENTIFIC NAME	NBER	LGT	D1	D2	COMMENTS

Appendix 3 Form used to assess habitats supporting finfish

Habitat Form UVC (new)

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

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

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

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

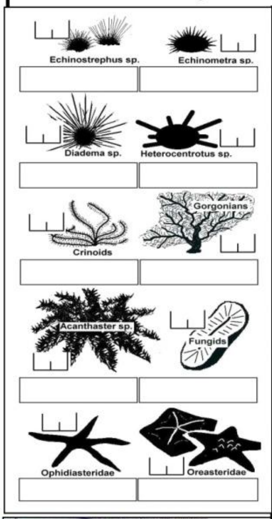
	current	oceanic influence	terrigenous influence
none	☐	☐	☐
medium	☐	☐	☐
strong	☐	☐	☐

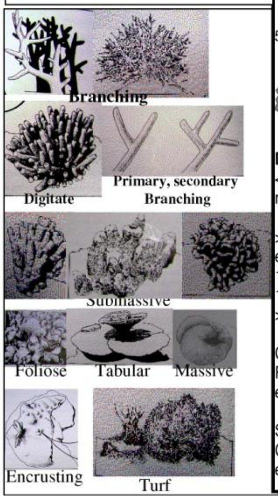
draw profile including estimate of slope in degree
Flat ☐ Floor ☐
Gentle slope ☐ Steep slope ☐

Remarks:

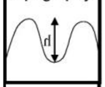
	Quadrat limits	0	10	20	30	40	50 %
	Depth of transect line (m)						
	Slope only: Depth of crest (m)						
	Slope only: Depth of floor (m)						
	Line of sight visibility (m)						
	Topography (1-5)						
	Complexity (1-5)						
1st layer	Hard substrate						100
	Soft substrate						
2nd layer	(1) Abiotic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

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

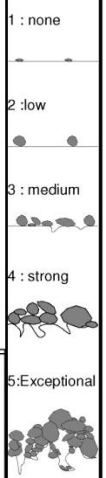




Topography



Complexity



Depth :
<10m : measure it ;
>10 m : estimate as
10-15m
15-20m
>20m

Crest side : Floor=transect depth

Slope side : Crest=transect depth

Appendix 4 PERMANOVA results for observed differences in finfish D-UVC surveys, 2012 vs. 2014

