Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change

Pohnpei
Federated States of Micronesia

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ACRONYMS

AusAID	Australian Agency for International Development
CPC	Coral Point Count
CPUE	Catch-per-unit-effort
CSP	Conservation Society of Pohnpei
D-UVC	Distance-sampling underwater visual census
EEZ	Exclusive Economic Zone
FL	Fork length
FSM	Federated States of Micronesia
FSM R&D	FSM Department of Resources and Development
g	gram(s)
GDP	Gross Domestic Product
GPS	Global Positioning System
GR	Government Revenue
ha	hectare
ICCAI	International Climate Change Adaptation Initiative (Australia)
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram(s)
m	metre(s)
mm	millemetre(s)
MPA	Marine Protected Area
MCRMP	Millennium Coral Reef Mapping Project
NASA	National Aeronautics and Space Administration
NGO	Non-government organisation
OFA	Office of Fisheries and Aquaculture
PCCSP	Pacific Climate Change Science Program
PERMANOVA	Permutational multivariate analysis of variance
PICT	Pacific Island Countries and Territories
PROCFish	Pacific Regional Oceanic and Coastal Fisheries Development Programme
RBt	Reef-benthos transect
SBt	Soft-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
USD	United States dollar(s)
VBGF	von Bertalannfy growth function

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EXECUTIVE SUMMARY

Introduction

Considering the concerns of climate change and its impacts on coastal fisheries resources, the Secretariat of the Pacific Community (SPC) is implementing the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project with funding assistance from the Australian Government's International Climate Change Adaptation Initiative (ICCAI). This project aims to assist Pacific Island Countries and Territories (PICTs) to determine whether changes are occurring in the productivity of coastal fisheries and, if changes are found, to identify the extent to which such changes may be due to climate change, as opposed to other causative factors. This report presents the results of the second survey for the project conducted in Pohnpei, Federated States of Micronesia, in February-March 2014. Results are compared against those from the baseline survey of Pohnpei conducted in 2012.

Survey Design

Survey work at Pohnpei covered six disciplines, including monitoring of water temperature, assessments of finfish and invertebrate resources and benthic habitats, creel surveys and biological monitoring of key reef fishes, and was conducted by staff from SPC's Coastal Fisheries Science and Management Section, Pohnpei States' Office of Fisheries and Aquaculture (OFA), FSM National Government's Department of Resources and Development (FSM R&D) and the Conservation Society of Pohnpei (CSP). In-water surveys were focused in and around the Kehpara Marine Sanctuary (Kehpara MPA) (for assessments of finfish, benthic habitats and reef-associated invertebrates) and the Pwudoi Mangrove Reserve (Pwudoi MPA) (for assessments of soft-benthos associated invertebrates), in the south-west of Pohnpei Island. Monitoring stations were established within the protected areas (MPA sites) and within surrounding areas open to fishing (Open sites). Creel surveys, included in the survey for the first time in 2014, focused on fishers landing at the Kitti and Kolonia municipalities. 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 Kehpara region were surveyed using distance-sampling underwater visual census (D-UVC) methodology, conducted at the same sites as both the 2012 assessment and the benthic habitat assessments. The following key observations were made:

- Finfish diversity was found to be consistently higher in 2014 compared to 2012 for most stations and habitats. Further monitoring is required to determine whether these changes are a result of different surveyor skill or increased experience levels or whether they represent 'real' changes in finfish populations.
- In terms of density, few statistically significant differences were evident among the 2012 and 2014 surveys at either the Kehpara MPA or Kehpara Open site. Differences that were observed showed little consistency among groups, sites or habitats. Accordingly, it is likely that these differences represent natural variations in finfish density, rather than being

indicative of long-terms trends. Further monitoring at the established sites is warranted to accurately define long-term trends in finfish density

- Similarly, few differences were observed in both density and biomass of fish within the Kehpara Marine Sanctuary (Kehpara MPA) and adjacent sites open to fishing. This suggests that the MPA is currently ineffective in protecting fish populations.

Benthic Habitat Assessments

Benthic habitats of Pohnpei were surveyed using two complementary approaches: a broad-scale method, using manta tows, and a fine-scale method, using a photoquadrat analysis.

Few differences in benthic habitat were evident from the broad-scale assessments at the Kehpara Open site, with cover of live and dead coral, bleached coral, rubble, coralline algae and other macroalgae all appearing similar among 2012 and 2014 surveys. At the Kehpara MPA site, significant reductions in dead coral and increases in coralline algae (primarily *Halimeda*) were noted. Ongoing surveys are required to determine whether these differences reflect variations in surveyor classification, slightly different paths in the manta tow among surveys, or real differences in the state of habitats.

Outer reef habitats were included in the broad-scale survey for the first time in 2014. Few differences were evident among the Kehpara MPA and the Open site, with cover of live coral, dead coral, rubble, coralline algae and macroalgae similar among sites.

Fine-scale assessments of benthic habitats were conducted at the same sites as the 2012 assessment and the assessments of finfish communities, with 18 x 50 m transects surveyed in each of the Kehpara MPA and Open sites. Benthic habitats of the Kehpara MPA showed little difference among surveys, and were in relatively good health, although lagoon reefs of the MPA had a significantly lower mean percent cover of live hard coral relative to those at the Open site. Outer reef transects within the MPA had a significantly higher cover of live hard coral than those within the Kehpara Open site in both 2012 and 2014.

As with the Kehpara MPA, no significant differences were evident in cover of benthic habitats at either lagoon reef or outer reef transects of the Open site among surveys. A reduction in live coral cover (in particular *Acropora* spp.) and a significant increase in cover of macroalgae was apparent on the back reef habitat of the Kehpara Open site amongst surveys. On note, the cover of cyanobacteria increased from 0.00% in 2012 to 14.45% in 2014. The causes for such changes are unclear, and ongoing monitoring is needed to determine whether these differences represent a permanent change in community composition or a short-term anomaly.

Invertebrate Surveys

Invertebrate resources of the study region were surveyed using three complementary approaches: a broad-scale method, using manta tows, and two fine-scale approaches, namely reef benthos and soft benthos transects.

Manta tow assessments of invertebrate populations focused on the back and lagoon reefs of both the Kehpara MPA and adjacent Open site, and used the same stations as surveyed in the 2012 assessment. No significant differences in invertebrate densities were observed among the 2012 and 2014 surveys within either the Kehpara MPA or Kehpara Open sites. Few differences in invertebrate densities were observed amongst the Kehpara MPA and Open sites during the 2014 survey, suggesting that the MPA has limited benefit in conserving invertebrate stocks. With the exception of tigerfish (*Bohadschia argus*), mean densities of sea cucumber species observed by manta tow were well below the regional reference densities for healthy sea cucumber stocks.

Reef benthos transects (RBt) were used to assess invertebrate resources associated with reef habitats at finer-spatial scales. Assessments were conducted at the same sites as the 2012 survey, with eight RBt stations surveyed in each of the Kehpara MPA and Open monitoring sites. Invertebrate diversity at RBt stations was lower in 2014 than 2012 at both sites. The Kehpara MPA had little effect on invertebrate diversity, with diversity in the Kehpara MPA similar to that at stations open to fishing. Significant declines in the densities of the popular food and ornamental gastropods *Cypraea* and *Strombus* were evident within the Kehpara MPA stations, while no differences were observed in mean densities of any species at the Kehpara Open site. Densities of sea cucumber species observed during the RBt surveys in both the Kehpara MPA and Open sites were generally lower than the regional reference densities for healthy sea cucumber stocks, with only tigerfish (*B. argus*) and pinkfish (*Holothuria edulis*) consistently occurring in densities exceeding the reference densities.

Soft benthos transects (SBt) were used to assess invertebrate resources associated with soft-bottom habitats at fine-spatial scales. Four SBt stations (6 x 40 m replicates) were surveyed each of the Pwudoi Mangrove Reserve (Pwudoi MPA) and adjacent areas open to fishing. Few differences were evident in densities of invertebrate species among surveys at the Kehpara Open site. Densities of lollyfish (*Holothuria atra*) in the Kehpara MPA appeared lower in 2014 relative to 2012, however such differences may be due to the inclusion of additional stations in the 2014 survey. Densities of the sea cucumbers *H. atra* and *H. scabra* were considerably higher in the Kehpara Open stations than in the MPA.

Creel surveys

Sixty-three creel surveys were completed during the 2014 assessment, with surveys conducted at Kolonia and Kitti municipalities. Most surveys were of gillnet, handline/bottom fishing or night spearfishing activities, although three instances of day spearfishing were surveyed.

Seven surveys of gillnetting were conducted, with all gillnet fishers surveyed at the Kolonia Ice Plant dock. The average catch per gillnet trip was 21.38 kg, or 36.14 individual fish. Average catch-per-unit effort (CPUE) was 17.14 fish per hour spent fishing. The gillnet catch was dominated by the families Scaridae, Siganidae, Kyphosidae, Carangidae and Acanthuridae. Thirty-five species were observed in the gillnet catch, the most common of which were the parrotfish *Hipposcarus longiceps* (representing 26.5% of the total catch by abundance), the drummer

Kyphosus cinerascens (7.5% of the total catch) and the goatfish *Parupeneus barberinus* (7.1% of the total catch).

Twenty-seven surveys of handlining/bottom fishing trips were completed, with all handline/bottom fishing surveys conducted at Kolonia. On average, handline trips involved 1.85 fishers, with an average time spent fishing of 5.62 hours. The average catch per trip was 20.57 kg, or 81.11 individual fish. Catch-per-unit-effort (CPUE) was 10.34 fish/fisher/hour, or 2.61 kg/fisher/hour. The catch was dominated by the families Carangidae, Holocentridae, Lethrinidae, Lutjanidae and Serranidae. Sixty-two species were observed in the catch, the most common of which were *Selar crumenophthalmus* (representing 33.1% of the total catch by abundance), *Lutjanus fulvus* (15.5% of the total catch by abundance) and *Lutjanus gibbus* (7.1% of the total catch by abundance).

Twenty-seven surveys of night spearfishing were completed, with 14 of these conducted in Kolonia and 13 at Kitti. At both locations the catch was dominated by members of the Acanthuridae, Scaridae, Siganidae and Serranidae, with *Hipposcarus longiceps*, *Naso unicornis*, *Naso lituratus*, *Siganus puellus* and *Siganus punctatus* the most commonly observed species. At Kolonia, trips involved an average of 1.3 fishers, with an average of 3.29 hours spent fishing, while at Kitti trips involved an average of 1.6 fishers with an average of 8.1 hours spent fishing. The average catch at Kolonia was 19.65 kg, or 49.15 individual fish per trip, while at Kitti the average catch was 35.5 kg or 92.6 fish per trip. Catch-per-unit effort was 11.51 and 9.3 fish/fisher/hour spent fishing for Kolonia and Kitti, respectively.

Perception information was collected from each fisher surveyed. The majority of fishers surveyed indicated that they had seen changes in the fishery in the last few years, with 77% of all respondents claiming they considered their catches had decreased compared to five years ago, and 87% of all respondents claiming sizes of fish had decreased compared to those five years ago.

Biological monitoring of key reef species

Biological monitoring of key reef fish species at Pohnpei was included for the first time during the 2014 survey, and focused on five commercially harvested species: peacock grouper (*Cephalopholis argus*), striated surgeonfish (*Ctenochaetus striatus*), blacktail snapper (*Lutjanus fulvus*), humpback red snapper (*Lutjanus gibbus*), and orangespine surgeonfish (*Naso lituratus*) and one unharvested (‘control’) species: redfin butterflyfish (*Chaetodon lunulatus*). 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 Pohnpei for future comparisons. Fishing mortality of *L. gibbus* was above the optimal rate indicating that this species is fished above its optimum level. Further exploitation would result in over-fishing of this species.

Management recommendations for improving the resilience of coastal fisheries of Pohnpei

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, we outline several key management recommendations, based on the findings of the current study and anecdotal observations, that will help improve the resilience of the coastal fisheries of Pohnpei to both long-term (e.g. climate change) and short-term (e.g. overfishing) stressors, namely:

1) Increase enforcement of fisheries management regulations.
2) Expand the network of Marine Protected Areas.
3) Place restrictions on destructive or highly efficient fishing practices, in particular night-time spearfishing.
4) Maintain the closure of sea cucumber fisheries.
5) Protect sharks and other iconic and ecologically-significant species.
6) Maintain healthy catchments on mainland Pohnpei.
7) Strengthen stakeholder awareness programs and exchange of information on coastal fisheries, the marine environment and climate change.
8) Strengthen collaborations with National, State and Municipal governments, NGOs, fishing communities and clan leaders.
9) Develop a coastal fisheries management plan.

1. Introduction

Project Background

Considering the concerns of climate change and its impacts on coastal fisheries resources, SPC is implementing the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project with funding assistance from 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), 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 Pohnpei, Federated States of Micronesia (FSM), between February and March 2014 by a team from SPC's Coastal Fisheries Science and Management Section and staff from Pohnpei States' Office of Fisheries and Aquaculture (OFA), FSM National Government's Department of Resources and Development (FSM R&D) and the Conservation Society of Pohnpei (CSP). 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 Pohnpei, FSM, 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)

Federated States of Micronesia

Background

The Federated States of Micronesia is located in the western North Pacific Ocean between the equator and 12°N, stretching from 136°E to 168°E (Figure 1). The country consists of four states: Yap, Chuuk, Pohnpei and Kosrae, listed in sequence from west to east. Of the total 607 islands, some are relatively large and mountainous (e.g. Pohnpei), while others consist of smaller islands, flat coral atolls and raised coralline islands. The total land area of FSM is approximately 700 km^2, while the Exclusive Economic Zone (EEZ) totals approximately 2.98 million km^2 (Gillet 2009). In 2010, the estimated population of the Federated States of Micronesia was 106,400 (CIA World Factbook 2012). The capital is Palikir in the state of Pohnpei.

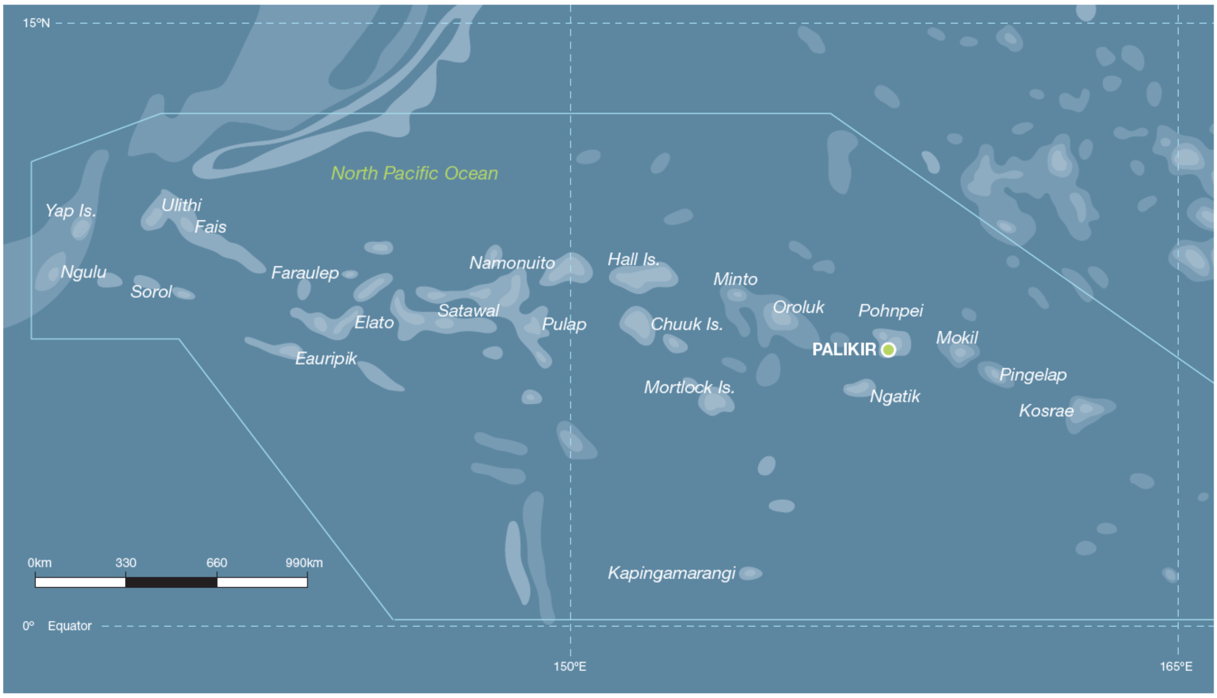

Figure 1 Federated States of Micronesia (from PCCSP 2011).

Fisheries of FSM

Oceanic fisheries

FSM has a locally-based surface fishery and longline fishery for tuna that operate both within and outside of its EEZ. Average annual catches by the local surface and longline fisheries are 19,500 tonnes, worth > USD 23 million, and > 900 tonnes, worth approximately USD 5 million, respectively. In 2007, these fisheries contributed approximately 4% to the gross domestic product (GDP) of FSM (Gillet 2009). FSM also licences foreign vessels to fish for tuna within its EEZ. Between 1999 and 2008, foreign purse-seine vessels made an average total annual catch of > 152,000 tonnes, worth approximately USD 126 million (Bell et al. 2011). Foreign longline fleets also landed average catches of > 5,500 tonnes, worth USD 26 million. In 2007, foreign vessels made an estimated annual total catch of approximately 143,000 tonnes, worth > USD 177 million (Gillet 2009) (Table 2). Licence fees for access to the fishery make up a significant portion of government revenue (GR). In 2007, licence fees from foreign (and national) vessels involved in the oceanic surface fishery contributed 10.2% of GR, while fees from longline vessels contributed a further 1.3% of GR (Gillet 2009).

Coastal fisheries

The coastal fisheries of FSM 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 12,600 tonnes, worth > USD 23.0 million (Gillet 2009) (Table 3). The commercial catch was 2,800 tonnes, while the subsistence catch was 9,800 tonnes (Gillet 2009). Approximately half of the total catch is estimated to be made up of demersal fish (Bell et al. 2011) (Table 3).

Table 2 Annual fisheries and aquaculture harvest in FSM, 2007 (Gillet 2009)

Harvest sector	Quantity (tonnes)	Value (USD million)
Offshore locally-based	16,222	23,908,377
Offshore foreign-based	143,315	177,195,590
Coastal commercial	2,800	7,560,000
Coastal subsistence	9,800	15,732,000
Freshwater	1	8,000
Aquaculture	16,000 pieces	80,000
Total	**12,600**	**224,483,967**

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

Coastal fishery category	Quantity (tonnes)	Contribution of catch (%)
Demersal finfish	6,290	50
Nearshore pelagic finfish	3,560	28
Targeted invertebrates	30	< 1
Inter/subtidal invertebrates	2,720	22
Total	**12,600**	**100**

Climate Change Projections for the FSM

Air temperature

Historical air temperature data records for FSM are available for Pohnpei and Yap states. For Pohnpei state, an increase in average daily temperatures of approximately 0.24°C per decade has been observed since recording began in 1950 (Figure 2). 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, for the eastern Federated States of Micronesia and +0.6, +0.8 and +0.7°C (relative to 1990 values) projected for 2030, under the IPCC B1, A1B and A2 emissions scenarios, respectively, for the western Federated States of Micronesia (PCCSP 2011) (Table 4).

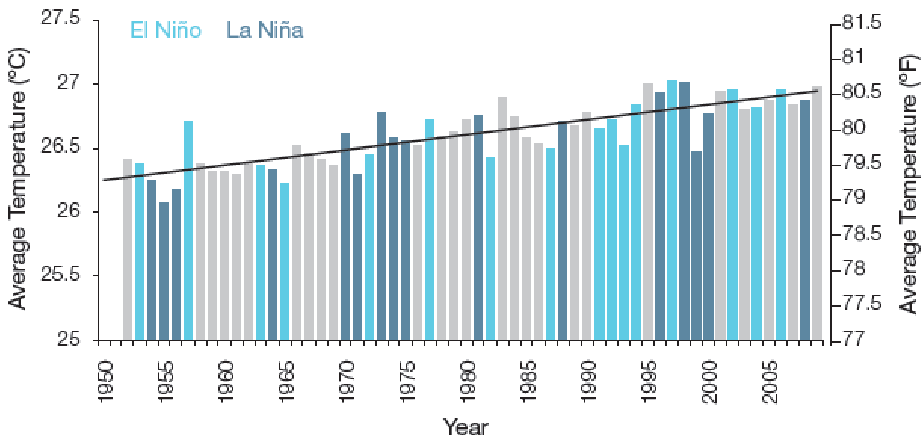

Figure 2 Annual mean air temperature at Pohnpei (1950–2009) (from PCCSP 2011).

Table 4 Projected air temperature increases (in °C) for a) eastern and b) western FSM under various IPCC emission scenarios (from PCCSP 2011)

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

Sea-Surface temperature

In accordance with mean air surface temperatures, sea-surface temperatures (SST) are projected to further increase, with increases of +0.6, +0.7 and +0.6°C (relative to 1990) values projected for 2030, under the IPCC B1 (low), A1B (medium) and A2 (high) emissions scenarios, respectively, for the eastern Federated States of Micronesia and +0.6, +0.7 and +0.7°C (relative to 1990) values projected for 2030, under the IPCC B1, A1B and A2 emissions scenarios, respectively, for the western Federated States of Micronesia (PCCSP 2011) (Table 5).

Table 5 Projected sea-surface temperature increases (in °C) for a) eastern and b) western FSM under various IPCC emission scenarios (from PCCSP 2011)

Region	Emission scenario	2030	2055	2090
a) Eastern FSM	B1	+0.6 ± 0.4	+1.0 ± 0.5	+1.4 ± 0.7
	A1B	+0.7 ± 0.5	+1.3 ± 0.5	+2.1 ± 0.8
	A2	+0.6 ± 0.4	+1.3 ± 0.5	+2.6 ± 0.7
b) Western FSM	B1	+0.6 ± 0.5	+1.1 ± 0.6	+1.5 ± 0.8
	A1B	+0.7 ± 0.5	+1.4 ± 0.6	+2.2 ± 0.9
	A2	+0.7 ± 0.4	+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 gauge was installed in Kolonia, on the north coast of Pohnpei, in December 2001. According to the 2010 Pacific country report on sea level and climate for FSM (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 near Kolonia (accounting for barometric pressure and tidal gauge movement) was calculated at +16.9 mm per year. Based on empirical modeling, mean sea-level is projected to continue to rise during the 21st century, with increases of up to +20 to +30 cm projected for 2035 and +90 to +140 cm projected for 2100 (Bell et al. 2011). Sea level rise may potentially create severe problems for low lying coastal areas, namely through increases in coastal erosion and saltwater intrusion (Mimura 1999). Such processes may result in increased fishing pressure on coastal habitats, as traditional garden crops fail, further exacerbating the effects of climate change on coastal fisheries.

Ocean acidification

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

In FSM, 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 model results suggested that by 2030 the annual maximum aragonite saturation state for FSM will reach values below 3.5 and continue to decline thereafter (PCCSP 2011). These projections suggest that coral reefs of FSM will be vulnerable to actual dissolution as they will have trouble producing the calcium carbonate needed to build their skeletons. This will impact the ability of coral reefs to have net growth rates that exceed natural bioerosion rates. Increasing acidity and decreasing levels of aragonite saturation are also expected to have negative impacts on ocean life apart from corals; including calcifying invertebrates, non-calcifying invertebrates and fish. High levels of CO_2 in the water are expected to negatively impact on the lifecycles of fish and large invertebrates through habitat loss and impacts on reproduction, settlement, sensory systems and respiratory effectiveness (Kurihara 2008, Munday et al. 2009a, Munday et al. 2009b). The impact of acidification change on the health of reef ecosystems is likely to be compounded by other stressors including coral bleaching, storm damage and fishing pressure (PCCSP 2011).

Projected Effects of Climate Change of Coastal Fisheries of FSM

FSM has extensive (> 15,000 km^2) coral reef areas, and extensive areas of mangrove (86 km^2) and seagrass (44 km^2) habitat (Bell et al. 2011). Climate change is expected to add to the existing local threats to these habitats, resulting in declines in the quality and area of all habitats (Table 6).

Accordingly, all coastal fisheries categories in FSM 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).

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

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

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

Table 7 Projected changes to coastal fisheries production in FSM 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[1]	0	-10	-15 to -20
Targeted invertebrates	-2 to -5	-10	-20
Inter/subtidal invertebrates	0	-5	-10

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

2. Site and Habitat Selection

Site Selection

Pohnpei was selected as a pilot site for the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project within FSM following consultations with staff from FSM's Office of Fisheries and Aquaculture (OFA), FSM Department of Resources & Development (FSM R&D), and Division of Land and Natural Resources - Marine Conservation Unit (DLNR-MCU). Pohnpei was selected as it offered a number of advantages as a study site, most notably:

- Pohnpei contains a number of gazetted marine protected areas (such as the Kehpara Marine Sanctuary and Pwudoi Mangrove Reserve), thereby allowing decoupling of the effects of over-fishing and pollution against other factors (i.e. climate change);
- A SEAFRAME gauge was installed in Pohnpei in 2001 as part of the AusAID-funded 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;
- SPC and federal offices are located in Pohnpei which simplifies logistics;
- The outer-reefs and passages of Pohnpei Island were surveyed by SPC in 2008 for trochus (Tardy et al. 2009) and the Conservation Society of Pohnpei and College of Micronesia regularly survey coral reefs, fish and seagrass beds (Kosrae and Pohnpei participate in SeagrassNet, a global seagrass monitoring network);
- Pohnpei is a high volcanic island and could be a case study for an integrated reef/watershed climate change project for a French Global Environment Fund proposal; and
- Pohnpei State conducts market surveys regularly.

Pohnpei State is located at approximately 6°50' N latitude and 158°15' E longitude, and is comprised of eight islands and atolls. The island of Pohnpei consists of approximately 318 km^2 of land area and 178 km^2 of lagoon surrounded by approximately 100 km of barrier reef (Rhodes and Sadovy 2002).

For the purposes of the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project, monitoring sites were established inside and adjacent to two marine reserves of Pohnpei Island: the Kehpara Marine Sanctuary and the Pwudoi Mangrove Reserve (Figure 3). Reef-based assessments (i.e. benthic habitat, finfish and reef-associated invertebrate surveys; Sections 4–6) were conducted within and adjacent to the Kehpara Marine Sanctuary (hereafter referred to as the Kehpara MPA). This gazetted marine protected area encompasses 1.89 km^2 of barrier reef habitat in the south-west of Pohnpei Island and was established in 1995 to reduce fishing pressure on spawning aggregations of groupers (Serranidae) (Rhodes and Sadovy 2002). Soft-benthos invertebrate assessments (see Section 6) were conducted within and adjacent to the Pwudoi Mangrove Reserve. This reserve was established in 2009 and encompasses 1.39 km^2 of mangrove forest, soft substratum and inshore fringing reef in the south-west of the island (Figure 3).

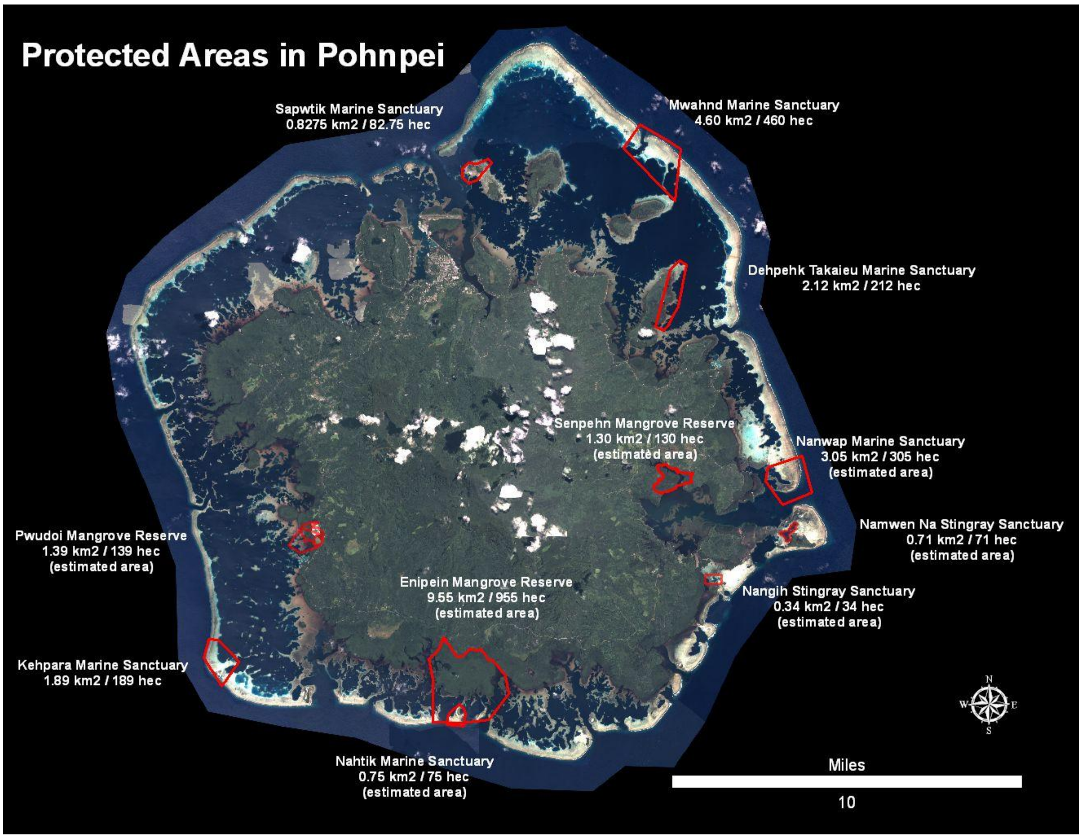

Figure 3 Map of Pohnpei indicating the Kehpara Marine Sanctuary (Kehpara MPA) and Pwudoi Mangrove Reserve (from the Conservation Society of Pohnpei).

Fisheries Resources of Pohnpei

Fishing is an important activity for the people of Pohnpei. Over 120 reef fish species inhabiting the waters of Pohnpei are edible (Tardy et al. 2009). Fishing within the lagoon areas is done at day and night using a variety of fishing techniques including nets, spears, hooks and lines (Tardy et al. 2009). Mid-water longlining for yellowfin tuna is practised off the northeast barrier reef at an upwelling zone. Surplus catch is sold at Kolonia market, while the rest supplies subsistence needs (Tardy et al. 2009).

Invertebrate fisheries of Pohnpei include trochus, giant clams, sea cucumbers and cockle shells. Trochus and sea cucumber are exclusively commercial fisheries and trochus is important in Pohnpei, Mwoakilloa and Sapwafik Islands, where the species were introduced (Tardy et al. 2009). Harvesting of trochus is tightly controlled by the state government. When the season is open, Pohnpei Island produces much of the State's trochus catch from its large reef area. From 1969 up to 2005, a total of 19 annual open seasons were made, producing an average of 94.6 mt/year of trochus, ranging from 27 mt in 1976 to 192 mt in 1988 (Tardy et al. 2009). Surveys on the status of Pohnpei Island's trochus populations on the outer-reef and passages habitats in 2008 revealed overall mean trochus densities of 699.8±112.5 individuals/ha and 840.3±180.5 individuals/ha for shallow water SCUBA and reef-benthos transect assessments, respectively (Tardy et al. 2009).

Habitat Definition and Selection

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

1) lagoon-reef: patch reef or finger of reef stemming from main reef body that is inside a lagoon or pseudo-lagoon;
2) back-reef: inner/lagoon side of outer reef/main reef body; and
3) outer-reef: ocean-side of fringing or barrier reefs.

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 FSM R&D, OFA and CSP 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 4).

Figure 4 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.

3. Monitoring of Water Temperature

Methodologies

In October 2010, two RBR TR-1060 temperature loggers were deployed in Pohnpei: one on the outer reef and one in the lagoon (Figure 5; Table 8). The loggers were calibrated to an accuracy of ±0.002ºC and programmed to record temperature every five minutes. For security reasons both loggers were housed in a PVC tube with holes to allow flow of water and encased in a concrete block. These blocks were then secured to the sea floor using rebars. Each logger was deployed at a depth of approximately 10 m.

The initial set of RBR TR-1060 loggers was retrieved and a second set deployed in July 2011. Upon retrieval, it was apparent that the batteries of the lagoon and outer reef loggers failed within 3 and 10 months of initial deployment. Due to such obvious battery life flaws in the RBR TR1060 loggers, both of the RBR TR-1060 loggers were permanently replaced with a superior model (Sea-Bird SBE 56) in early March 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 in the lagoon and on the outer reef on the 12th and 19th February 2014, respectively. Initial inspection indicates that both Seabird SBE 56 loggers collected water temperature data continuously from their deployment in March 2012 to their retrieval in February 2014.

Figure 5 Location of water temperature loggers deployed in Pohnpei.

Table 8 Details of temperature loggers deployed at Pohnpei Island.

Details	Pohnpei 1	Pohnpei 2
Initial deployment date	1/10/2010	1/10/2010
Location	Mwahnd, Pohnpei	Kehpara, Pohnpei
Habitat	Lagoon	Outer reef
Longitude (E)	158.2969	158.1119
Latitude (N)	7.0093	6.8001
Depth	10 m	10 m

Figure 6 Members of the survey team replacing the temperature logger in the lagoon at Mwahnd, Pohnpei, Feb 2014.

Results

Loggers showed high correlation in water temperatures of the outer reef and lagoon (Figure 7). Water temperatures were typically highest around September-October, and lowest around January-February, consistent with seasonal expectation (Figure 7).

On the outer reef, a maximum average daily temperature of 30.23°C was recorded on the 14th August 2013; while a minimum average daily water temperature of 28.66°C was recorded on the 21st January 2012. The average daily temperature at the Kehpara outer reef site for 2013, where a full year of data was collected, was 29.23°C.

In the lagoon, a maximum average daily temperature of 30.51°C was recorded on the 31st August 2013; while a minimum average daily water temperature of 28.38°C was recorded on the 27th January 2013. The average daily temperature for 2013 was 29.12°C.

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

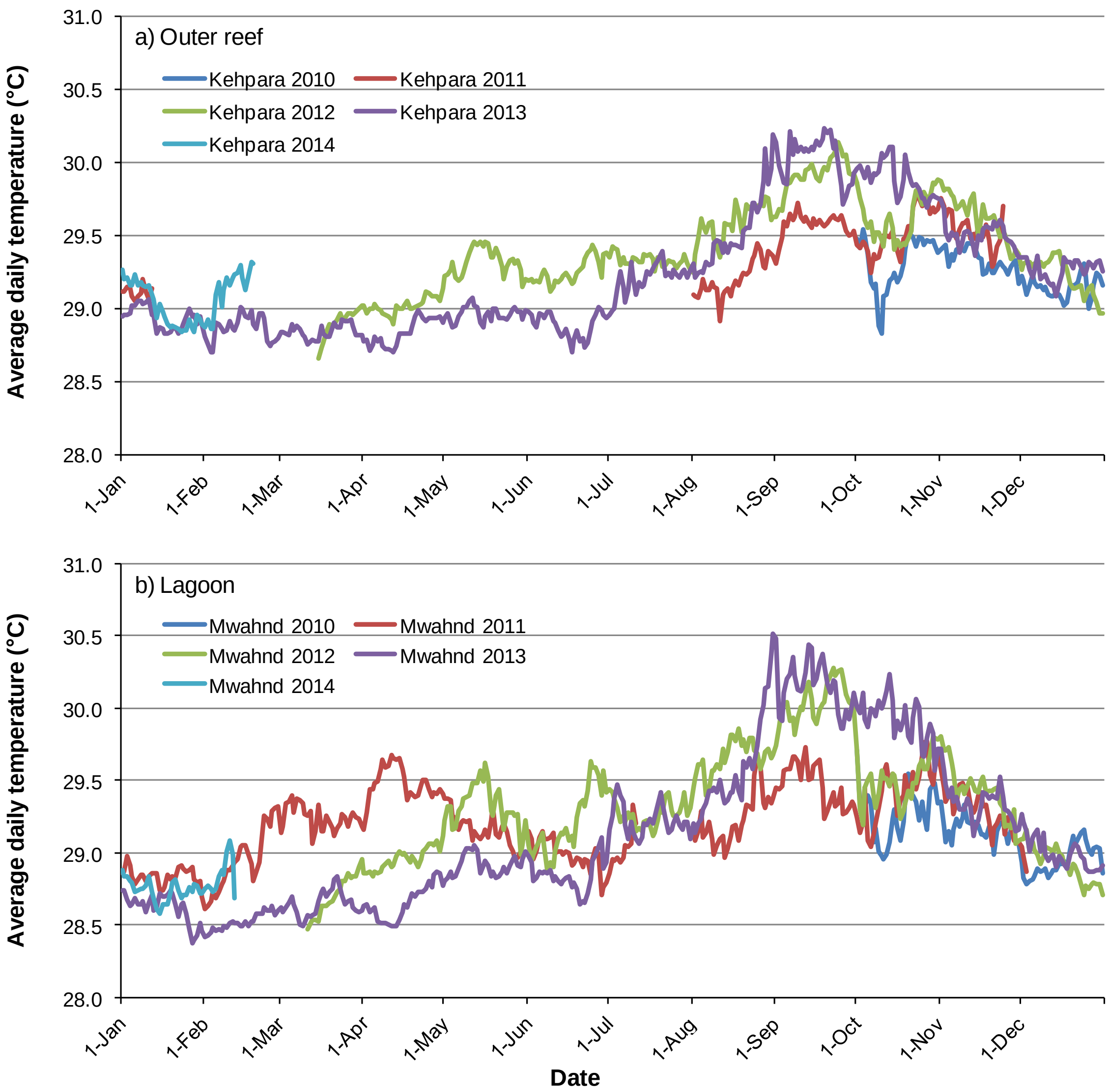

Figure 7 Mean daily water temperature at the a) outer reef (Kehpara) and b) lagoon (Mwahnd) of Pohnpei. See Figure 5 for logger locations.

4. Finfish Assessments

Methodologies

Data collection

Fish on reef habitats were surveyed using distance-sampling underwater visual census (D-UVC) methodology. Finfish survey design followed that of the baseline assessment by Moore et al. (2012). Briefly, finfish assessments were conducted at two sites around the south-west of Pohnpei: within the Kehpara MPA and adjacent to the MPA (Kehpara Open), with two stations established in each site (Figure 8; Appendix 1). Within each station, finfish assessments typically focused on three habitats (back reefs, lagoon reefs and outer reefs), with up to three replicate 50 m transects surveyed in each habitat at each station. 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 9). Two distance measurements were recorded for a school of fish belonging to the same species and size (D1 and D2; Figure 9), 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.

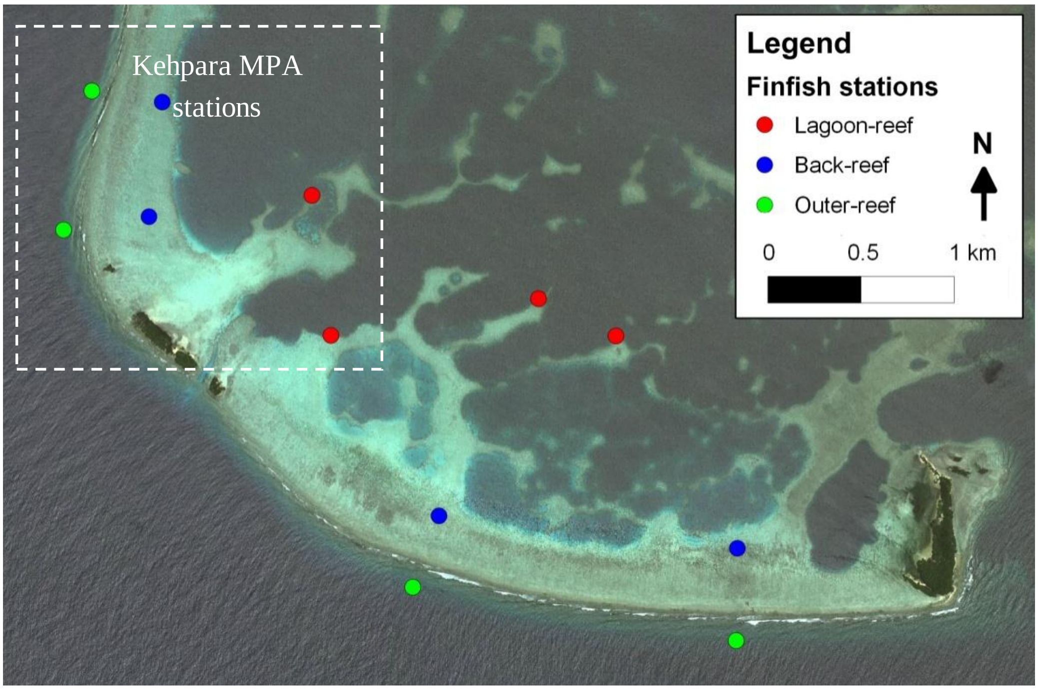

Figure 8 Location of finfish and fine-scale benthic habitat monitoring stations in the Kehpara region.

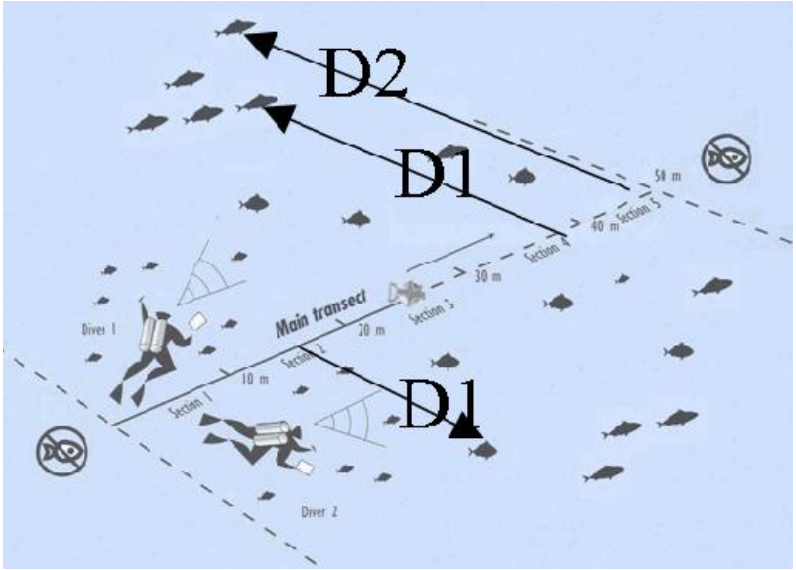

Figure 9 Diagram portraying the D-UVC method.

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.

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.

While all observed finfish species were recorded, including both commercial and non-commercial species, for the purposes of this report results of analyses of density, biomass, size, size ratio, are based on data for functional groups (see below) and 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.

Assignment of functional groups

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

1) Macro-carnivores (feed predominantly on mobile benthic organisms and fish) (e.g. some members of the Lethrinidae, Lutjanidae, Serranidae);
2) Micro-carnivores (feed predominantly on small benthic organisms and ecto-parasites) (e.g. some members of the Labridae);
3) Corallivores (feed predominantly on coral polyps) (e.g. some members of the Chaetodontidae);
4) Planktivores (feed predominantly on macro- and micro-zooplankton, including both diurnal and nocturnal species) (e.g. some members of the families Acanthuridae, Apogonidae, Chaetodontidae, Holocentridae, Pomacentridae and Serranidae);
5) Scrapers/excavators (roving herbivores that feed on turf algae, and remove reef substratum as they feed. Members of this group play a key role in coral reef resilience by limiting the establishment of macroalgae, intensely grazing turf algae and providing areas of clean substratum for coral recruitment) (e.g. members of the Scaridae);
6) Grazer/detritivores (roving herbivores that feed on turf algae, but do not scrape or excavate the reef substrate as they feed) (e.g. some members of the families Acanthuridae, all Siganidae except *Siganus canaliculatus*);
7) Browsers (roving herbivore that tends to bite or 'crop' algae leaving the basal portions and substrate intact. Browsers play 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. Kehpara MPA 2014) and habitat (reef flat, 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 999 permutations of the data.

Site results

Kehpara MPA

Finfish assessments within the Kehpara MPA in both 2012 and 2014 covered three habitats, with six 50 m transects completed in each habitat (Appendix 2).

Finfish diversity within the Kehpara MPA was considerably higher during the 2014 survey relative to 2012 for all three habitats examined (Table 9). Most functional groups were represented during both surveys, with only browsers absent from the back reef transects during 2012 and the lagoon reef transects in 2014 (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 Kehpara MPA monitoring site, 2012 and 2014.