Site + habitat	Variable tested	Outcome	t	P	Unique perms
Ahus back reef	Mean density - Balistidae	2014 > 2012	3.1619	0.012	59
Ahus back reef	Mean density - Chaetodontidae	2014 > 2012	3.1550	0.014	236
Ahus back reef	Mean density - Scaridae	2014 > 2012	2.5953	0.025	317
Ahus back reef	Mean biomass - Balistidae	2014 > 2012	2.2221	0.039	206
Ahus back reef	Mean biomass - Scaridae	2014 > 2012	2.5928	0.028	410
Ahus back reef	Mean density - Corallivores	2014 > 2014	3.3895	0.012	200
Ahus back reef	Mean density – Micro-carnivores	2014 > 2012	2.9802	0.014	312
Ahus back reef	Mean density – Scraping herbivores	2014 > 2012	2.5953	0.033	316
Ahus back reef	Mean biomass – Scraping herbivores	2014 > 2012	2.5928	0.025	403
Ahus outer reef	Mean total density	2014 > 2012	3.9786	0.003	400
Ahus outer reef	Mean total biomass	2014 > 2012	4.0836	0.008	416
Ahus outer reef	Mean density - Acanthuridae	2014 > 2012	2.6485	0.014	312
Ahus outer reef	Mean density - Balistidae	2014 > 2012	3.1792	0.012	237
Ahus outer reef	Mean density - Lutjanidae	2014 > 2012	2.3844	0.032	24
Ahus outer reef	Mean density - Mullidae	2014 > 2012	2.8587	0.019	149
Ahus outer reef	Mean density – Scaridae	2014 > 2012	2.5967	0.047	200
Ahus outer reef	Mean biomass - Acanthuridae	2014 > 2012	3.7427	0.021	405
Ahus outer reef	Mean biomass - Holocentridae	2014 > 2012	2.5853	0.038	117
Ahus outer reef	Mean biomass - Labridae	2014 > 2012	2.8658	0.040	407
Ahus outer reef	Mean biomass - Mullidae	2014 > 2012	3.0582	0.021	407
Ahus outer reef	Mean biomass - Nemipteridae	2014 > 2012	2.2432	0.044	16
Ahus outer reef	Mean biomass - Pomacanthidae	2014 > 2012	3.1136	0.017	413
Ahus outer reef	Mean biomass - Pomacentridae	2014 > 2012	4.0507	0.012	407
Ahus outer reef	Mean biomass - Scaridae	2014 > 2012	3.4450	0.013	415
Ahus outer reef	Mean biomass - Zanclidae	2014 > 2012	2.5862	0.028	63
Ahus outer reef	Mean density - detritivores	2014 > 2012	2.2265	0.028	415
Ahus outer reef	Mean density – macro-carnivores	2014 > 2012	2.9169	0.019	313
Ahus outer reef	Mean density – micro-carnivores	2014 > 2012	4.1041	0.008	406
Ahus outer reef	Mean density - planktivores	2014 > 2012	2.7452	0.031	411
Ahus outer reef	Mean density – scraping herbivores	2014 - 2012	2.5967	0.029	195
Ahus outer reef	Mean biomass – browsing herbivores	2014 > 2012	2.8055	0.034	62
Ahus outer reef	Mean biomass - Corallivores	2014 > 2012	2.8628	0.027	407
Ahus outer reef	Mean biomass - detritivores	2014 > 2012	3.1626	0.018	401
Ahus outer reef	Mean biomass – macro-carnivores	2014 > 2012	4.2211	0.008	402
Ahus outer reef	Mean biomass – micro-carnivores	2014 > 2012	5.9929	0.003	404
Ahus outer reef	Mean biomass - planktivores	2014 > 2012	2.6401	0.026	409

Ahus outer reef	Mean biomass – scraping herbivores	2014 > 2012	3.445	0.014	410
Ahus outer reef	Mean biomass – farming herbivores	2014 > 2012	2.6284	0.021	414
Andra back reef	Mean density - Balistidae	2014 > 2014	2,7191	0.012	31
Andra back reef	Mean density - Chaetodontidae	2014 > 2012	4.1285	0.004	409
Andra back reef	Mean density - Pomacanthidae	2014 > 2012	2.6341	0.017	122
Andra back reef	Mean density - Serranidae	2014 > 2012	1.4787	0.048	22
Andra back reef	Mean density - Siganidae	2014 > 2012	2.5395	0.024	23
Andra back reef	Mean biomass - Balistidae	2014 > 2012	3.8434	0.002	118
Andra back reef	Mean biomass - Chaetodontidae	2014 > 2012	3.0153	0.020	406
Andra back reef	Mean biomass - Mullidae	2014 > 2012	2.7471	0.027	398
Andra back reef	Mean biomass - Siganidae	2014 > 2012	2.5766	0.014	32
Andra back reef	Mean density - Corallivores	2014 > 2012	4.3391	0.007	313
Andra back reef	Mean biomass - Corallivores	2014 > 2012	3.0150	0.021	408
Andra outer reef	Mean total density	2014 > 2012	4.1304	0.005	408
Andra outer reef	Mean density - Chaetodontidae	2014 > 2012	2.8268	0.029	110
Andra outer reef	Mean density - Nemipteridae	2014 > 2012	1.9123	0.016	23
Andra outer reef	Mean density - Pomacanthidae	2014 > 2012	6.2684	0.002	236
Andra outer reef	Mean density - Pomacentridae	2014 > 2012	3.2061	0.011	403
Andra outer reef	Mean density - Scaridae	2014 > 2012	3.0350	0.016	313
Andra outer reef	Mean biomass - Nemipteridae	2014 > 2012	2.5005	0.007	62
Andra outer reef	Mean biomass - Pomacanthidae	2014 > 2012	5.0169	0.002	315
Andra outer reef	Mean biomass - Pomacentridae	2014 > 2012	2.3246	0.039	404
Andra outer reef	Mean biomass - Scaridae	2014 > 2012	2.1914	0.043	398
Andra outer reef	Mean density – Browsing herbivores	2014 > 2012	2.1431	0.009	12
Andra outer reef	Mean density - Corallivores	2014 > 2012	4.5645	0.004	406
Andra outer reef	Mean density – Micro-carnivores	2014 > 2012	3.2192	0.006	418
Andra outer reef	Mean density - Planktivores	2014 > 2012	4.2180	0.002	407
Andra outer reef	Mean density - Scraping herbivores	2014 > 2012	3.0350	0.023	311
Andra outer reef	Mean biomass - Browsing herbivores	2014 > 2012	2.3653	0.018	16
Andra outer reef	Mean biomass - Corallivores	2014 > 2012	2.9201	0.020	419
Andra outer reef	Mean biomass - Micro-carnivores	2014 > 2012	2.6573	0.036	414
Andra outer reef	Mean biomass - Planktivores	2014 > 2012	3.7195	0.008	406
Andra outer reef	Mean biomass – Scraping herbivores	2014 > 2012	2.1914	0.040	411

Appendix 5 PERMANOVA results for observed differences in fine-scale benthic habitat assessments, 2012 vs. 2014

Site + habitat	Variable tested	Outcome	t	P	Unique perms
Ahus outer reef	Turf algae	2014 < 2012	3.8431	0.011	412
Andra back reef	Sand / silt	2014 > 2012	2.3078	0.039	416
Andra back reef	Turf algae	2014 < 2012	4.4626	0.005	416
Andra lagoon reef	Turf algae	2014 < 2012	2.8557	0.020	410
Andra outer reef	Macroalgae	2014 < 2012	2.9355	0.015	412

Appendix 6 Invertebrate survey form

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

DATE		RECORDER		Pg No	

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

Appendix 7 GPS positions of manta tow surveys conducted at the Ahus, Andra and Onetah monitoring sites

Site	Station ID	Replicate	Start Latitude (S)	Start Longitude (E)
Ahus 2014	Manta 3	1	-1.942667	147.110767
Ahus 2014	Manta 3	2	-1.944350	147.108717
Ahus 2014	Manta 3	3	-1.944967	147.105917
Ahus 2014	Manta 3	4	-1.944817	147.102967
Ahus 2014	Manta 3	5	-1.945033	147.100317
Ahus 2014	Manta 3	6	-1.944833	147.097233
Ahus 2014	Manta 4	1	-1.944067	147.093900
Ahus 2014	Manta 4	2	-1.944067	147.090967
Ahus 2014	Manta 4	3	-1.943983	147.088167
Ahus 2014	Manta 4	4	-1.943333	147.086333
Ahus 2014	Manta 4	5	-1.942167	147.084617
Ahus 2014	Manta 4	6	-1.942350	147.087033
Ahus 2014	Manta 7	1	-1.940433	147.112233
Ahus 2014	Manta 7	2	-1.937983	147.111967
Ahus 2014	Manta 7	3	-1.93595	147.110400
Ahus 2014	Manta 7	4	-1.934983	147.107683
Ahus 2014	Manta 7	5	-1.934367	147.104933
Ahus 2014	Manta 7	6	-1.933683	147.102267
Ahus 2014	Manta 8	1	-1.932200	147.092250
Ahus 2014	Manta 8	2	-1.931883	147.089200
Ahus 2014	Manta 8	3	-1.931833	147.085883
Ahus 2014	Manta 8	4	-1.931433	147.083033
Ahus 2014	Manta 8	5	-1.931017	147.080050
Ahus 2014	Manta 8	6	-1.930400	147.077100
Andra 2014	Manta 1	1	-1.930350	146.931733
Andra 2014	Manta 1	2	-1.932067	146.932850
Andra 2014	Manta 1	3	-1.931600	146.934833
Andra 2014	Manta 1	4	-1.937983	146.946300
Andra 2014	Manta 1	5	-1.938300	146.949017
Andra 2014	Manta 1	6	-1.938400	146.952517
Andra 2014	Manta 2	1	-1.939217	146.955867
Andra 2014	Manta 2	2	-1.940933	146.958183
Andra 2014	Manta 2	3	-1.941750	146.960950
Andra 2014	Manta 2	4	-1.942150	146.963783
Andra 2014	Manta 2	5	-1.941917	146.966767
Andra 2014	Manta 2	6	-1.941467	146.969633
Andra 2014	Manta 5	1	-1.925583	146.969133
Andra 2014	Manta 5	2	-1.925300	146.966367
Andra 2014	Manta 5	3	-1.925800	146.963417
Andra 2014	Manta 5	4	-1.926300	146.960950
Andra 2014	Manta 5	5	-1.925750	146.958017
Andra 2014	Manta 5	6	-1.925250	146.955200
Andra 2014	Manta 6	1	-1.924467	146.948750