Parameter	Back-reef		Lagoon-reef		Outer-reef	
	2012	2014	2012	2014	2012	2014
No. of families	21	18	16	20	21	26
No. of genera	49	44	36	54	56	72
No. of species	93	101	79	119	120	170
Diversity	31.83±3.59	43.83±4.92	28.83±1.38	50.00±2.78	45.00±2.37	70.17±5.33
Functional groups	7/8	8/8	8/8	7/8	8/8	8/8

Back reefs

Mean total density and mean total biomass of finfish was significantly higher on back reef transects of the Kehpara MPA site in 2014 relative to 2012 (Figure 10; Figure 11). Similarly, mean densities of Labridae and Scaridae and mean biomass of Chaetodontidae, Labridae, Mullidae and Pomacentridae appeared significantly higher in 2014 than 2012 (Figure 12; Figure 13; Appendix 4). Mean biomass of Pomacanthidae was lower in 2014 relative to 2012 (Figure 12; Figure 13). In terms of functional groups, mean density of micro-carnivores and scraping herbivores, and mean biomass of corallivores, macro-carnivores/piscivores and micro-carnivores, all appeared significantly higher in 2014 relative to 2012 (Figure 14; Figure 15; Appendix 4).

Lagoon reefs

Consistent to back reefs, mean total density and mean total biomass of finfish was significantly higher on lagoon reef transects of the Kehpara MPA site in 2014 relative to 2012 (Figure 10; Figure 11). Mean density of Acanthuridae, Chaetodontidae, Holocentridae, Labridae, Pomacentridae and Scaridae, and mean biomass of Acanthuridae, Holocentridae, Labridae, Pomacentridae and Scaridae, all appeared significantly higher in 2014 than 2012 (Figure 12; Figure 13; Appendix 4). In terms of functional groups, a number of significant differences were evident among survey years, with both the mean density and mean biomass of corallivores, grazing herbivores, macro-carnivores, planktivores and scraping herbivores, the mean density of micro-carnivores and the mean biomass of territorial/farming herbivores on lagoon reefs all appearing significantly higher in 2014 relative to 2012 (Figure 14; Figure 15; Appendix 4).

Outer reefs

Mean total density of finfish was significantly higher on outer reef transects of the Kehpara MPA site in 2014 relative to 2012, while no difference was evident in mean total biomass amongst survey years (Figure 10; Figure 11). For the individual families, mean density of Acanthuridae, Chaetodontidae, Labridae, Scaridae, Serranidae and Siganidae, and mean biomass of Labridae, Pomacentridae, Scaridae and Serranidae all appeared significantly higher on outer reef habitats in 2014 relative to 2012 (Figure 12; Figure 13; Appendix 4). In terms of functional groups, mean densities of browsing herbivores, corallivores and scraping herbivores, and mean biomass of corallivores and scraping herbivores all appeared significantly higher in 2014 relative to 2012 (Figure 14; Figure 15; Appendix 4).

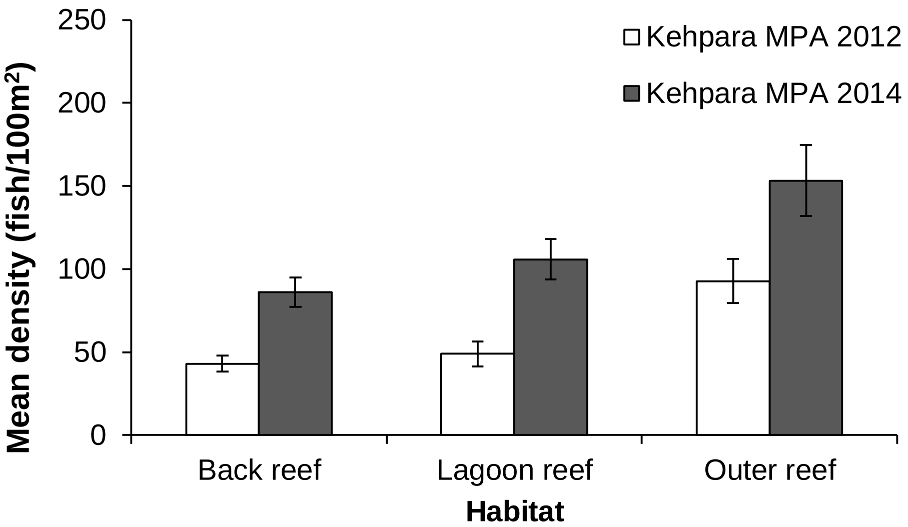

Figure 10 Mean total density of finfish (±SE) on back, lagoon and outer reef transects within the Kehpara MPA monitoring site, 2012 and 2014.

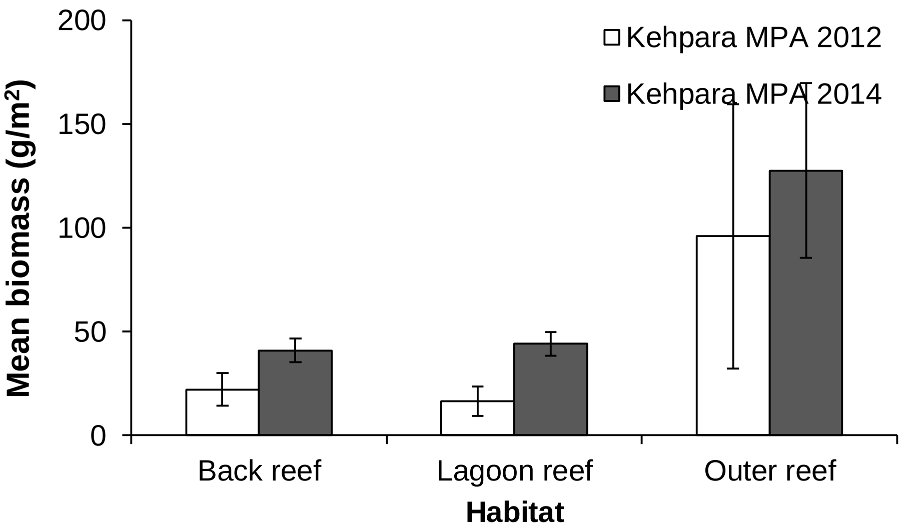

Figure 11 Mean total biomass of finfish (±SE) on back, lagoon and outer reef transects within the Kehpara MPA monitoring site, 2012 and 2014.

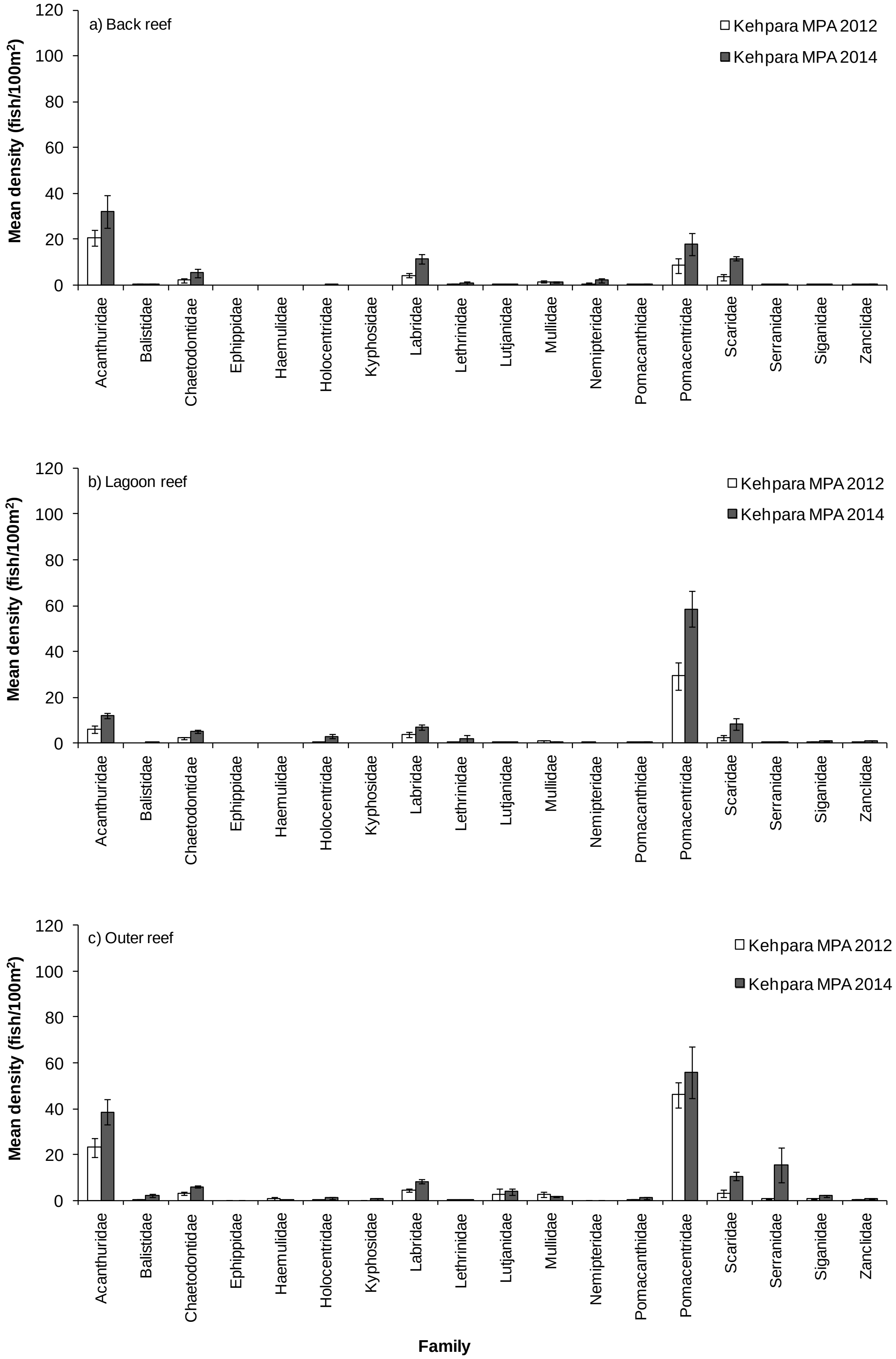

Figure 12 Mean density (±SE) of common finfish families among a) back reef, b) lagoon reef and c) outer reef habitats of the Kehpara MPA monitoring site during the 2012 and 2014 surveys.

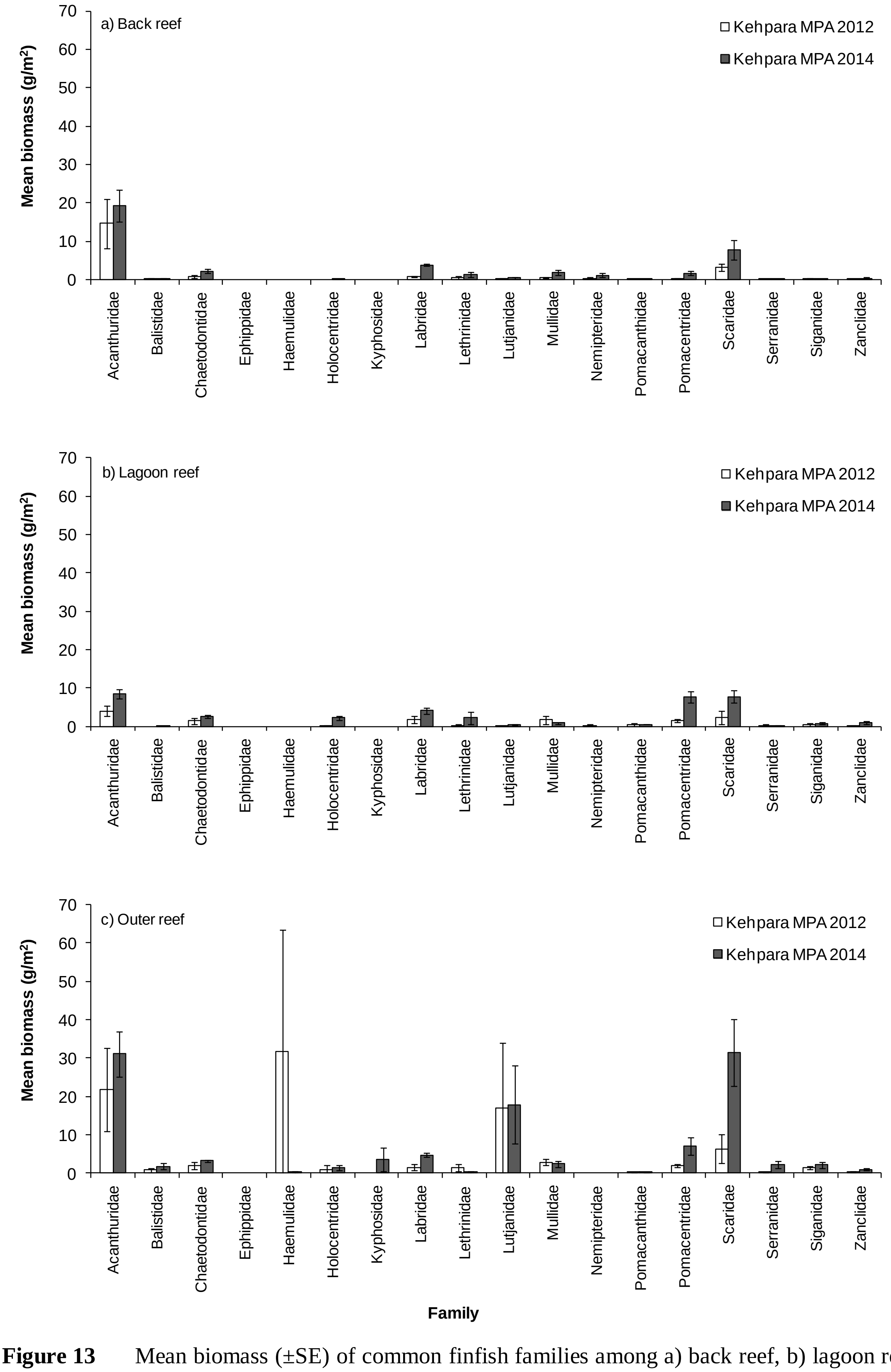

Figure 13 Mean biomass (±SE) of common finfish families among a) back reef, b) lagoon reef and c) outer reef habitats of the Kehpara MPA monitoring site during the 2012 and 2014 surveys.

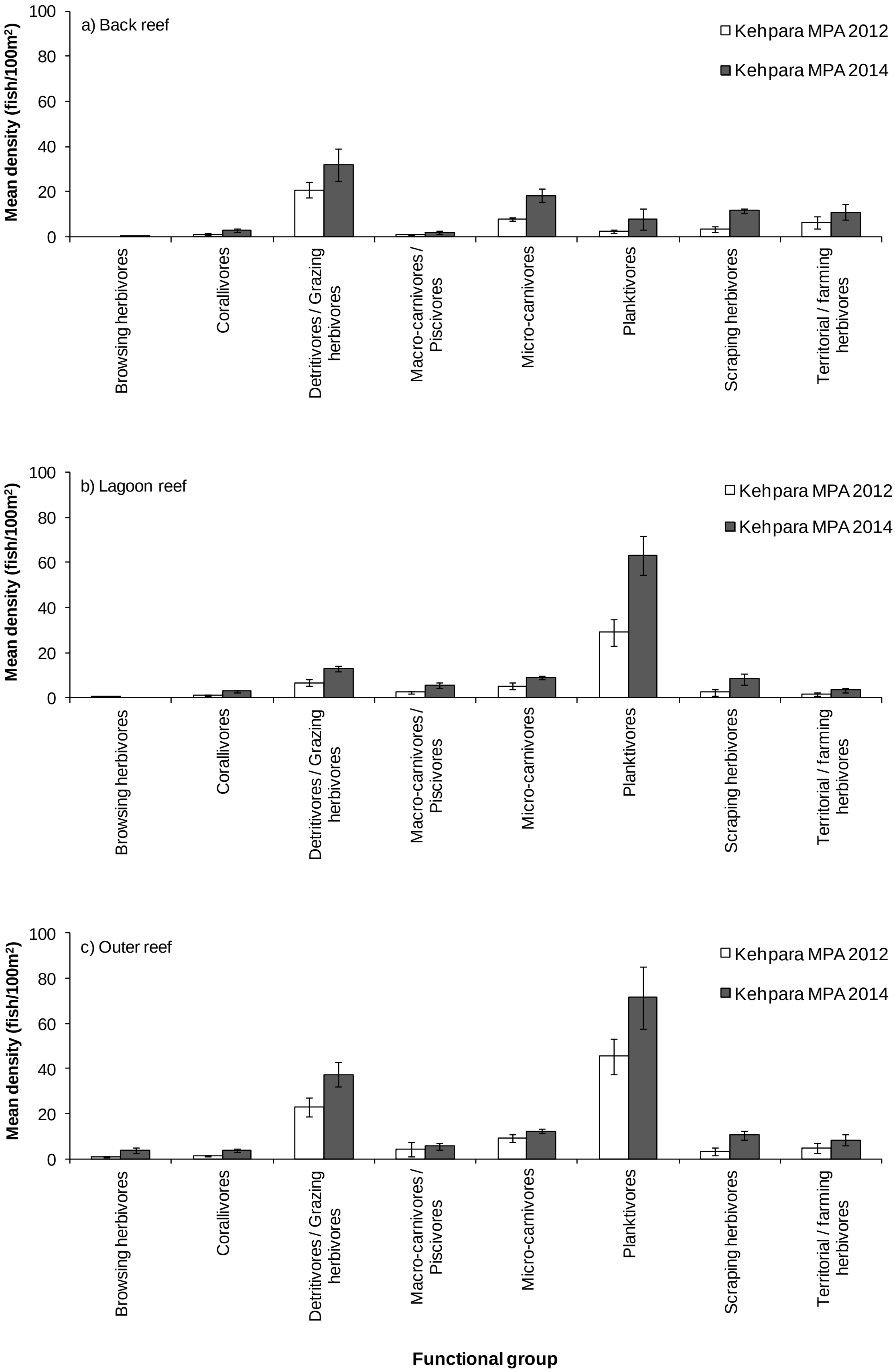

Figure 14 Mean densities (±SE) of key functional groups among a) back reef, b) lagoon reef and c) outer reef habitats of the Kehpara MPA monitoring site during the 2012 and 2014 surveys.

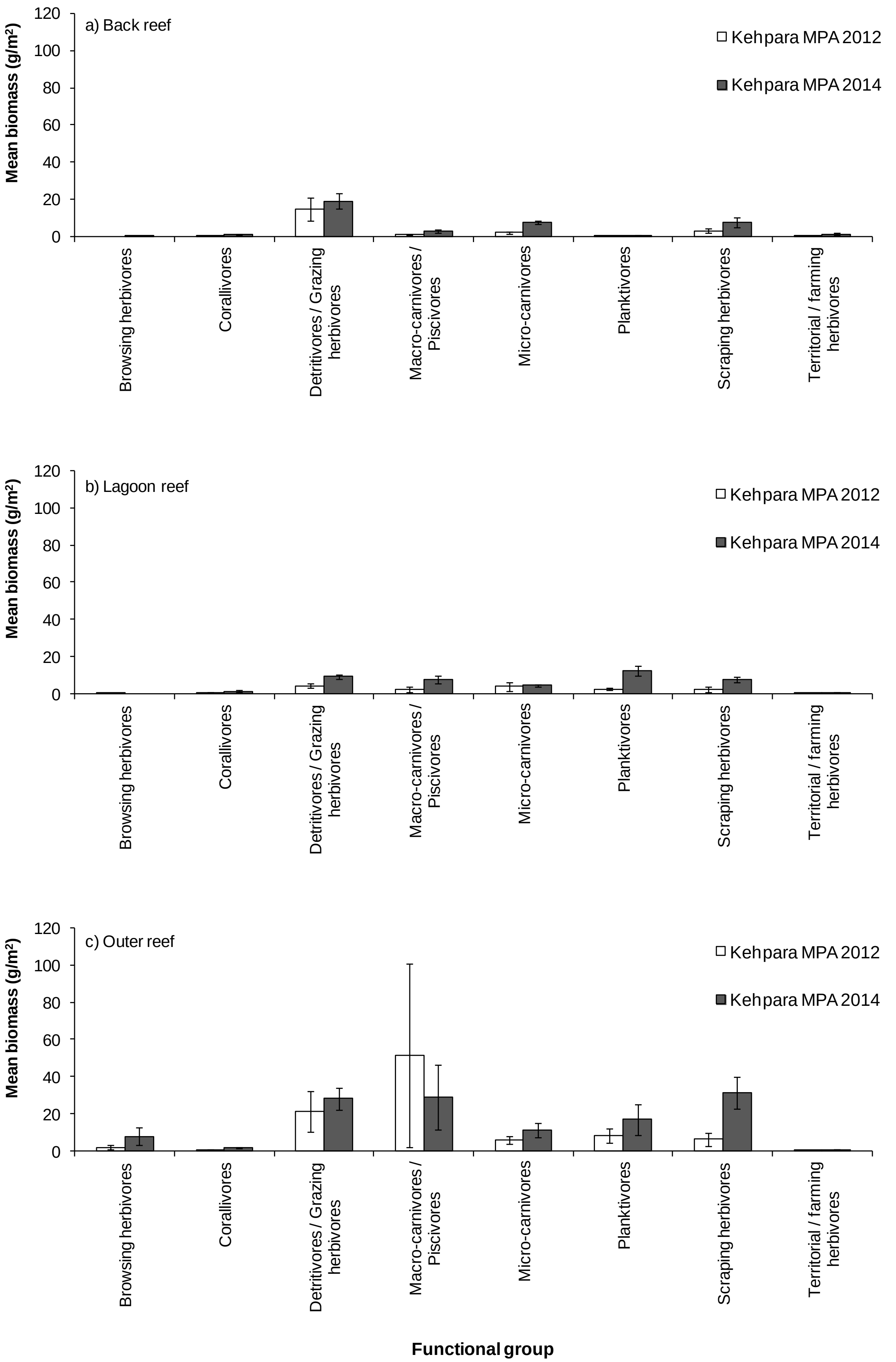

Figure 15 Mean biomass (±SE) of key functional groups among a) back reef, b) lagoon reef and c) outer reef habitats of the Kehpara MPA monitoring site during the 2012 and 2014 surveys.

Kehpara Open

As with the Kehpara MPA, finfish assessments within the Kehpara Open site in both 2012 and 2014 covered three habitats, with six 50 m transects completed in each habitat (Appendix 1).

Finfish diversity within the Kehpara Open site was considerably higher on lagoon and outer reef transects, and lower on back reef transects, during the 2014 survey relative to 2012 (Table 9). Most functional groups were represented during both surveys, with only browsers absent from back reef transects during 2012 and 2014 surveys (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 Kehpara Open monitoring site, 2012 and 2014.

Parameter	Back-reef		Lagoon-reef		Outer-reef	
	2012	2014	2012	2014	2012	2014
No. of families	17	14	10	20	19	22
No. of genera	42	29	25	49	43	62
No. of species	82	55	48	102	94	144
Diversity	32.50±0.81	23.83±2.73	19.00±0.97	43.50±3.73	34.33±1.50	63.83±3.40
Functional groups	7/8	7/8	8/8	8/8	8/8	8/8

Back reefs

No significant difference was evident in mean total density of finfish resources on back reef habitats amongst the 2012 and 2014 surveys (Figure 16). Mean total biomass appeared slightly, yet significantly higher in 2014 than 2012 (Figure 17). Mean densities of Balistidae, Labridae and Scaridae, and mean biomass of Labridae and Scaridae appeared significantly higher in 2014 than 2012 (Figure 18; Figure 19; Appendix 4). No other differences were observed for any other family. In terms of functional groups, densities and biomass of micro-carnivores and scraping herbivores, and biomass of territorial / farming herbivores, were higher in 2014 relative to 2012 (Figure 20; Figure 21; Appendix 4).

Lagoon reefs

Mean total density and mean total biomass of finfish was significantly higher on lagoon reef transects of the Kehpara Open site in 2014 relative to 2012 (Figure 16; Figure 17). Of the indicator families, mean densities of Acanthuridae, Chaetodontidae and Pomacentridae, and mean biomass of Chaetodontidae and Pomacentridae, appeared significantly higher in 2014 than 2012 (Figure 18; Figure 19). In terms of functional groups, mean densities of corallivores and territorial / farming herbivores, and mean biomass of Corallivores, grazers, planktivores and territorial / farming herbivores all appeared significantly higher in 2014 relative to 2012 (Figure 20; Figure 21; Appendix 4).

Outer reefs

On the outer reef, mean total density of finfish appeared higher in 2014 than 2012, while no difference was observed in mean total biomass (Figure 16; Figure 17). Mean densities of Acanthuridae, Balistidae, Chaetodontidae, Lutjanidae, Pomacanthidae and Serranidae, and mean biomass of Labridae, Lutjanidae, Scaridae and Serranidae all appeared significantly higher in 2014 relative to 2012 (Figure 18; Figure 19). Of the eight functional groups, mean density of corallivores, detritivores/grazing herbivores, and macro-carnivores, and mean biomass of macro-carnivores, micro-carnivores, scraping herbivores and territorial/farming herbivores all appeared significantly higher in 2014 relative to 2012 (Figure 20; Figure 21; Appendix 4).

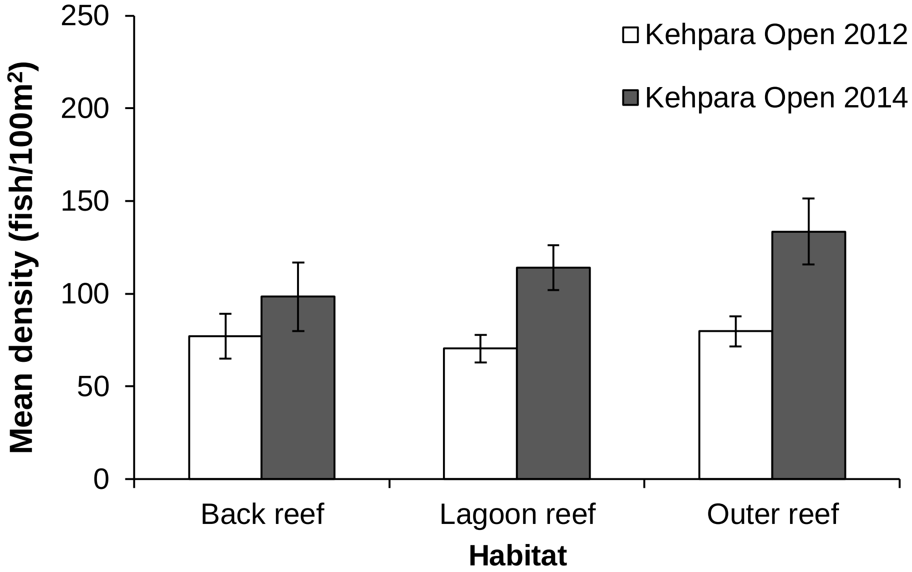

Figure 16 Mean total density of finfish (±SE) on back, lagoon and outer reef transects within the Kehpara Open monitoring site, 2012 and 2014.

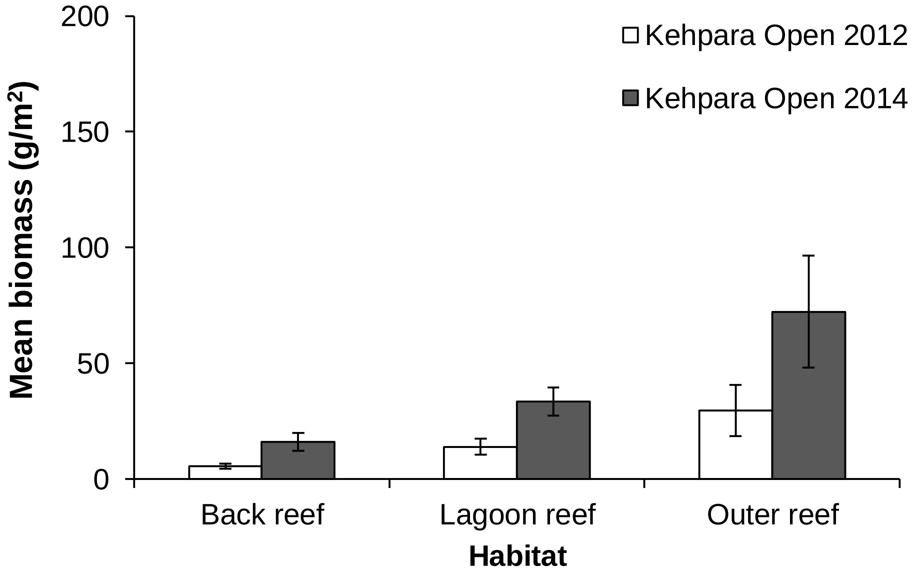

Figure 17 Mean total biomass of finfish (±SE) on back, lagoon and outer reef transects within the Kehpara Open monitoring site, 2012 and 2014.

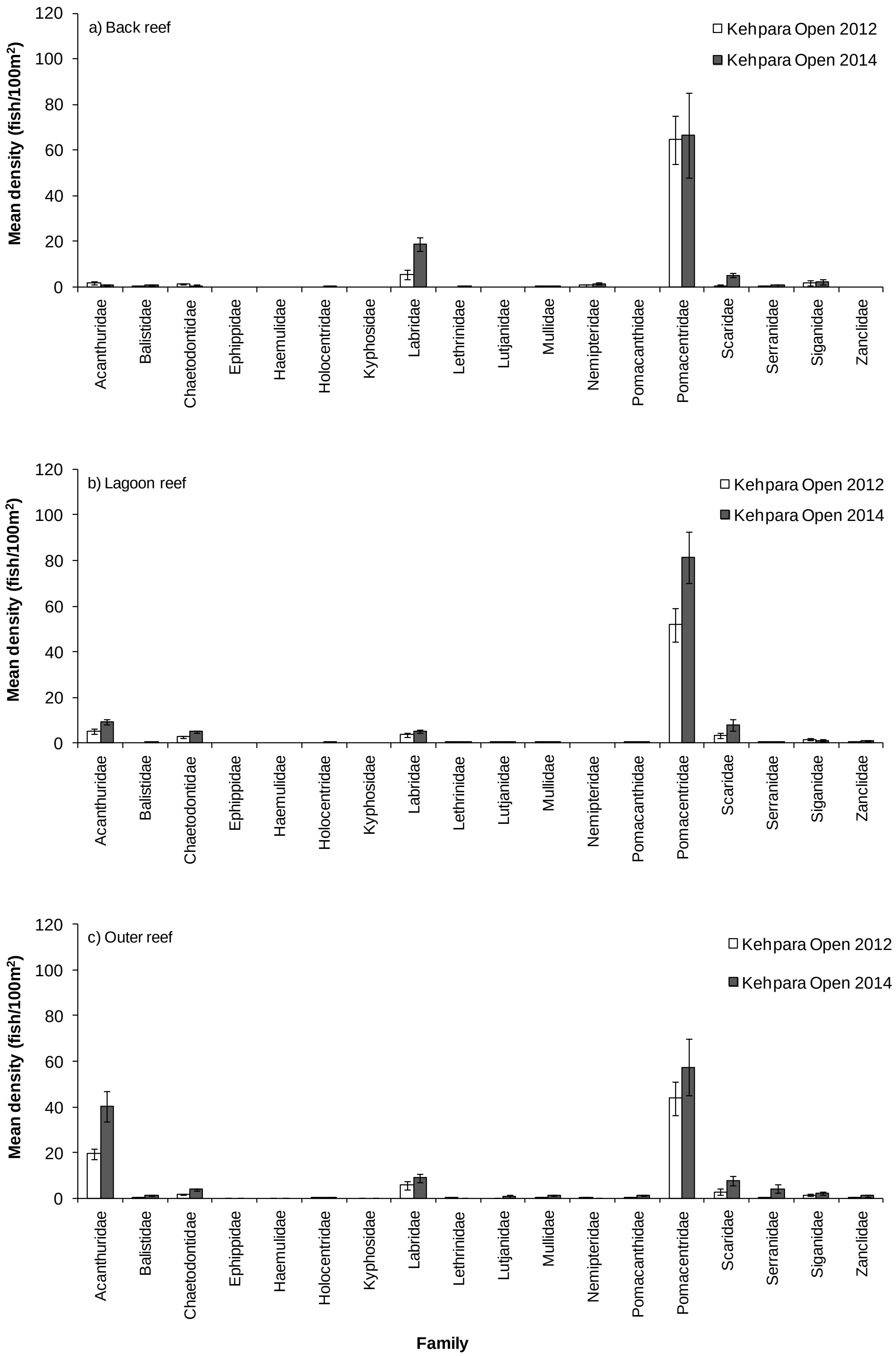

Figure 18 Mean densities (±SE) of common finfish families among a) back reef, b) lagoon reef and c) outer reef habitats of the Kehpara Open monitoring site during the 2012 and 2014 surveys.

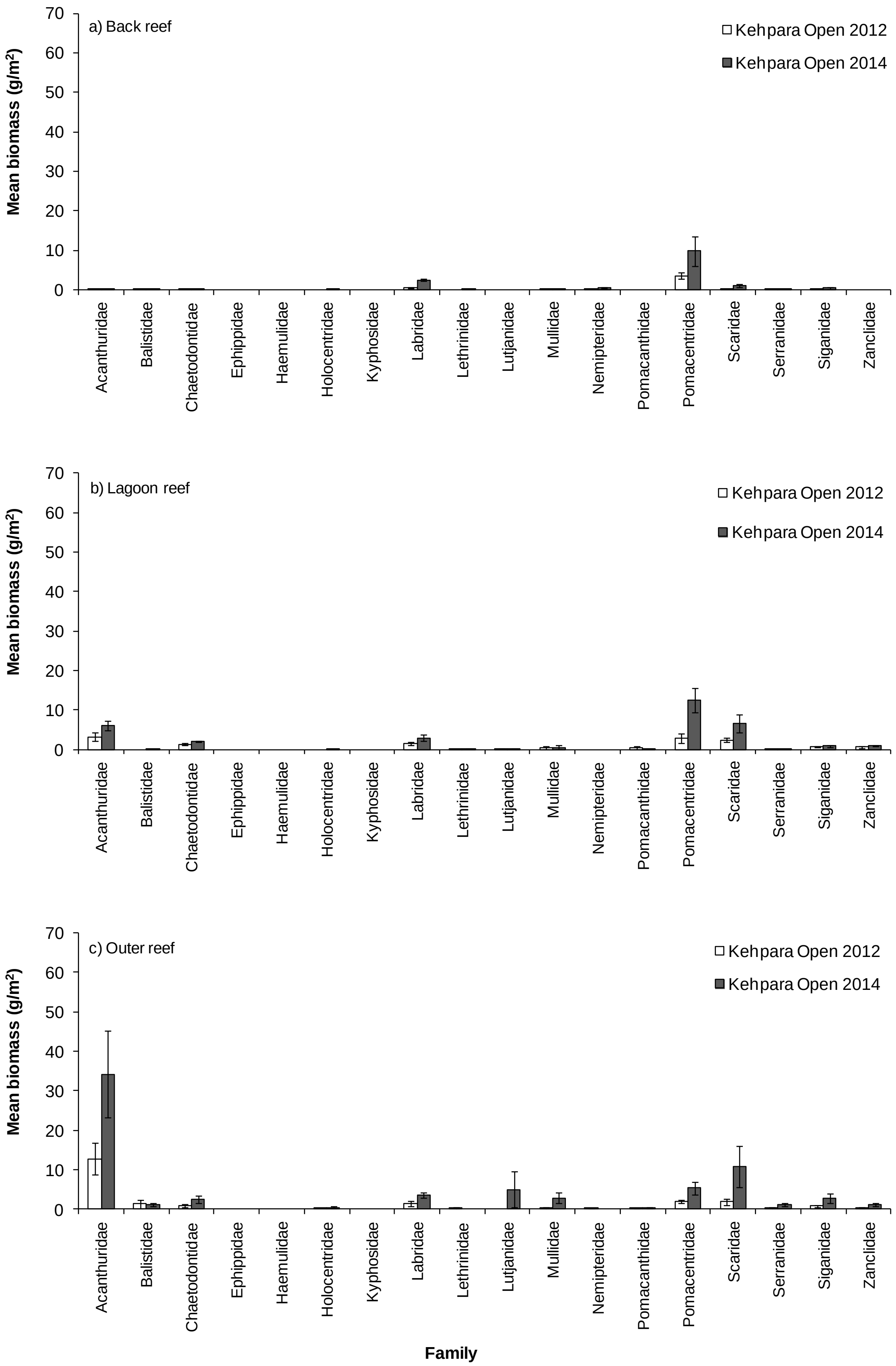

Figure 19 Mean biomass (±SE) of common finfish families among a) back reef, b) lagoon reef and c) outer reef habitats of the Kehpara Open monitoring site during the 2012 and 2014 surveys.

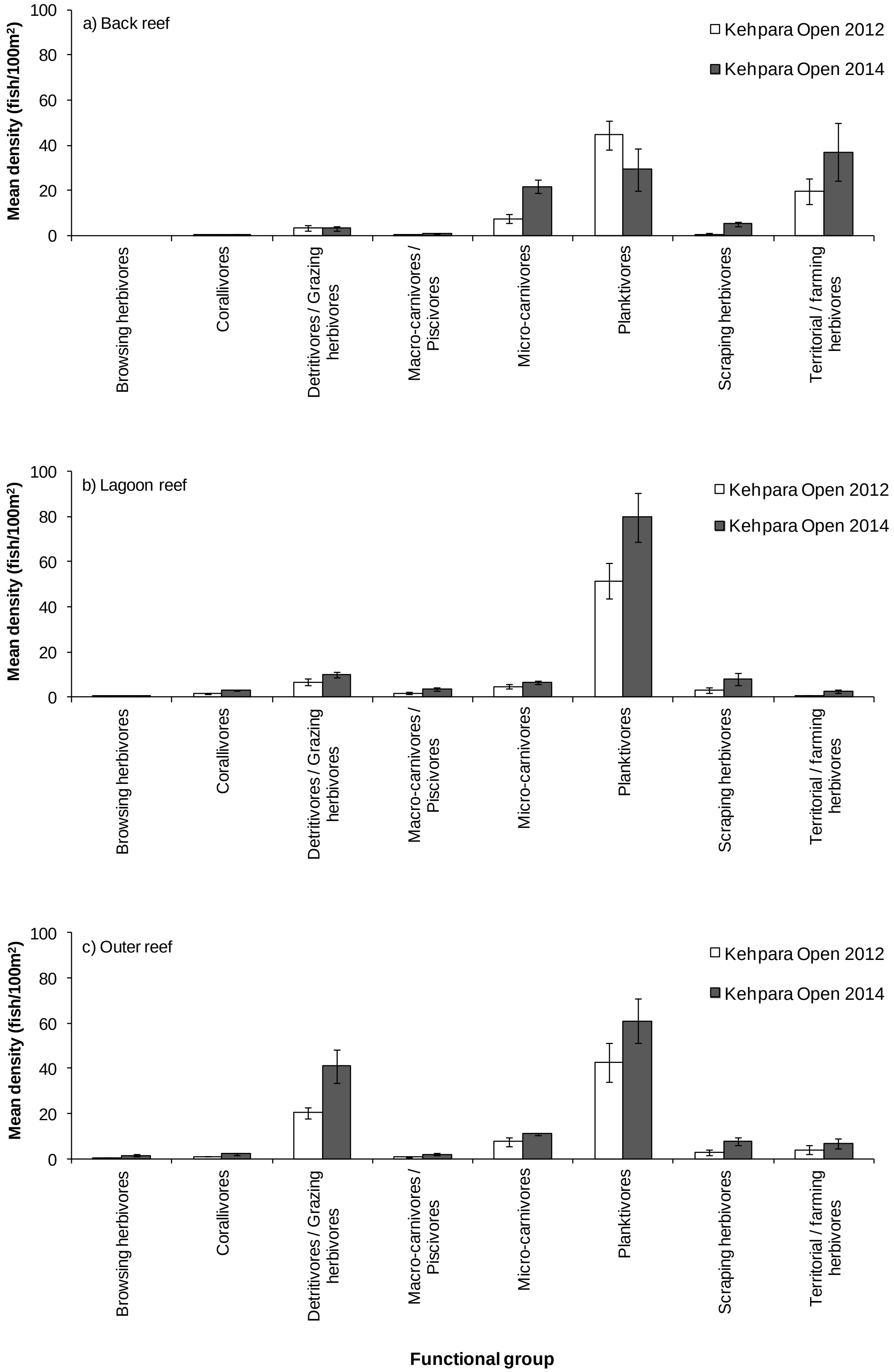

Figure 20 Mean densities (±SE) of key functional groups among a) back reef, b) lagoon reef and c) outer reef habitats of the Kehpara Open monitoring site during the 2012 and 2014 surveys.

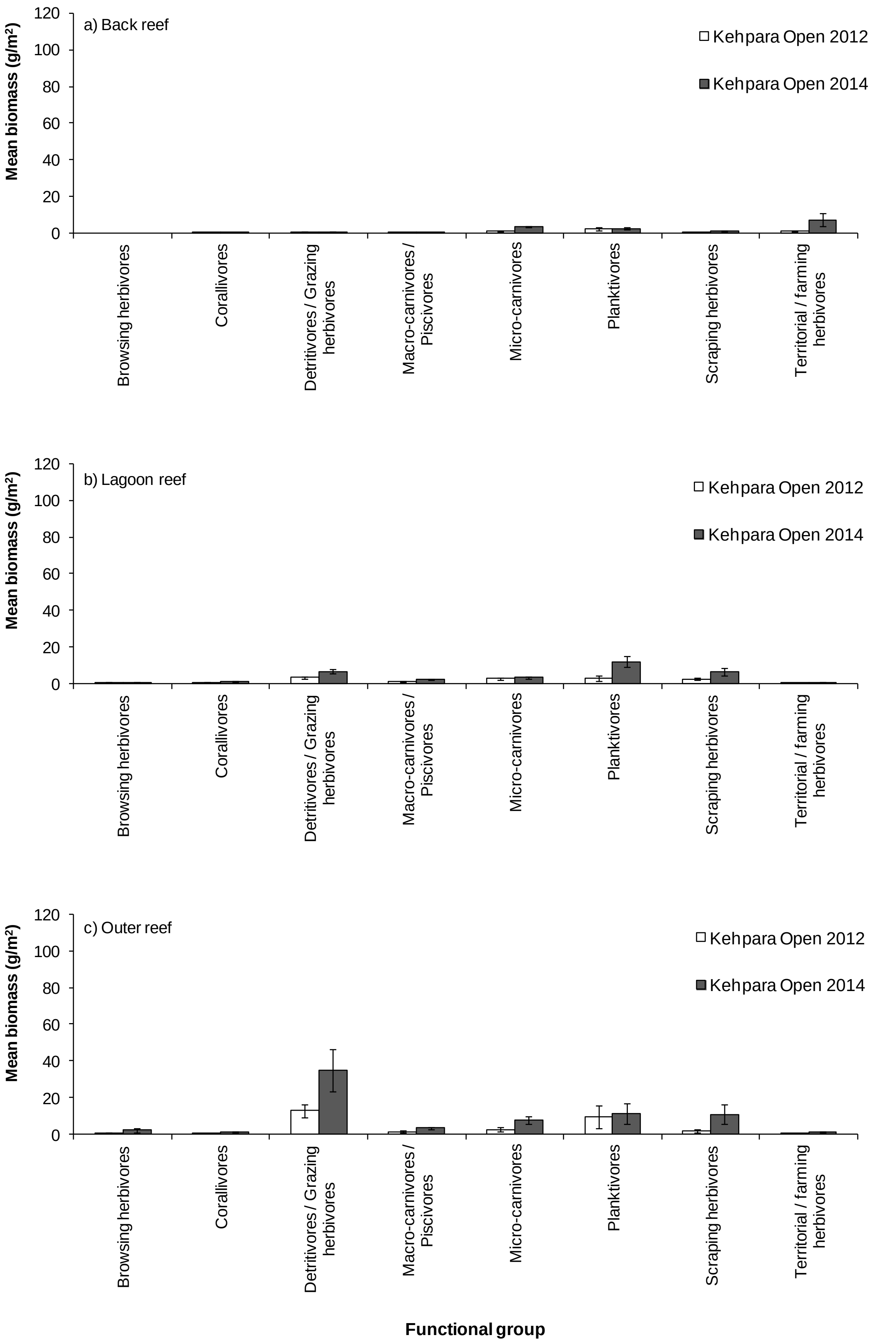

Figure 21 Mean biomass (±SE) of key functional groups among a) back reef, b) lagoon reef and c) outer reef habitats of the Kehpara Open monitoring site during the 2012 and 2014 surveys.