Site	Station ID	Replicate	Start Latitude (S)	Start Longitude (E)
Andra 2014	Manta 6	2	-1.924867	146.945867
Andra 2014	Manta 6	3	-1.924533	146.943117
Andra 2014	Manta 6	4	-1.925233	146.940267
Andra 2014	Manta 6	5	-1.925083	146.937433
Andra 2014	Manta 6	6	-1.923883	146.934350
Onetah 2014	Manta 9	1	-1.946717	147.138600
Onetah 2014	Manta 9	2	-1.947033	147.137583
Onetah 2014	Manta 9	3	-1.947217	147.135017
Onetah 2014	Manta 9	4	-1.947217	147.132383
Onetah 2014	Manta 9	5	-1.947067	147.130250
Onetah 2014	Manta 9	6	-1.946517	147.129450
Onetah 2014	Manta 10	1	-1.940000	147.136567
Onetah 2014	Manta 10	2	-1.939083	147.133867
Onetah 2014	Manta 10	3	-1.938150	147.131333
Onetah 2014	Manta 10	4	-1.938533	147.129417
Onetah 2014	Manta 10	5	-1.938650	147.127267
Onetah 2014	Manta 10	6	-1.939450	147.125067

Appendix 8 GPS positions of reef-benthos transects conducted at the Ahus, Andra and Onetah monitoring sites

Site	Station ID	Latitude (S)	Longitude (E)
Ahus 2014	RBt_7	-1.944033	147.094233
Ahus 2014	RBt_8	-1.943950	147.088267
Ahus 2014	RBt_9	-1.942350	147.088550
Ahus 2014	RBt_10	-1.942683	147.110833
Ahus 2014	RBt_11	-1.944667	147.106333
Ahus 2014	RBt_12	-1.945017	147.097683
Andra 2014	RBt_1	-1.928783	146.938950
Andra 2014	RBt_2	-1.928450	146.941750
Andra 2014	RBt_3	-1.928867	146.944617
Andra 2014	RBt_4	-1.940917	146.958200
Andra 2014	RBt_5	-1.942083	146.963783
Andra 2014	RBt_6	-1.940083	146.971883
Onetah 2014	RBt_13	-1.944933	147.127217
Onetah 2014	RBt_14	-1.945267	147.129100
Onetah 2014	RBt_15	-1.946200	147.130433
Onetah 2014	RBt_16	-1.947167	147.132967
Onetah 2014	RBt_17	-1.947267	147.134817
Onetah 2014	RBt_18	-1.947233	147.137333

Appendix 9 Form used during creel surveys

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

Slice C1 basic information on fishers

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

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

C3 Species sizes and C4 Species weights

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

C5 Effort data for CPUE

How many hours spent on the fishing trip today (includes travel time)?	hrs

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

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

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

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

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

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

Where did you leave from?

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

Site	Location (on map, lat/long, or distance to each fishing ground)	Time spent at location
1.		
2.		
3.		
4.		

What kind of boat used today?

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

If "Other", What kind of boat?

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

C6 Catch prices

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

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

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

2.				
3.				
4.				