Performance of the Kehpara Marine Sanctuary in 2014

Few consistent differences in finfish density or biomass were observed among the Kehpara MPA and Kehpara Open sites during the 2014 survey. On the back reef, no significant differences were evident among sites in mean total density, or mean density and mean biomass of the families Balistidae, Ephippidae, Haemulidae, Holocentridae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Nemipteridae, Serranidae, Siganidae or Zanclidae. Both mean densities and mean biomass of Acanthuridae, Chaetodontidae, Mullidae, Pomacanthidae and Scaridae appeared higher in the MPA than the Open site, while the mean density and mean biomass of Pomacentridae appeared higher in the Open site relative to the MPA (Figure 12; Figure 13; Figure 18; Figure 19; Appendix 4).

Fewer differences were evident for lagoon and outer reef habitats. For lagoon reefs, no differences in mean total density or mean total biomass were evident among the MPA and Open sites. Mean densities and mean biomass of Holocentridae and Pomacanthidae appeared slightly higher within the MPA than the Open sites, while no differences were evident among sites in the mean densities or mean biomass of the families Acanthuridae, Balistidae, Chaetodontidae, Ephippidae, Haemulidae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Mullidae, Nemipteridae, Pomacentridae, Scaridae, Serranidae, Siganidae or Zanclidae (Appendix 4). Similarly, on the outer reef, no differences were evident among sites in mean total density, mean biomass, or the mean density and biomass of the families Acanthuridae, Balistidae, Ephippidae, Haemulidae, Holocentridae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Mullidae, Nemipteridae, Pomacanthidae, Pomacentridae, Serranidae, Siganidae or Zanclidae. The mean density of Chaetodontidae, and mean biomass of Scaridae, appeared slightly higher on the outer reefs of the MPA relative to those of the Open site (Figure 12; Figure 13; Figure 18; Figure 19; Appendix 4).

5. Benthic Habitat Assessment

Methodologies

Data collection

Broad-scale assessments

Broad-scale assessments of the benthic habitat of the Kehpara MPA and Kehpara Open sites 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 Kehpara MPA and Kehpara Open sites (Figure 22). 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.

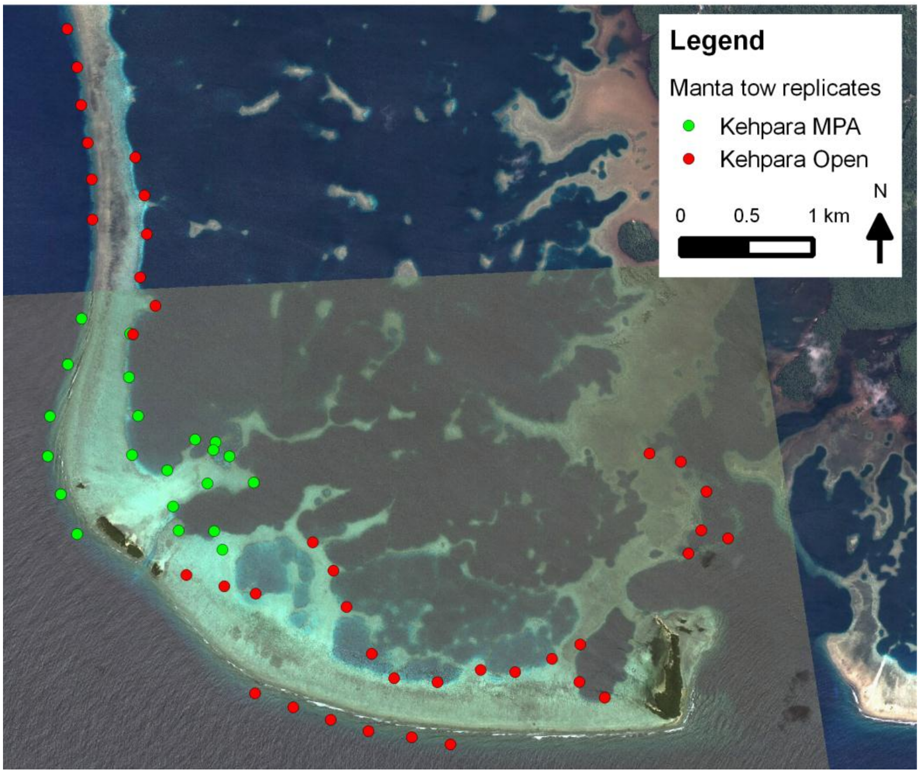

Figure 22 Location of broad-scale (manta tow) benthic habitat monitoring transects at the Kehpara region. Note each point represents a single 300 m replicate transect.

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 8), 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.

Data processing and analysis

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

1. Live hard coral – cover of different types of live hard coral, identified to genus level[2];
2. Other invertebrates – cover of invertebrate types including *Anemones*, *Ascidians*, *Cup sponge*, *Discosoma*, *Dysidea sponge*, *Gorgonians*, *Olive sponge*, *Terpios sponge*, *Other sponges*, *Soft coral*, *Zoanthids*, and *Other invertebrates* (other invertebrates not included in this list);
3. Macroalgae – cover of macroalgae *Asparagopsis*, *Blue-green algae*, *Boodlea*, *Bryopsis, Chlorodesmis, Caulerpa*, *Dicotyota*, *Dictosphyrea*, *Galaxura*, *Halimeda*, *Liagora, Lobophora*, *Mastophora*, *Microdictyton*, *Neomeris*, *Padina*, *Sargassum*, *Schizothrix, Turbinaria*, *Tydemania*, *Ulva*, and *Other macroalgae* (other macroalgae not included in this list);
4. Branching coralline algae (e.g. *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;
8. Seagrass – cover 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. Kehpara MPA 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. As with the finfish assessments, this design allowed for a comparison of each site over time, and an

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

assessment of the performance of the protected area vs. comparably-situated sites that are open to fishing.

Results

Broad-scale assessments

Cover of benthic habitats of the inner reefs of the Kehpara Open site was generally consistent among surveys. Cover of live coral appeared slightly higher in 2014, while cover of dead coral appeared slightly lower in 2014, however these differences were not significant at P = 0.05 (Figure 23; Appendix 5). At the Kehpara MPA site, cover of dead coral was significantly lower, while cover of coralline algae (e.g. *Halimeda*) was significantly higher, in 2014 (Figure 23; Appendix 5).

Broad-scale surveys of the outer reefs of the region were conducted for the first time in 2014. Cover of live coral, dead coral, bleached coral and rubble was generally similar among the Kehpara MPA and Open sites (Figure 23). Cover of coralline algae was slightly, yet significantly, higher at the Open site (Figure 23; Appendix 5).

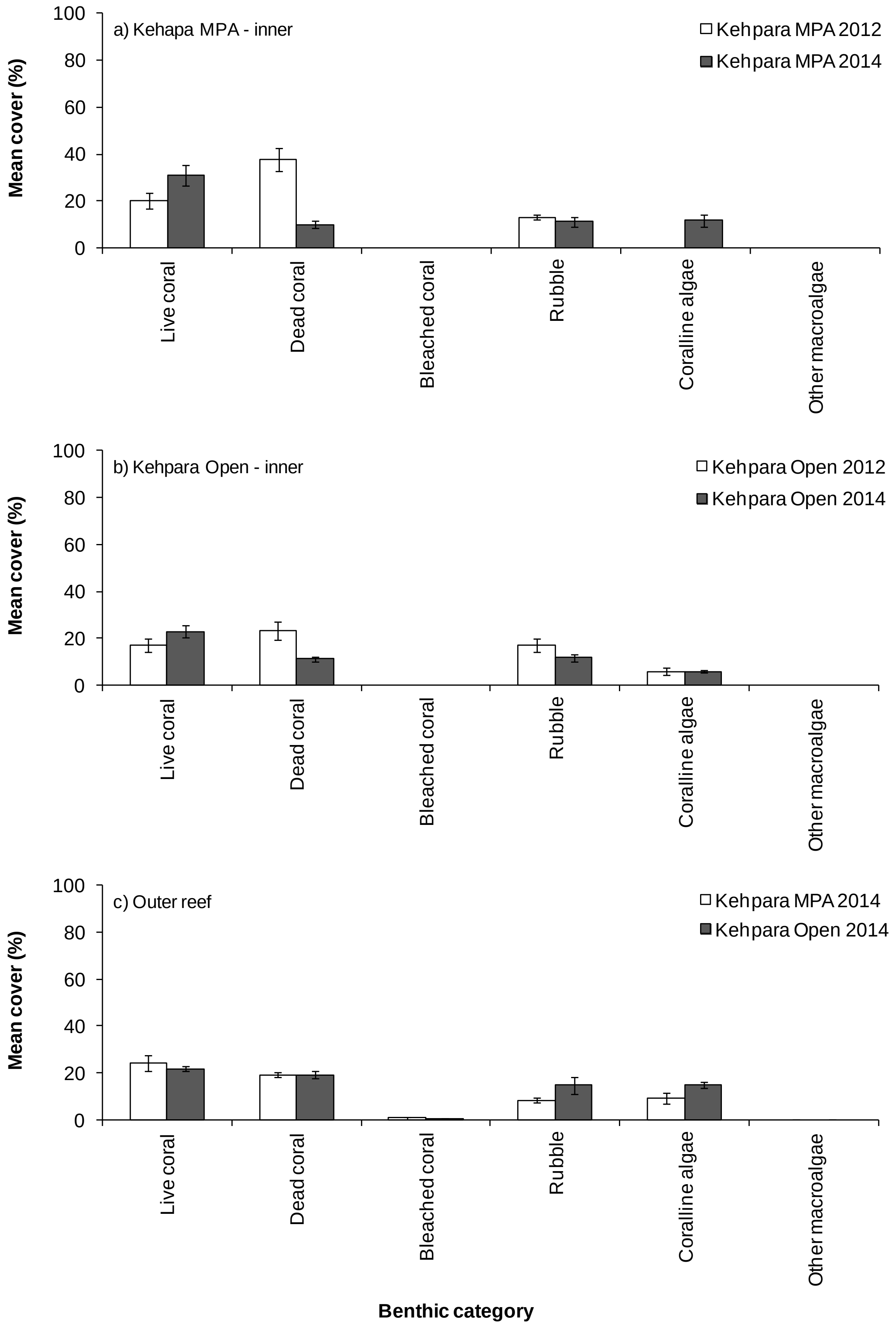

Figure 23 Percent cover of coral and algae observed during broad-scale habitat assessments via manta tow.

Fine-scale assessments

Kehpara MPA

Benthic communities of the Kehpara MPA site have been monitored at three habitats during the project, with back reefs, lagoon reefs and outer reefs each monitored in 2012 and 2014.

Few significant differences were evident in cover of major benthic categories at any habitat within the Kehpara MPA among the 2012 and 2014 surveys. On the back reef, cover of rubble increased significantly from 8.60±1.56% in 2012 to 17.10±2.68% in 2014, while the cover of macroalgae decreased significantly from 5.52±0.90 in 2012 to 2.25±0.54 on 2014. In general, back reef habitats during both the 2012 and 2014 surveys were characterised by a relatively high percent cover of sand / silt and moderate cover of live hard coral (in particular *Porites*-massive) and rubble (Figure 24; Figure 25; Appendix 5).

No significant differences in benthic habitat composition were evident on the lagoon reefs of the Kehpara MPA site between the 2012 and 2014 surveys (Figure 24). Lagoon reefs of the Kehpara MPA were dominated by live hard coral (in particular *Porites*-rus, *Porites*-massive and *Porites*), sand /silt and rubble (Figure 26; Figure 27). Lagoon reefs of the Kehpara MPA site had a significantly lower mean percent cover of live hard coral and significantly higher mean percent cover of sand than those at the Kehpara Open site (Figure 24; Appendix 5).

Similarly, no significant differences in benthic habitat composition were evident on the outer reefs of the Kehpara MPA site between the 2012 and 2014 surveys (Figure 24). Outer reefs during both surveys were characterised by a high cover of live hard coral and crustose coralline algae, and moderate cover of rubble, macroalgae (primarily *Halimeda*), other invertebrates (in particular sponges) and sand /silt (Figure 24; Figure 28). The cover of live hard coral on outer reef transects within the MPA was significantly higher than those within the Kehpara Open site in both 2012 and 2014 (Figure 24). In terms of cover, *Porites*-massive, *Montipora* and *Porites*-rus were the most common hard coral types on the outer reef transects of the Kehpara MPA, representing 22.05±366%, 6.77±2.97% and 5.22±1.32% cover, respectively, in 2014.

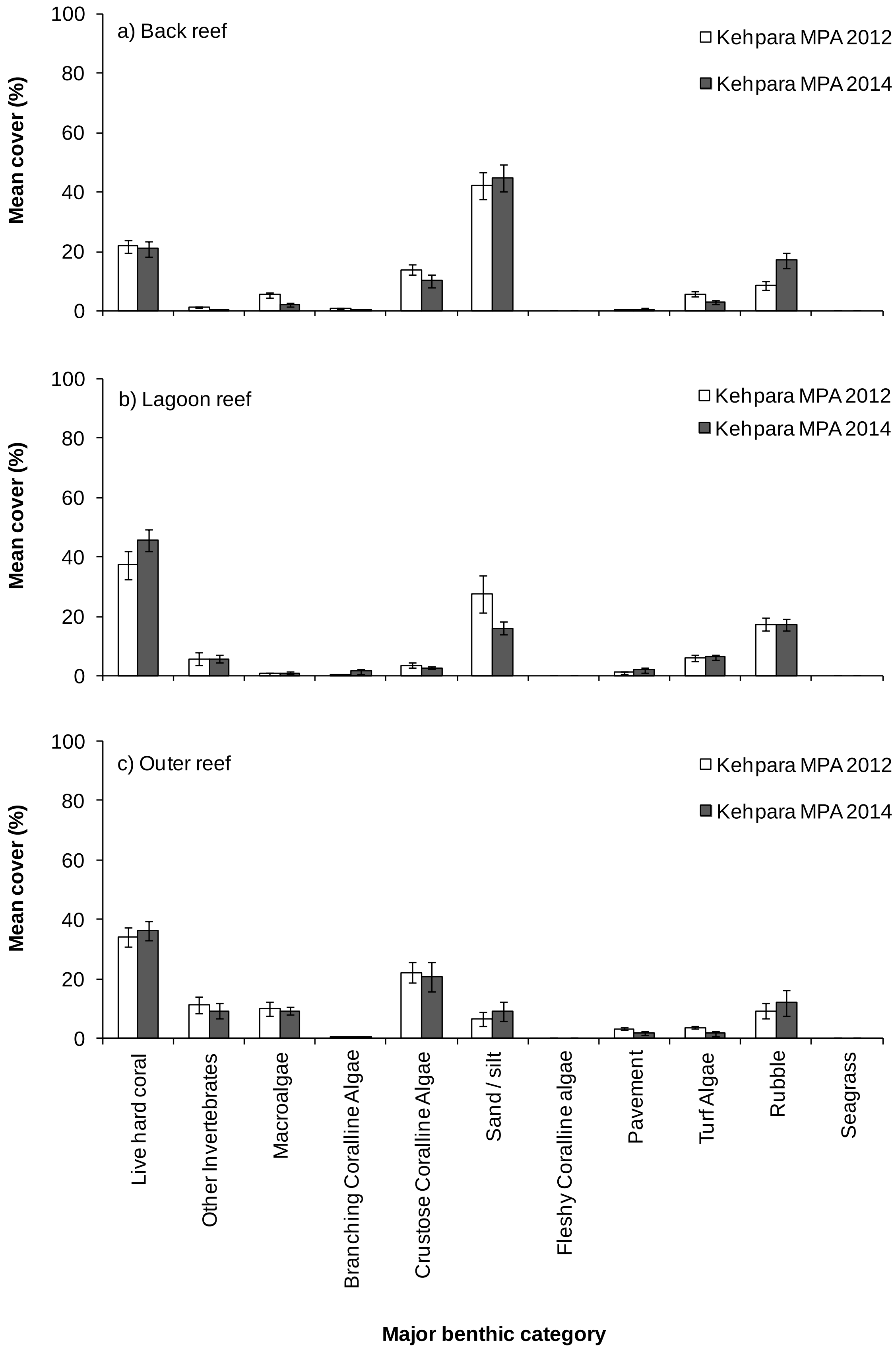

Figure 24 Percent cover of major benthic categories at a) back reef, b) lagoon reef and c) outer reef transects of the Kehpara MPA monitoring site among 2012 and 2014 surveys.

Figure 25 Back reef habitats of the Kehpara MPA site were characterised by a relatively high percent cover of sand / silt and moderate cover of live hard coral (in particular *Porites*-massive) and rubble.

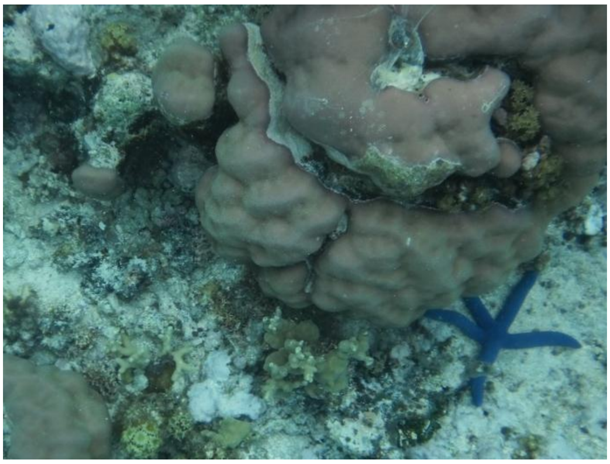

Figure 26 Lagoon reefs of the Kehpara MPA were dominated by live hard coral (in particular *Porites*-rus, *Porites*-massive and *Porites*.

Figure 27 A stand of *Porites-rus* on the lagoon reef of the Kehpara MPA site.

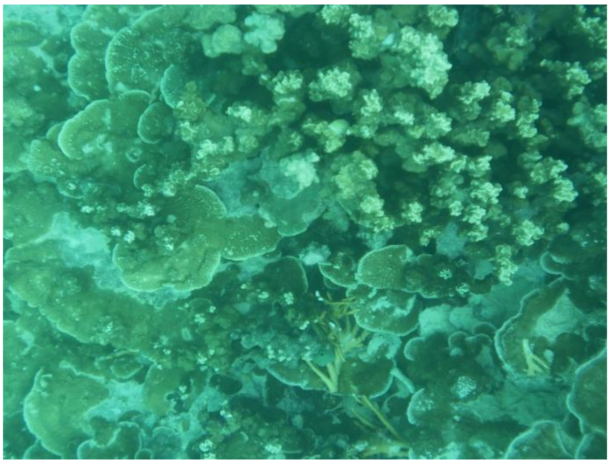

Figure 28 Benthic habitats of the outer reefs of the Kehpara MPA had high cover of live coral, in particular *Porites* spp., and high structural complexity.

Kehpara Open monitoring site

As with the Kehpara MPA site, benthic communities of the Kehpara Open site have been monitored at three habitats during the project, with back reefs, lagoon reefs and outer reefs each monitoring in 2012 and 2014.

A reduction in live coral cover (in particular *Acropora* spp.) and a significant increase in cover of macroalgae was apparent on the back reef habitat of the Kehpara Open site amongst surveys (Figure 29). In particular, cyanobacteria increased from 0.00% to 14.49±4.08% cover (Figure 30; Figure 31; Appendix 5). Ongoing monitoring is needed to determine whether these differences represent a permanent change in community composition or a short-term anomaly, and the likely causes of such changes.

In contrast to back reefs, no significant differences in benthic habitat composition were evident on the lagoon reefs of the Kehpara Open site among the 2012 and 2014 surveys (Figure 32). Lagoon reefs of the Kehpara Open site were dominated by live hard coral (in particular *Porites*-rus and *Porites*), reaching up to 95.6% cover on individual transects (Figure 32).

Similarly, no significant differences in benthic habitat composition were evident on the outer reefs of the Kehpara Open site among the 2012 and 2014 surveys (Figure 29). While the cover of sand /silt appeared lower in 2014 relative to 2012, this difference was not significant at $P < 0.05$. As with the 2012 surveys, in 2014 the outer reef habitats of the Kehpara Open site were characterised by moderate cover of crustose coralline algae, rubble, macroalgae and relatively low cover of live hard coral (Figure 29; Figure 33).

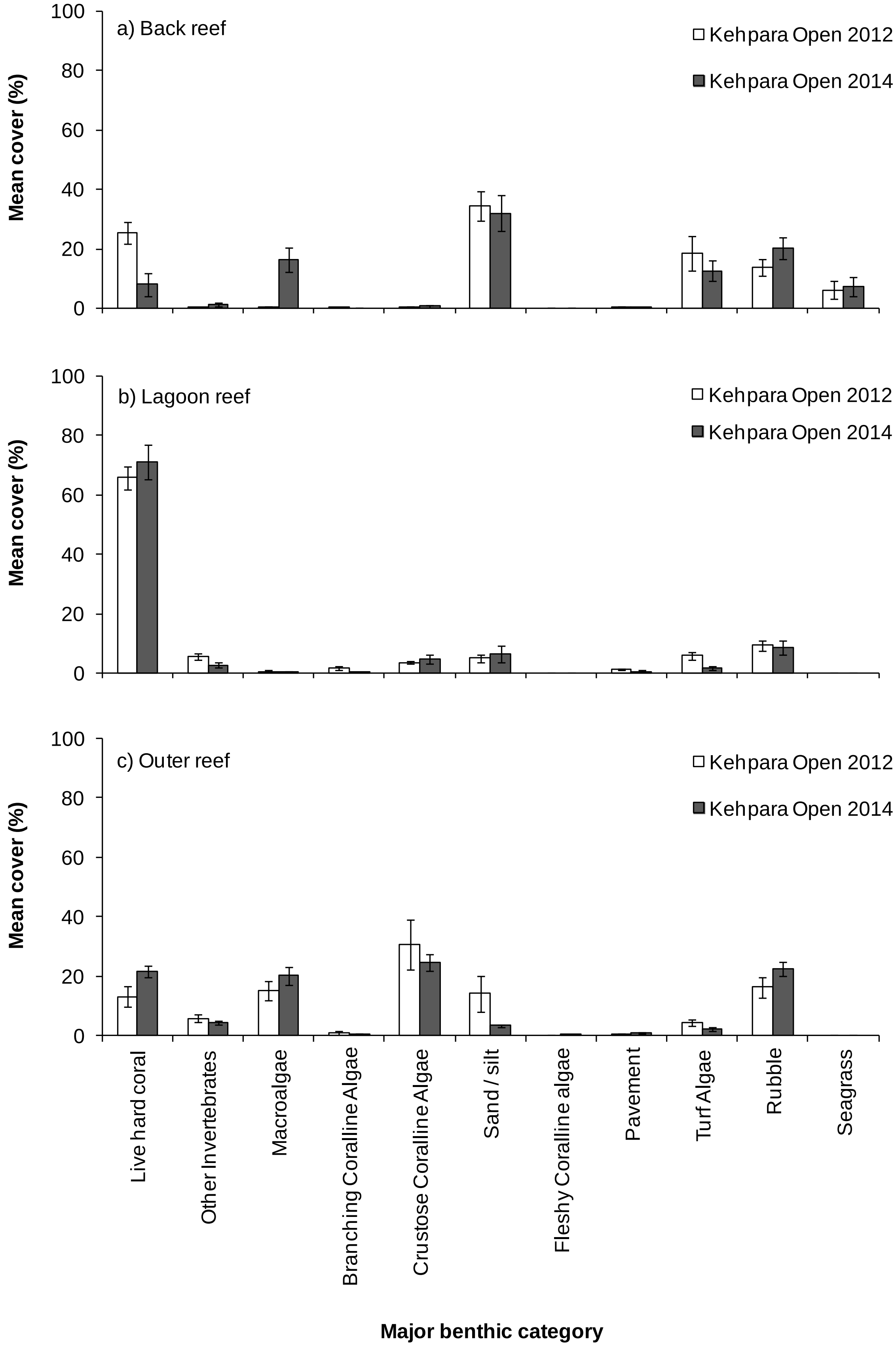

Figure 29 Percent cover of major benthic categories at a) back reef, b) lagoon reef and c) outer reef transects of the Kehpara Open monitoring site among 2012 and 2014 surveys

Figure 30 Once relatively healthy, coral communities of the reef flat at the Kehpara Open site are now dominated by cyanobacteria, macroalgae, turf algae and rubble.