C7 Perceptions of fishers

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

Appendix 10 Number of individuals observed from various methods during creel surveys, May–June 2014 and relative percent contribution to overall catch by method

Fishing method	Species	Number observed	% contribution by abundance	% contribution by weight
Bottom fishing	*Aethaloperca rogaa*	2	0.97	1.33
	Aprion virescens	1	0.49	1.10
	Canthidermis maculata	1	0.49	0.39
	Carangoides orthogrammus	6	2.91	1.85
	Caranx papuensis	2	0.97	1.36
	Caranx sexfasciatus	32	15.53	22.75
	Carcharhinus melanopterus	2	0.97	1.88
	Cephalopholis argus	1	0.49	0.15
	Cephalopholis miniata	1	0.49	0.49
	Cephalopholis sonnerati	1	0.49	0.29
	Epinephelus coioides	1	0.49	0.91
	Lethrinus atkinsoni	1	0.49	0.56
	Lethrinus erythropterus	4	1.94	2.29
	Lethrinus harak	4	1.94	0.94
	Lethrinus laticaudis	1	0.49	1.03
	Lethrinus lentjan	1	0.49	0.32
	Lethrinus miniatus	1	0.49	0.42
	Lethrinus obsoletus	7	3.40	1.38
	Lethrinus ornatus	5	2.43	1.33
	Lethrinus rubrioperculatus	2	0.97	0.56
	Lethrinus xanthochilus	3	1.46	0.99
	Lutjanus bohar	3	1.46	4.34
	Lutjanus gibbus	54	26.21	16.86
	Lutjanus kasmira	3	1.46	0.29
	Lutjanus lutjanus	4	1.94	0.34
	Lutjanus monostigma	1	0.49	0.32
	Lutjanus semicinctus	3	1.46	0.49
	Lutjanus timorensis	12	5.83	15.51
	Lutjanus vitta	10	4.85	1.40
	Monotaxis grandoculis	1	0.49	1.14
	Parupeneus cyclostomus	1	0.49	0.29
	Plectorhinchus picus	2	0.97	1.12
	Sargocentron tiere	3	1.46	0.32
	Scomberomorus commerson	4	1.94	7.13
	Selar boops	8	3.88	1.06
	Sphyraena forsteri	6	2.91	2.73
	Sphyraena qenie	4	1.94	2.73
	Variola louti	8	3.88	1.60
Drop-stone	*Canthidermis maculata*	45	65.22	52.70
	Caranx papuensis	1	1.45	0.26
	Carcharhinus amblyrhynchos	5	7.25	26.38
	Elagatis bipinnulata	13	18.84	15.85

Fishing method	Species	Number observed	% contribution by abundance	% contribution by weight
	Naso vlamingii	4	5.80	4.37
	Scomberoides commersonnianus	1	1.45	0.44
Spearfishing (day)	*Acanthurus lineatus*	6	8.33	2.16
	Acanthurus mata	1	1.39	2.71
	Acanthurus nigricans	7	9.72	1.57
	Acanthurus nigricauda	6	8.33	4.47
	Acanthurus nigrofuscus	6	8.33	5.38
	Acanthurus xanthopterus	2	2.78	12.56
	Carangoides orthogrammus	1	1.39	2.34
	Cetoscarus ocellatus	1	1.39	2.93
	Chlorurus microrhinos	1	1.39	2.50
	Ctenochaetus striatus	1	1.39	0.21
	Epinephelus coeruleopunctatus	1	1.39	2.98
	Epinephelus merra	1	1.39	0.40
	Epinephelus polyphekadion	1	1.39	2.40
	Hipposcarus longiceps	4	5.56	5.22
	Kyphosus vaigiensis	5	6.94	5.24
	Leptoscarus vaigiensis	5	6.94	1.78
	Lethrinus olivaceus	1	1.39	4.88
	Lutjanus fulvus	1	1.39	0.48
	Naso lituratus	3	4.17	1.78
	Naso unicornis	1	1.39	3.46
	Octopus cyanea	3	4.17	5.64
	Panulirus ornatus	2	2.78	0.56
	Parupeneus multifasciatus	1	1.39	0.11
	Plectorhinchus lineatus	4	5.56	19.16
	Plectorhinchus vittatus	2	2.78	3.33
	Scarus ghobban	2	2.78	4.29
	Siganus fuscescens	1	1.39	0.53
	Strongylura incisa	2	2.78	0.93
Spearfishing (night)	*Acanthurus auranticavus*	2	0.43	0.33
	Acanthurus dussumieri	6	1.28	3.73
	Acanthurus grammoptilus	2	0.43	0.21
	Acanthurus lineatus	35	7.46	4.12
	Acanthurus mata	2	0.43	0.35
	Acanthurus nigricauda	4	0.85	0.69
	Acanthurus nigrofuscus	17	3.62	2.85
	Acanthurus olivaceus	1	0.21	0.19
	Acanthurus triostegus	3	0.64	0.26
	Aluterus scriptus	1	0.21	1.04
	Caranx melampygus	1	0.21	0.23
	Cephalopholis argus	6	1.28	1.84
	Cetoscarus ocellatus	14	2.99	3.12
	Chaetodon auriga	1	0.21	0.12

Fishing method	Species	Number observed	% contribution by abundance	% contribution by weight
	Cheilinus trilobatus	2	0.43	0.46
	Chlorurus bleekeri	4	0.85	0.66
	Chlorurus microrhinos	1	0.21	0.49
	Chlorurus sordidus	2	0.43	0.56
	Choerodon anchorago	1	0.21	0.30
	Ctenochaetus striatus	5	1.07	0.62
	Epinephelus fuscoguttatus	1	0.21	2.86
	Epinephelus maculatus	1	0.21	0.57
	Gnathodentex aureolineatus	1	0.21	0.13
	Hipposcarus longiceps	15	3.20	3.64
	Kyphosus vaigiensis	4	0.85	0.75
	Lethrinus erythropterus	1	0.21	0.16
	Lethrinus harak	2	0.43	0.31
	Lethrinus laticaudis	4	0.85	1.05
	Lethrinus obsoletus	2	0.43	0.34
	Lethrinus ornatus	1	0.21	0.23
	Lethrinus rubrioperculatus	5	1.07	0.95
	Lethrinus xanthochilus	7	1.49	1.13
	Lutjanus argentimaculatus	1	0.21	1.66
	Lutjanus bohar	1	0.21	0.93
	Lutjanus gibbus	10	2.13	1.76
	Macolor macularis	1	0.21	0.29
	Monotaxis grandoculis	2	0.43	1.59
	Mulloidichthys vanicolensis	5	1.07	0.76
	Myripristis adusta	1	0.21	0.08
	Naso lituratus	13	2.77	2.25
	Naso unicornis	1	0.21	0.20
	Naso vlamingii	14	2.99	3.13
	Neoniphon sammara	1	0.21	0.12
	Panulirus penicillatus	1	0.21	0.00
	Parupeneus barberinoides	1	0.21	0.05
	Parupeneus barberinus	68	14.50	10.80
	Parupeneus crassilabris	10	2.13	1.23
	Parupeneus cyclostomus	7	1.49	1.64
	Parupeneus indicus	14	2.99	2.99
	Parupeneus multifasciatus	2	0.43	0.15
	Platax boersii	1	0.21	1.52
	Platax teira	1	0.21	0.19
	Plectorhinchus vittatus	2	0.43	0.25
	Plectropomus areolatus	4	0.85	2.74
	Pseudobalistes flavimarginatus	1	0.21	2.39
	Sargocentron cornutum	2	0.43	0.21
	Scarus chameleon	1	0.21	0.37
	Scarus dimidiatus	2	0.43	0.27