Figure 31 Once healthy coral communities of the reef flat at the Kehpara Open site now covered with cyanobacteria and macroalgae.

Figure 32 Lagoon reef transects of the Kehpara MPA were characterised by a high cover of *Porites* and *Porites-rus*.

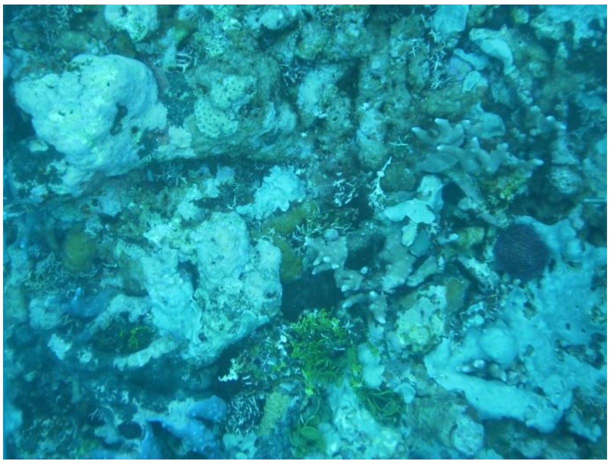

Figure 33 Benthic habitats of the outer reefs of the Kehpara Open had low cover of live coral.

6. Invertebrate Surveys

Methods and Materials

Data collection

Three 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 22; Appendix 7). 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 34). 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.

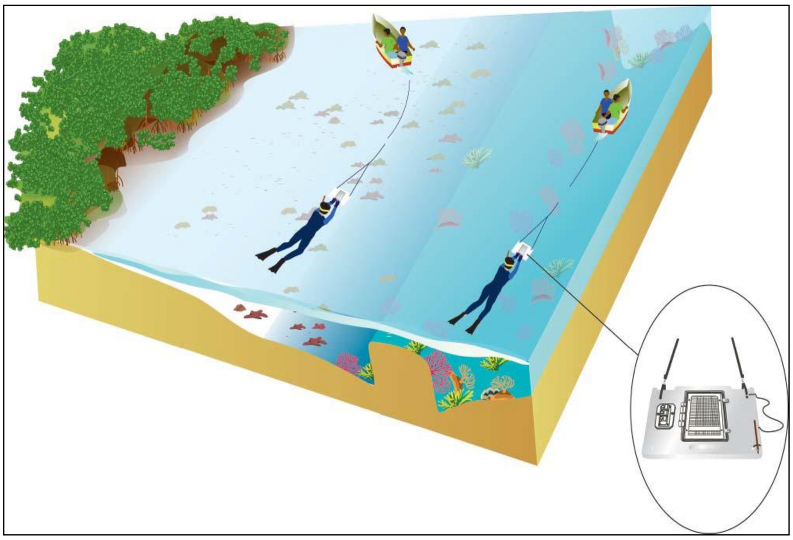

Figure 34 Diagrammatic representation of the manta tow survey method.

To assess the abundance, size and condition of invertebrate resources at finer-spatial scales, reef benthos transects (RBt) and soft benthos (SBt) transects were conducted. The methods were conducted by two snorkellers equipped with measuring instruments attached to their record boards (slates) for recording the abundance and size of invertebrate species. For some species, such as sea urchins, only abundance was recorded due to difficulty in measuring the size of these organisms. Each transect was 40 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 35). The GPS position of each station was recorded in the centre of the station. RBt stations were established within the Kehpara MPA and Kehpara Open sites (Figure 36), while SBt stations were established within and adjacent to the Pwudoi Mangrove Reserve (with sites termed Pwudoi MPA and Pwudoi Open for purposes of this report) (Figure 37). Due to low numbers of SBt stations established in the baseline survey (n=1), an additional three stations were established during this second survey.

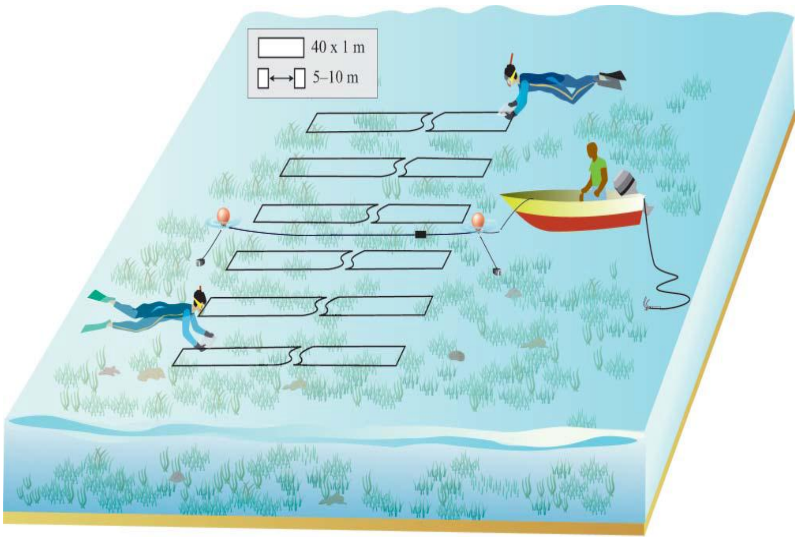

Figure 35 Diagrammatic representation of the reef benthos and soft benthos transect method.

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).

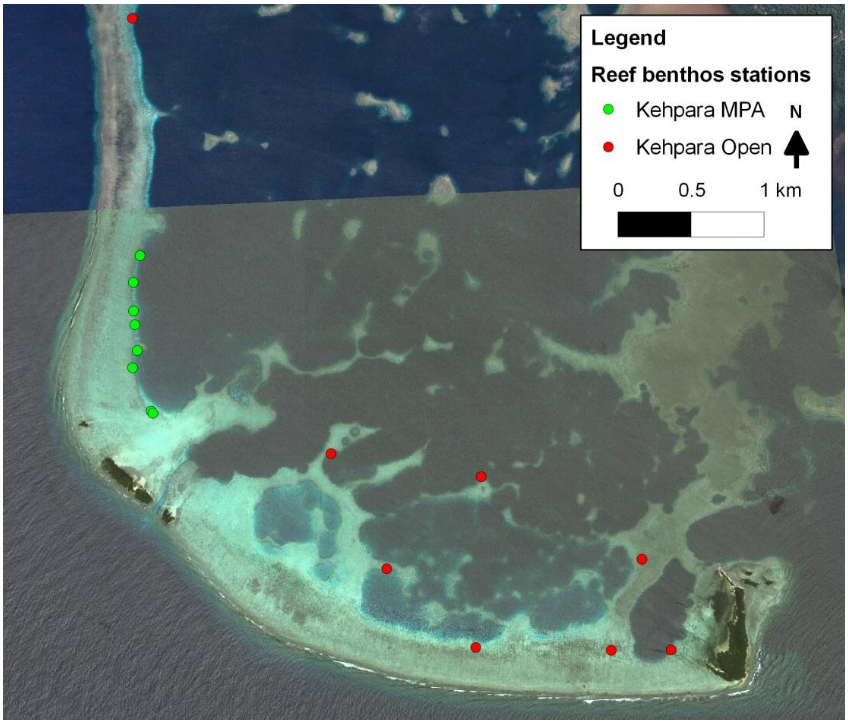

Figure 36 Approximate positions of reef benthos transect (RBt) stations. A list of GPS waypoints for the RBt stations is included as Appendix 8.

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, RBt and SBt stations. Data was analysed on an individual species level except for gastropods and urchins, which were pooled to a genus level. To test for differences in invertebrate densities observed during manta tows, RBts and SBts 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. Kehpara MPA 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 the inclusion of additional stations in the 2014 survey, no higher statistical analyses were performed on the SBt data.

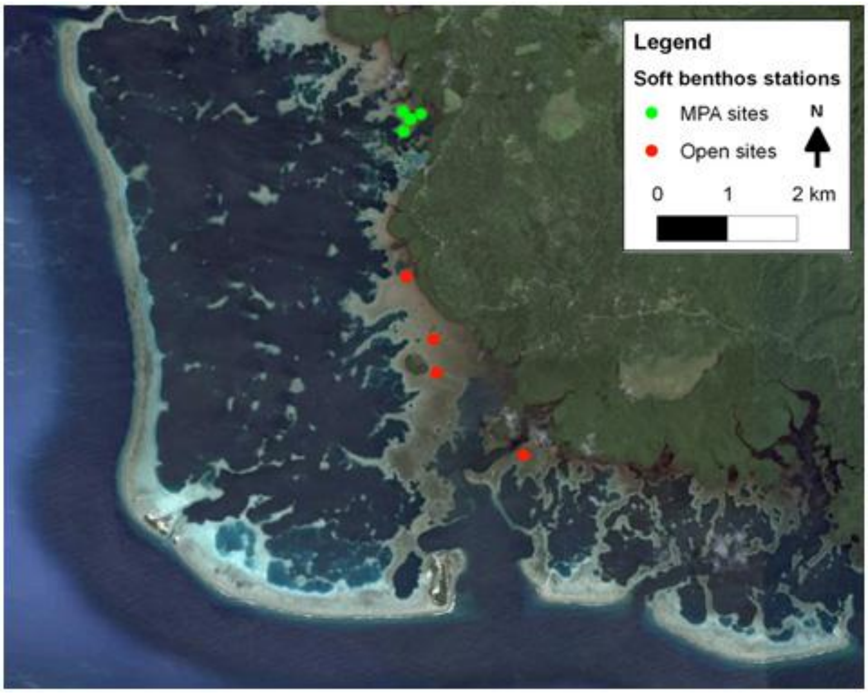

Figure 37 Approximate positions of soft benthos transect (SBt) stations. A list of GPS waypoints for the SBt stations is included as Appendix 9.

Table 11 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

No significant differences in invertebrate densities were observed among the 2012 and 2014 manta tow surveys within either the Kehpara MPA or Kehpara Open sites (Figure 38; Figure 39). Similarly, few differences in invertebrate densities were observed amongst the Kehpara MPA and Open sites during the 2014 survey, with the density of only curryfish (*Stichopus herrmanni*) differing among sites (Figure 40). With the exception of tigerfish (*Bohadschia argus*), mean observed densities were well below the regional reference densities for healthy sea cucumber stocks estimated by Pakoa et al. (2014) (Table 12).

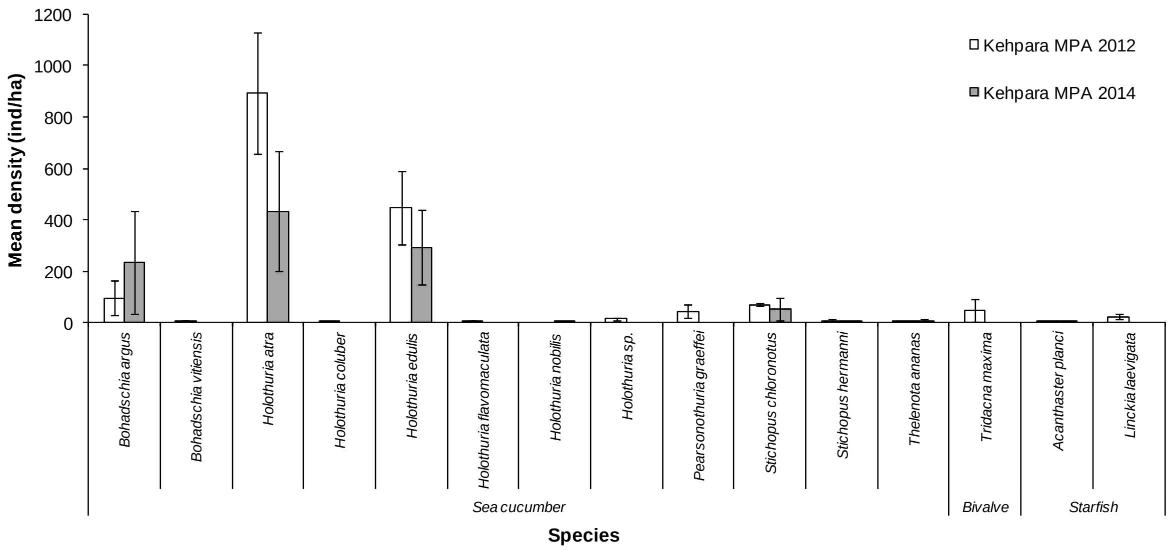

Figure 38 Overall mean density of invertebrate species (±SE) observed during manta tows at Kehpara MPA stations, 2012 and 2014.

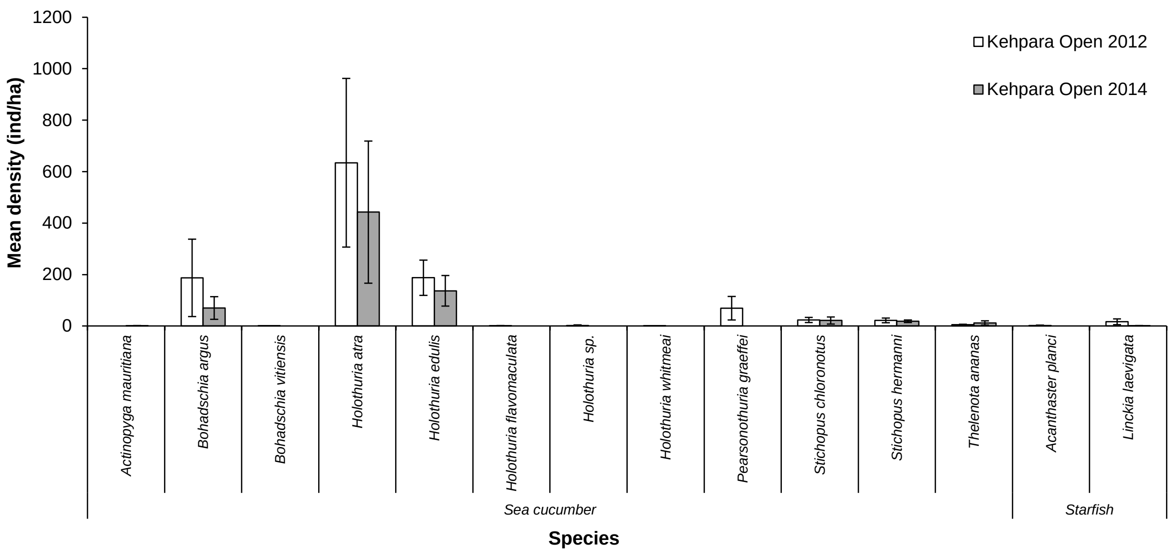

Figure 39 Overall mean density of invertebrate species (±SE) observed during manta tows at Kehpara Open stations, 2012 and 2014.

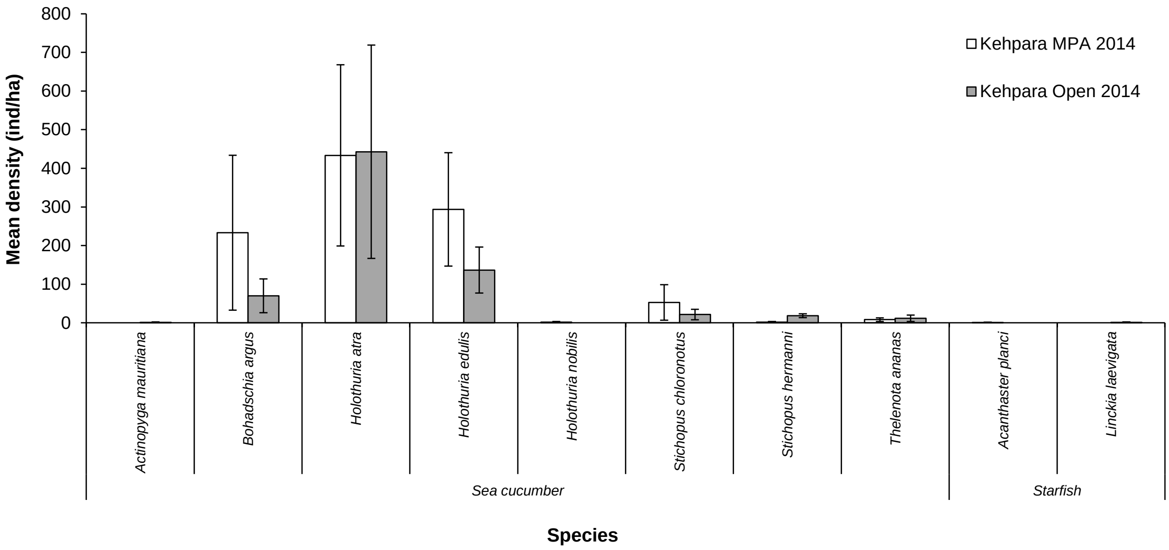

Figure 40 Overall mean density of invertebrate species (±SE) observed during manta tows at Kehpara MPA and Open stations, 2014.

Table 12 Mean overall densities (±SE) of sea cucumber species at manta tow stations in 2012 and 2014. The regional reference density for healthy stocks (for manta tow surveys) is provided in the last column (from Pakoa et al. 2014).

Species	Kehpara MPA		Kehpara Open		Manta tow reference density
	2012	2014	2012	2014	
Actinopyga mauritiana	0.0±0.00	0.00±0.00	0.00±0.00	1.11±1.11	20
Bohadschia argus	94.44±67.36	233.33±200.64	187.22±149.94	70.00±43.74	50
Bohadschia vitiensis	5.56±3.21	0.00±0.00	0.56±0.56	0.00±0.00	160
Holothuria atra	893.52±236.01	433.33±234.54	634.44±327.82	442.78±276.03	2,400
Holothuria coluber	2.78±2.78	0.00±0.00	0.00±0.00	0.00±0.00	350
Holothuria edulis	445.37±142.20	293.52±146.78	187.78±68.55	136.67±59.47	250
Holothuria flavomaculata	4.63±3.34	0.00±0.00	1.11±0.68	0.00±0.00	-
Holothuria nobilis	0.00±0.00	1.85±1.85	0.00±0.00	0.00±0.00	-
Holothuria whitmeai	0.00±0.00	0.00±0.00	0.56±0.56	0.00±0.00	10
Pearsonothuria graeffei	43.52±25.37	0.00±0.00	69.44±45.51	0.00±0.00	50
Stichopus chloronotus	70.37±5.16	52.78±45.84	23.89±9.88	21.67±13.62	1,000
Stichopus hermanni	6.48±6.48	1.85±1.85	21.67±9.23	18.33±5.02	130
Thelenota ananas	2.78±2.78	8.33±4.81	5.56±1.76	11.67±8.35	10

Reef benthos transects

Invertebrate diversity at RBt stations was higher in 2012 than 2014 at both the Kehpara MPA and Kehpara Open sites (Table 13). No noticeable differences were evident in invertebrate diversity among the Kehpara MPA and Open sites in 2014 (Table 13). Within the Kehpara MPA, mean densities of *Cypraea* spp. and *Strombus* spp. were significantly lower in 2014 relative to 2012 (10.42±6.82 vs. 109.37±57.62 ind/ha and 5.21±5.21 vs. 57.29±33.23 ind/ha, respectively) (Figure 41). No significant differences were observed within the Kehpara Open site during the 2012 and 2014 surveys (Figure 42). In 2014, densities of *Holothuria coluber* were significantly higher at the Kehpara Open site relative to the Kehpara MPA site (Figure 43). No other differences were evident amongst sites or surveys.

As with the manta tow surveys, densities of sea cucumber species observed during the RBt surveys were generally considerably lower than the regional reference densities for healthy sea cucumber stocks, with only tigerfish (*B. argus*) and pinkfish (*Holothuria edulis*) consistently occurring in densities exceeding the reference densities (Table 14).

Table 13 Total number of genera and species, and diversity of invertebrates observed during reef benthos transects at the Kehpara MPA and Open sites, 2012 and 2014.

Parameter	Kehpara MPA		Kehpara Open	
	2012	2014	2012	2014
No. stations surveyed	8	8	8	8
No. of genera	27	16	17	14
No. of species	45	20	25	18
Diversity	5.63	2.50	3.13	2.25

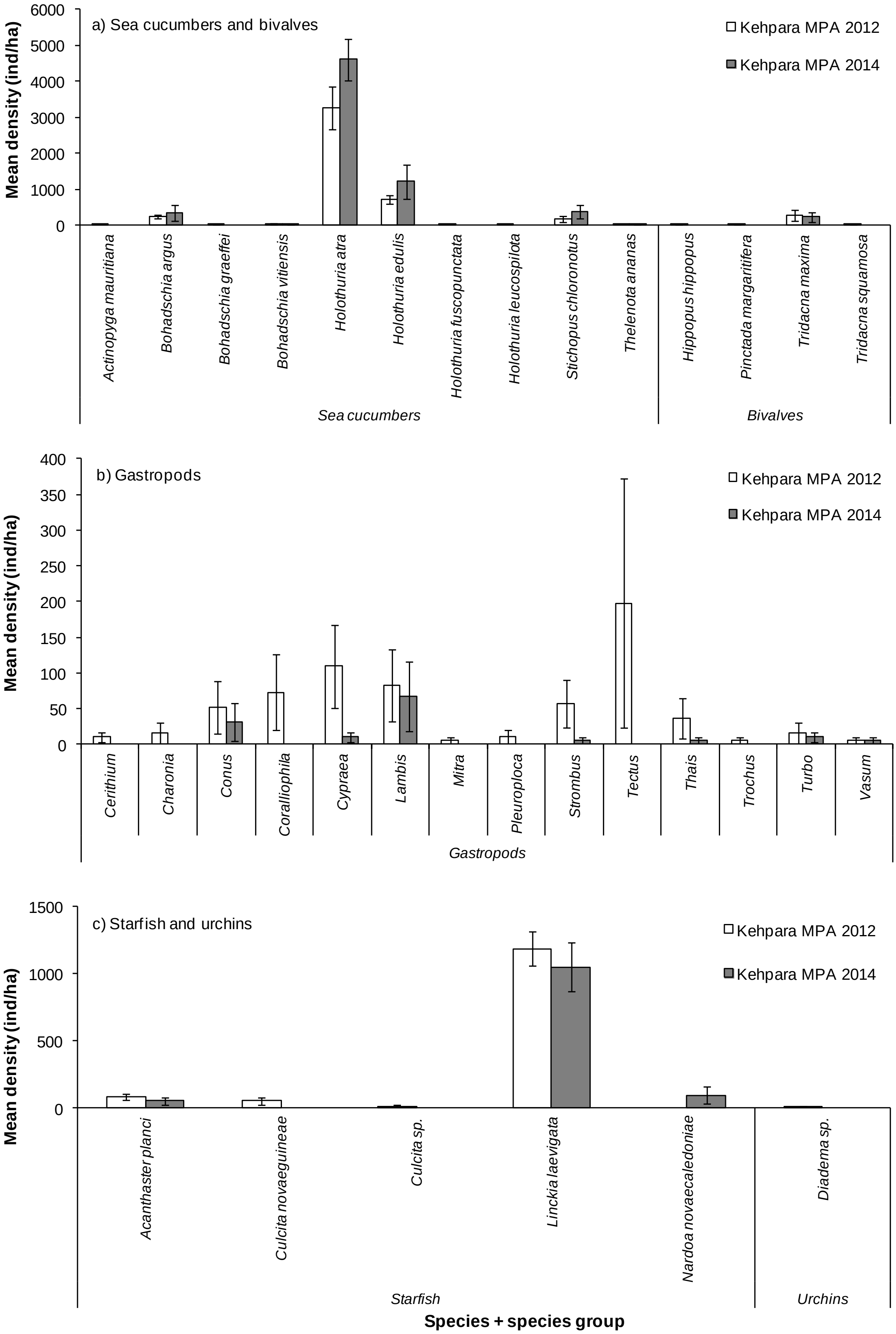

Figure 41 Overall mean densities (±SE) of a) sea cucumbers and bivalves, b) gastropods and c) starfish and urchins observed at RBt stations at the Kehpara MPA site, 2012 and 2014.

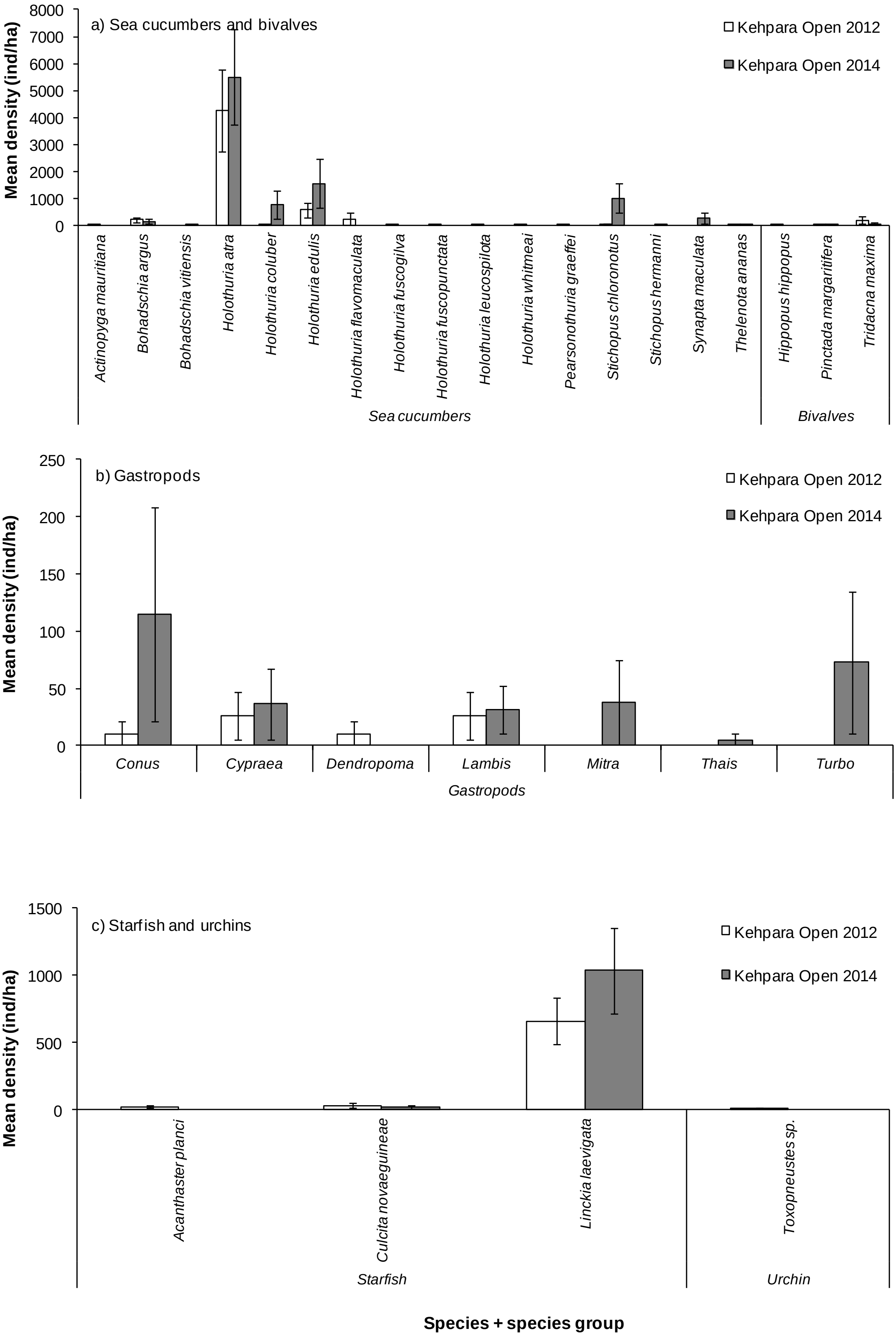

Figure 42 Overall mean densities (±SE) of a) sea cucumbers and bivalves, b) gastropods and c) starfish and urchins observed at RBt stations at the Kehpara Open site, 2012 and 2014.

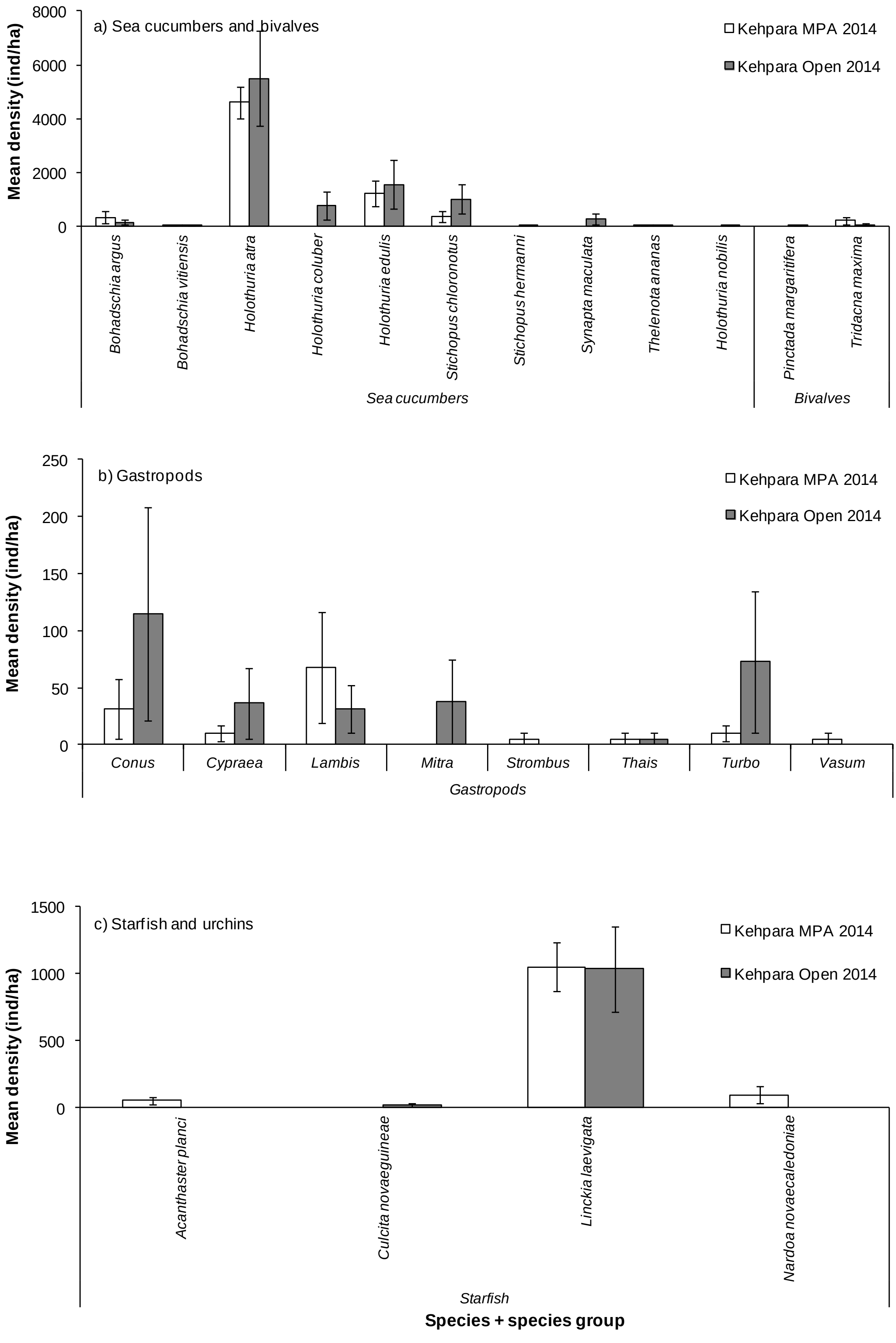

Figure 43 Overall mean densities (±SE) of a) sea cucumbers and bivalves, b) gastropods and c) starfish and urchins observed at RBt stations at the Kehpara MPA and Open sites during the 2014 survey.

Table 14 Mean overall densities (±SE) of sea cucumber species at RBt stations in 2012 and 2014. The regional reference density for healthy stocks (for RBt surveys) is provided in the last column (from Pakoa et al. 2014). na = no reference density available.

Species	Kehpara MPA		Kehpara Open		RBt reference density
	2012	2014	2012	2014	
Actinopyga mauritiana	5.21±5.21	0.00±0.00	5.21±5.21	0.00±0.00	200
Bohadschia argus	250.00±63.97	354.17±232.26	223.96±97.70	166.67±82.96	120
Bohadschia graeffei	10.42±10.42	0.00±0.00	0.00±0.00	0.00±0.00	na
Bohadschia vitiensis	52.08±26.99	10.42±10.42	0.00±0.00	15.63±10.96	100
Holothuria atra	3276.04±601.18	4609.38±578.10	4270.83±1506.95	5503.13±1759.37	5,600
Holothuria coluber	0.00±0.00	0.00±0.00	15.63±15.63	800.00±522.70	1,100
Holothuria edulis	729.17±107.97	1223.96±479.42	583.33±260.45	1576.04±894.35	260
Holothuria flavomaculata	0.00±0.00	0.00±0.00	255.21±237.59	0.00±0.00	na
Holothuria fuscogilva	0.00±0.00	0.00±0.00	5.21±5.21	0.00±0.00	20
Holothuria fuscopunctata	5.21±5.21	0.00±0.00	5.21±5.21	0.00±0.00	10
Holothuria leucospilota	5.21±5.21	0.00±0.00	26.04±26.04	0.00±0.00	na
Holothuria nobilis	0.00±0.00	0.00±0.00	0.00±0.00	25.00±25.00	na
Holothuria whitmeai	0.00±0.00	0.00±0.00	10.42±10.42	0.00±0.00	50
Pearsonothuria graeffei	0.00±0.00	0.00±0.00	5.21±5.21	0.00±0.00	100
Stichopus chloronotus	182.29±100.20	380.21±185.41	52.08±21.92	1030.21±531.60	3,500
Stichopus hermanni	0.00±0.00	0.00±0.00	0.00±0.00	5.21±5.21	100
Synapta maculata	0.00±0.00	0.00±0.00	0.00±0.00	286.46±187.90	na
Thelenota ananas	5.21±5.21	15.63±10.96	5.21±5.21	5.21±5.21	30

Soft benthos transects

Few differences were evident in densities of invertebrate species at SBt sites at the Kehpara Open site (Figure 44). Densities of lollyfish (*Holothuria atra*) in the Kehpara MPA appeared lower in 2014 relative to 2012 (Figure 44), however such differences may be due to the inclusion of additional stations with naturally lower densities in the 2014 survey. Densities of the sea cucumbers *H. atra* and *H. scabra* were considerably higher in the Kehpara Open stations than in the MPA (Figure 43 vs. Figure 44).

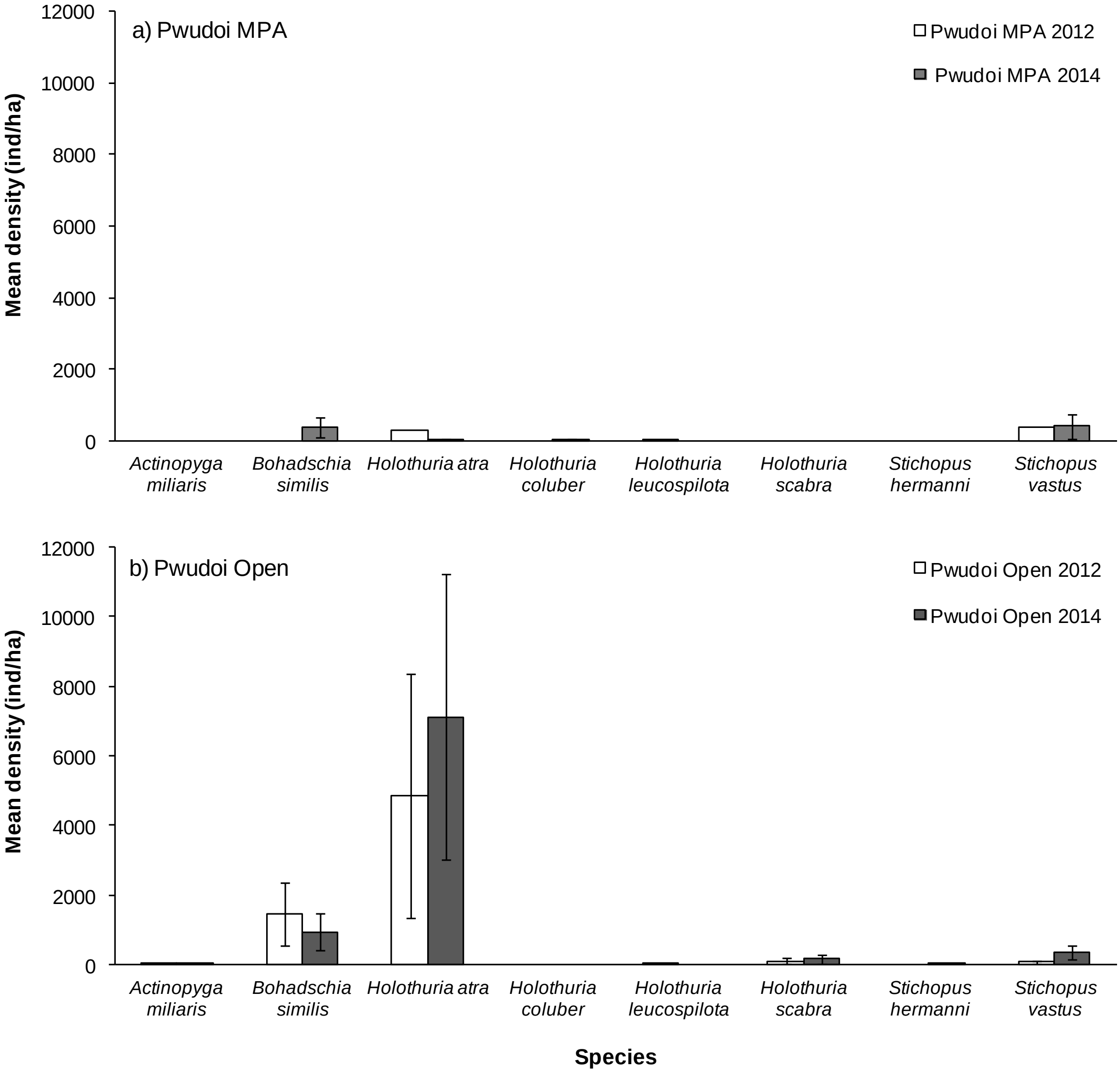

Figure 44 Mean densities of sea cucumber species observed at SBt stations at the Kehpara MPA and Open sites, 2012 and 2014.

7. Creel Surveys

Methods

Creel surveys at Pohnpei focused on fishers landing at Kolonia and Kitti municipalities, and primarily focused on commercial gillnet, handline/bottom fishing and spear fishers. 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 fish caught were identified to species, measured to the nearest mm, and weighed to the nearest 10 g, unless damaged. A copy of the survey form used in the creel surveys is included as Appendix 10.

Figure 45 Members of the survey team undertaking a creel survey at the ice plant jetty, Kolonia Municipality.

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 and weight of fish caught per fisher per hour spent fishing for spear and handline fishing, and number of fish and weight of fish caught per hour spent fishing for gillnetting. 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.

Results

Kolonia Municipality

Gillnet

Seven surveys of gillnet fishing were completed at Kolonia. On average, gillnetting trips involved 2.71±0.61 fishers with 2.29±0.49 hours spent fishing (Table 15). The average catch per trip was 21.38±5.19 kg, or 36.14±6.98 individual fish (Figure 46). Average CPUE was 17.14±2.85 fish/hour spent fishing, or 9.47±2.01 kg/hour spent fishing (Table 15). The average furthest distance travelled per gillnet trip was 4.71±0.99 km.

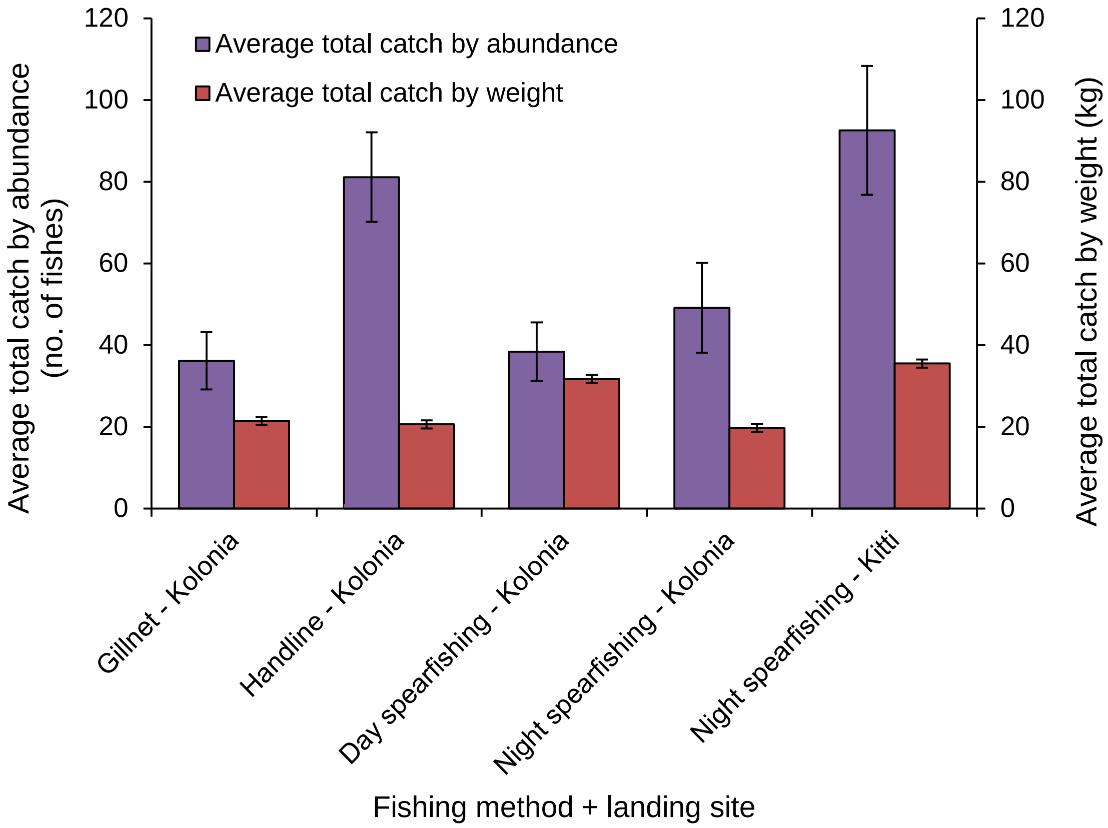

Figure 46 Average total catch for each major fishing method and landing site.

A total of 253 individuals fishes were observed in the 7 gillnet surveys, representing 35 species from 12 families. Members of the Scaridae (parrotfishes), Siganidae (rabbitfishes), Kyphosidae (drummers), Carangidae (trevallies) and Acanthuridae (surgeonfishes) dominated the catch in terms of both abundance and weight (Appendix 11). The most common species observed in the gillnet catch were the parrotfish *Hipposcarus longiceps* (representing 26.5% of the total catch by abundance and 35.4% of the total catch by weight), the drummer *Kyphosus cinerascens* (7.5% of the total catch by abundance and 3.9% of the total catch by weight), the goatfish *Parupeneus barberinus* (7.1% of the total catch by abundance and 10.3% of the total catch by weight), the rabbitfish *Siganus argenteus* (6.7% of the total catch by abundance and 2.8% of the total catch by weight) and the jack *Caranx melampygus* (5.5% of the total catch by abundance and 5.1% of the total catch by weight) (Appendix 11).