Fishing method	Species	Number observed	% contribution by abundance	% contribution by weight
	Scarus frenatus	12	2.56	3.19
	Scarus ghobban	1	0.21	0.62
	Scarus globiceps	20	4.26	3.68
	Scarus niger	2	0.43	0.40
	Scarus oviceps	1	0.21	0.16
	Scarus prasiognathos	1	0.21	0.45
	Scarus psittacus	6	1.28	1.21
	Scarus quoyi	11	2.35	1.59
	Scarus rivulatus	11	2.35	2.38
	Scarus spinus	1	0.21	0.11
	Scarus tricolor	1	0.21	0.30
	Siganus argenteus	10	2.13	1.57
	Siganus canaliculatus	12	2.56	1.82
	Siganus doliatus	14	2.99	2.48
	Siganus guttatus	2	0.43	0.36
	Siganus lineatus	9	1.92	2.23
	Siganus punctatus	3	0.64	0.68
	Siganus spinus	20	4.26	2.77
	Siganus vermiculatus	2	0.43	0.72
	Siganus vulpinus	1	0.21	0.17
	Zebrasoma veliferum	8	1.71	1.27
Trolling	*Coryphaena hippurus*	8	2.92	19.14
	Elagatis bipinnulata	4	1.46	0.86
	Euthynnus affinis	10	3.65	4.15
	Katsuwonus pelamis	25	9.12	10.43
	Sarda orientalis	226	82.48	65.18
	Thunnus albacares	1	0.36	0.24
Mixed gleaning (handline)	*Acanthurus triostegus*	1	1.67	0.75
	Cheilinus trilobatus	6	10.00	7.18
	Cheilio inermis	1	1.67	0.98
	Choerodon anchorago	1	1.67	5.14
	Epinephelus areolatus	1	1.67	2.30
	Epinephelus merra	4	6.67	3.40
	Leptoscarus vaigiensis	1	1.67	0.34
	Lethrinus harak	3	5.00	5.53
	Lethrinus obsoletus	3	5.00	7.26
	Lethrinus ornatus	7	11.67	16.08
	Lethrinus rubrioperculatus	18	30.00	29.75
	Lutjanus semicinctus	1	1.67	1.65
	Novaculichthys taeniourus	2	3.33	4.41
	Rhinecanthus aculeatus	1	1.67	1.65
	Rhinecanthus verrucosus	8	13.33	10.09
	Scarus frenatus	1	1.67	1.55
	Scarus spinus	1	1.67	1.95

Fishing method	Species	Number observed	% contribution by abundance	% contribution by weight
Mixed gleaning (collecting)	*Cypraea annulus*	3	0.16	-
	Cypraea moneta	9	0.48	-
	Cypraea tigris	6	0.32	-
	Hippopus hippopus	7	0.38	-
	Lambis crocata	6	0.32	-
	Lambis scorpius	7	0.38	-
	Lambis truncata	27	1.45	-
	Octopus cyanea	1	0.05	-
	Scylla serrata	1	0.05	-
	Strombus luhuanus	1770	94.91	-
	Strombus thersites	16	0.86	-
	Tridacna gigas	1	0.05	-
	Tridacna squamosa	10	0.54	-
	Trochus maculata	1	0.05	-
Mixed gleaning (spear)	*Acanthurus nigricauda*	1	0.73	0.62
	Acanthurus triostegus	55	40.15	15.59
	Arothron meleagris	2	1.46	2.02
	Balistapus undulatus	2	1.46	0.67
	Chaetodon ephippium	1	0.73	0.26
	Chaetodon rafflesii	1	0.73	0.19
	Cheilinus trilobatus	4	2.92	1.40
	Chlorurus sordidus	1	0.73	0.28
	Epinephelus hexagonatus	5	3.65	2.49
	Epinephelus merra	9	6.57	2.61
	Lethrinus ornatus	1	0.73	0.68
	Lethrinus rubrioperculatus	1	0.73	0.90
	Myripristis murdjan	1	0.73	0.19
	Novaculichthys taeniourus	14	10.22	9.43
	Octopus cyanea	32	23.36	60.50
	Sargocentron microstoma	1	0.73	0.22
	Sargocentron rubrum	1	0.73	0.25
	Scarus dimidiatus	1	0.73	0.56
	Scarus globiceps	1	0.73	0.16
	Siganus spinus	1	0.73	0.44
	Sufflamen chrysopterum	1	0.73	0.22
	Zanclus cornutus	1	0.73	0.34