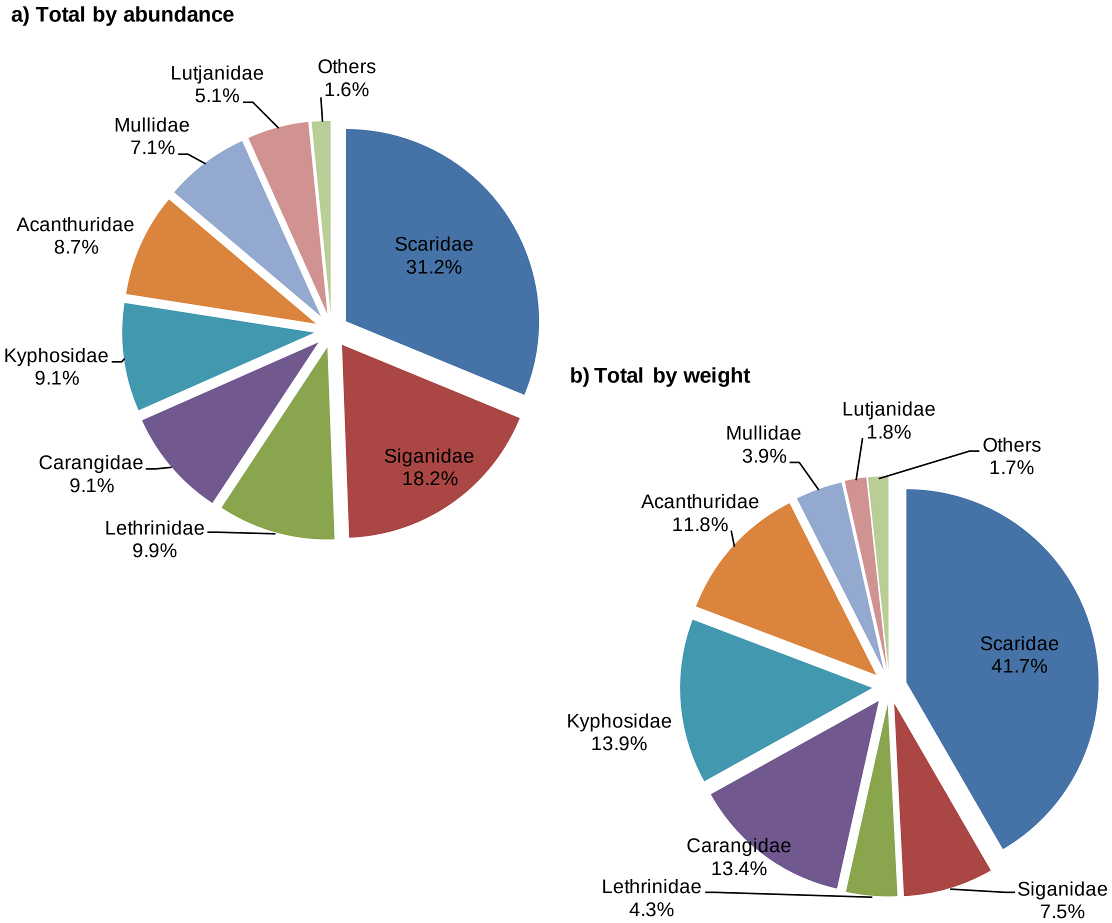

Figure 47 Percent contribution by abundance (top) and weight (below) of families caught by gillnetting, Kolonia municipality, March 2014.

Handline/bottom fishing

Twenty-seven surveys of handlining/bottom fishing were completed at Kolonia. On average, handline trips involved 1.85±0.12 fishers (range = 1–3) with an average time spent fishing of 5.62±0.45 hours (Table 15). The average catch per trip was 20.57±2.52 kg, or 81.11±10.96 individual fish. Average CPUE was 10.34±1.75 fish/fisher/hour, or 2.61±0.41 kg/fisher/hour (Table 15). The average furthest distance travelled was 5.13±0.54 km.

The handline/bottom fishing catch was dominated by members of the families Carangidae (trevallies), Lutjanidae (snappers), Holocentridae (squirrelfishes and soldierfishes), Serranidae (groupers) and Lethrinidae (emperors) in terms of both individuals and weight (Figure 48). Sixty-two species were observed in the handline catch (Appendix 11), with 2,190 individuals weighing an estimated 555 kg recorded. The most common species observed in the handline catch were *Selar crumenophthalmus* (representing 33.1% of the total catch by abundance and 21.9% of the total catch by weight), the snappers *Lutjanus fulvus* (15.5% of the total catch by abundance and 10.8% of the total catch by weight) and *Lutjanus gibbus* (7.1% of the total catch by abundance and 10.3% of the total catch by weight), the jack *Caranx sexfasciatus* (6.8% of the total catch by abundance and 9.5% of the total catch by weight) and the soldierfish *Myrpristis adusta* (5.5% of the total catch by abundance and 4.9% of the total catch by weight) (Appendix 11).

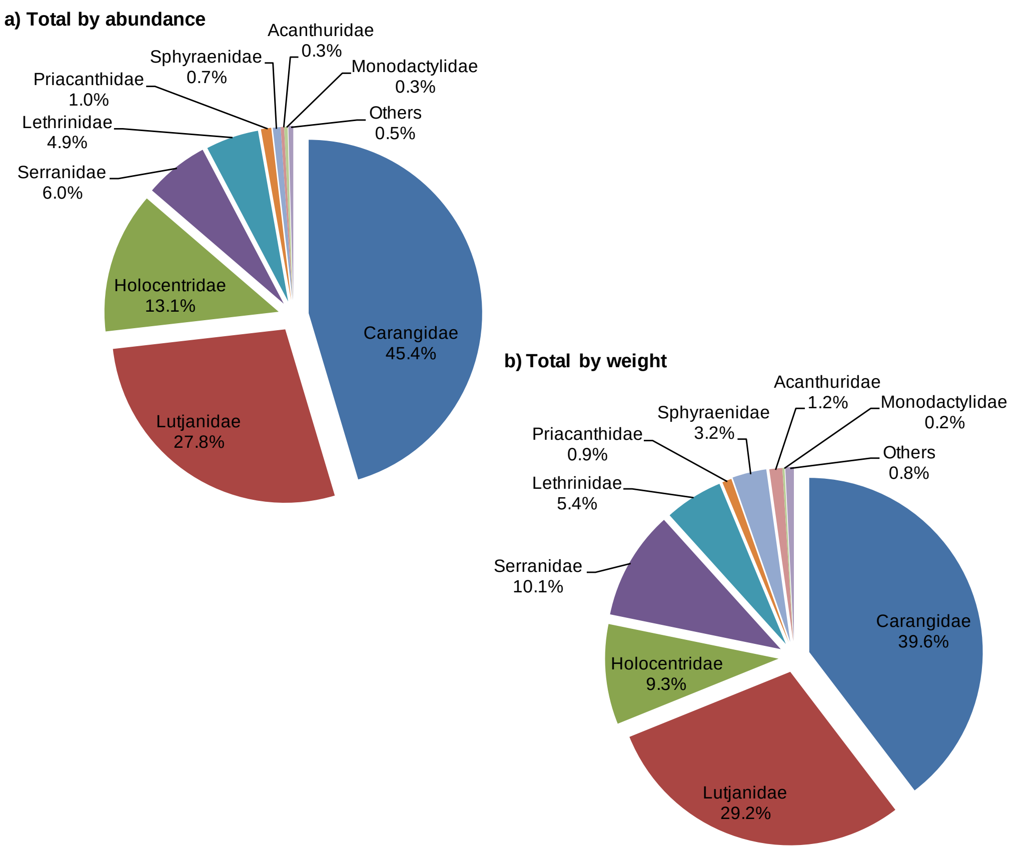

Figure 48 Percent contribution by abundance (top) and weight (below) of families caught by handlining, Kolonia municipality, March 2014.

Day spearfishing

Three landings of day spearfishing were completed at Kolonia. Trips involved an average of 2.00±0.58 fishers with an average time spent fishing of 5.33±0.67 hours (Table 15). The average catch per trip was 31.69±5.23 kg or 38.33±7.17 individual fish (Figure 46). Catch-per-unit effort was 5.33±3.09 fish/fisher/hour, or 3.80±1.58 kg/fisher/hour (Table 15). The average distance travelled per trip was 5.67±1.33 km. A total of 115 individuals were observed from the day spearfishing catch. Twenty-nine species from 11 families were observed in the catch (Appendix 11), with members of the Acanthuridae (surgeonfishes), Scaridae (parrotfishes), Kyphosidae (drummers), Carangidae (trevallies) and Haemulidae (sweetlips) dominating the total catch by both abundance and weight (Figure 49). The most common finfish species caught included the surgeonfish *Acanthurus xanthopterus*, *Naso unicornis*, *Chlorurus microrhinos*, *Kyphosus vaigiensis* and *Naso lituratus* (Appendix 11).

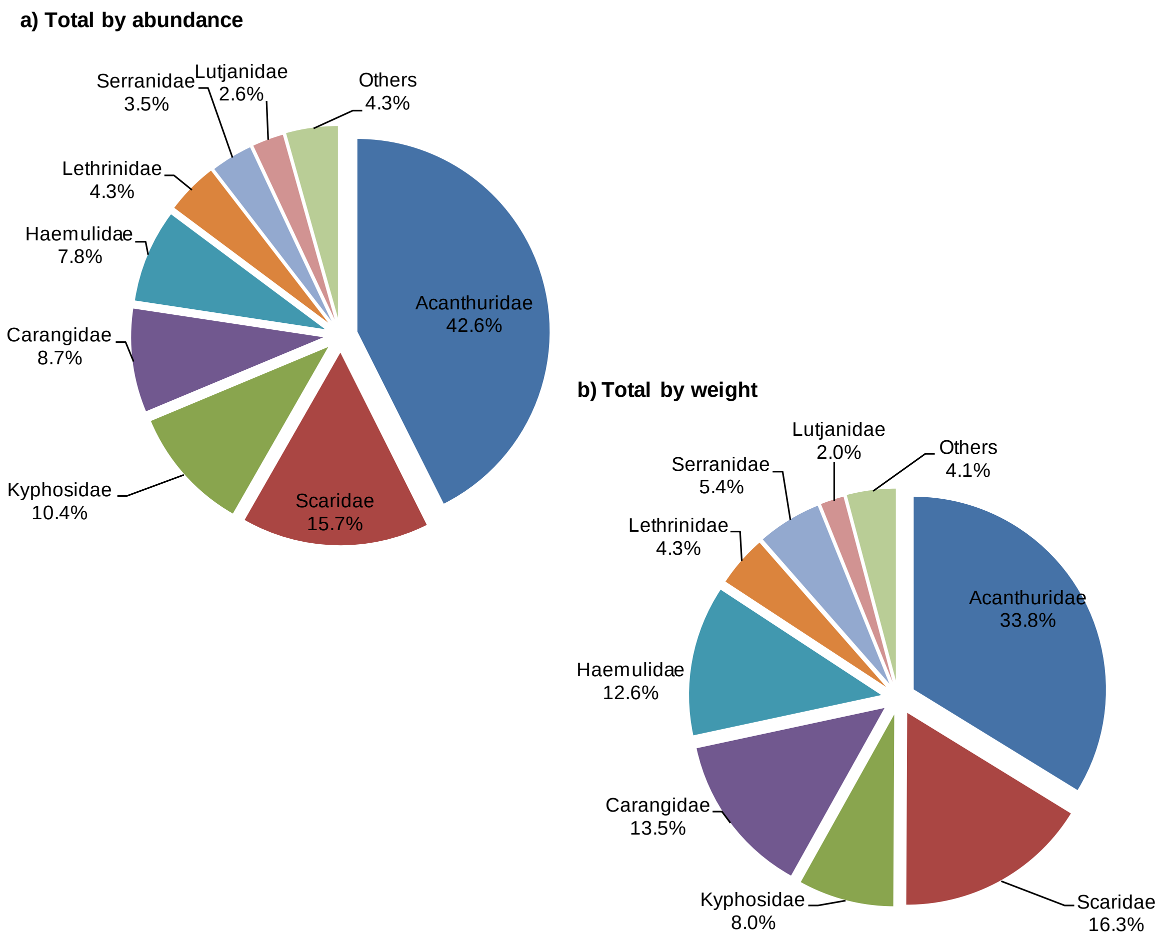

Figure 49 Percent contribution by abundance (top) and weight (below) of families caught by day spearfishing, Kolonia municipality, March 2014.

Night spearfishing

Thirteen surveys of night spearfishing were completed at Kolonia. On average, night spearfishing trips at Kolonia involved 1.31±0.13 fishers with an average of 3.29±0.31 hours spent fishing (Table 15). The average catch was 19.65±5.39 kg, or 49.15±10.99 individual fish, per trip (Figure 46). Catch-per-unit effort (CPUE) was 11.51±1.36 fish/fisher/hour, or 4.50±0.85 kg/fisher/hour (Table 15). The average furthest distance travelled was 5.82±1.84 km.

A total of 639 individual fishes were observed from the night spearfishing catch at Kolonia. Fifty-three species from 16 families were observed (Appendix 11), with members of the Acanthuridae (surgeonfishes), Scaridae (parrotfishes), Siganidae (rabbitfishes), Mullidae (goatfishes) and Serranidae (groupers) dominating the total catch by both abundance and weight (Figure 50; Appendix 11). The most common finfish species caught included the parrotfish *Hipposcarus longiceps* (representing 19.3% of the total catch by abundance and 24.5% of the total catch by weight), the surgeonfish *Naso unicornis* (11.9% of the total catch by abundance and 22.8% of the total catch by weight), the rabbitfishes *Siganus puellus* and *Siganus punctatus* (8.6% and 7.5% of the total catch by abundance and 4.0% and 5.0% of the total catch by weight, respectively and the goatfish *Parupeneus barberinus* (5.8% of the total catch by abundance and 6.1% of the total catch by weight) (Appendix 11).

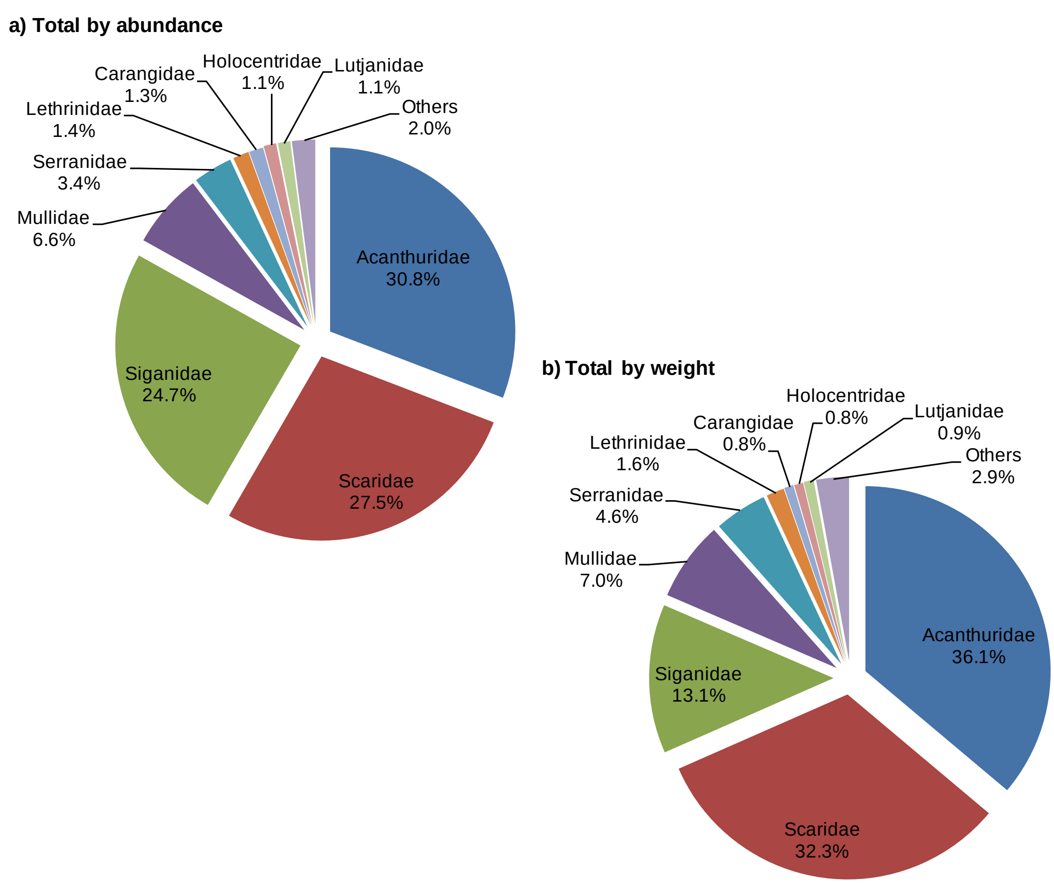

Figure 50 Percent contribution by abundance (top) and weight (below) of families caught by night spearfishing, Kolonia municipality, March 2014.

Kitti Municipality

Fourteen surveys were completed at Kitti. All landing encountered were from night spearfishing trips. On average, spearfishing trips at Kitti involved 1.6±0.3 fishers (range = 1–4), with 8.1±0.7 hours spent fishing (Table 15). The average catch was 35.5±7.7 kg, or 92.6±15.8 individual fish, per trip (Figure 46). Catch-per-unit effort (CPUE) was 9.3±1.8 fish/fisher/hour, or 3.2±0.4 kg/fisher/hour (Table 15). The average furthest distance travelled per trip was 12.43±1.83 km.

A total of 1.296 individual fishes were observed from the night spearfishing catch at Kitti. Seventy-one species from 17 families were observed (Appendix 11), with members of the Acanthuridae (surgeonfishes), Siganidae (rabbitfishes), Scaridae (parrotfishes) and Serranidae (groupers) dominating the total catch by both abundance and weight (Appendix 11). The most common finfish species caught included the surgeonfishes *Acanthurus lineatus* (representing 24.8% of the total catch by abundance and 8.4% of the total catch by weight), *Naso unicornis* (14.3% of the total catch by abundance and 37.3% of the total catch by weight), *Naso lituratus* (10.6% of the total catch by abundance and 5.3% of the total catch by weight) and *Acanthurus nigricauda* (6.4% of the total catch by abundance and 2.5% of the total catch by weight) (Appendix 11).

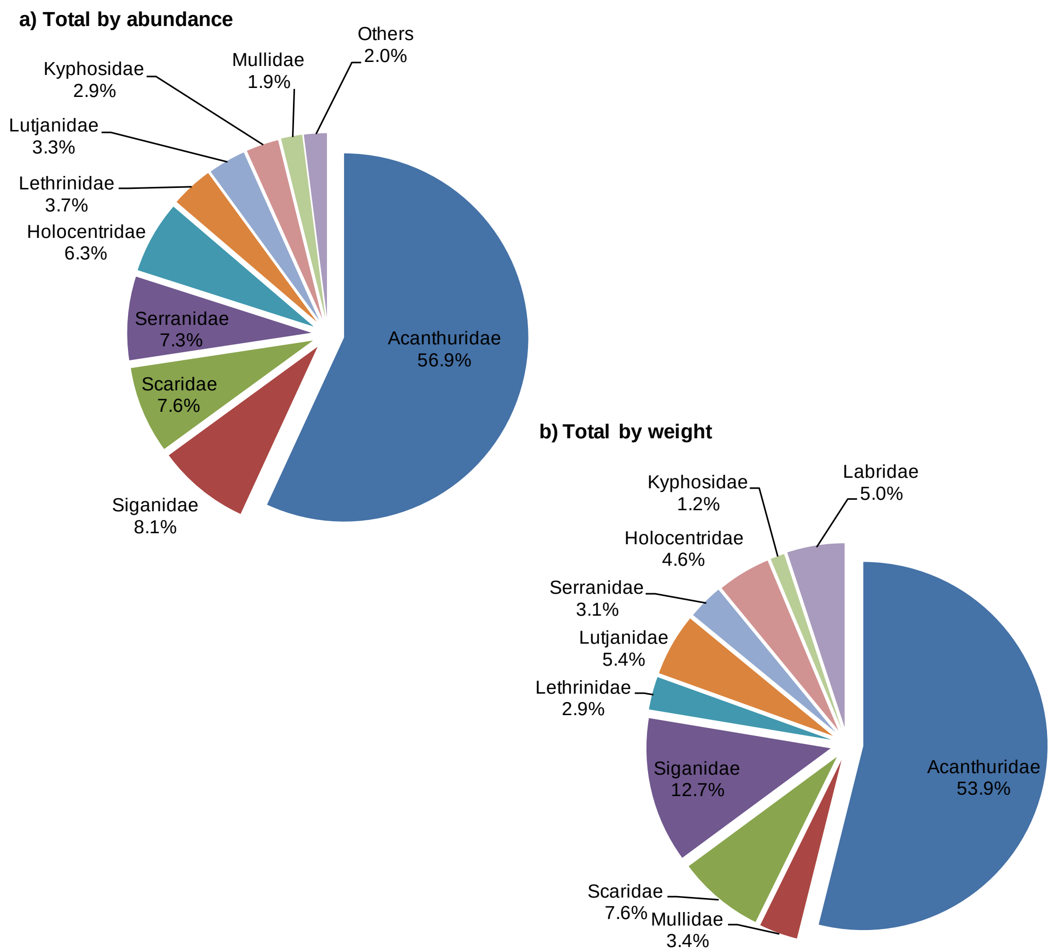

Figure 51 Percent contribution by abundance (top) and weight (below) of families caught by night spearfishing, Kitti municipality, March 2014.

Length frequencies

Length frequency plots for nine of the most commonly observed species are presented as Figure 52. Despite being subject to a ban on sale from March-April, a number of *Epinephelus polyphekadion* were observed during the March survey. Of these, the majority (77%) were under the median length of maturity of 35. 2 cm estimated for populations in Pohnpei by Rhodes et al. (2011), with undersized individuals mainly observed in the handline catch (Figure 52; Figure). Similarly, 52% of the *L. gibbus* captured were under the regional estimated median length of maturity of 25 cm FL (SPC unpublished data). In contrast, approximately 88% of all *Hipposcarus longiceps*, 97% of *N. lituratus* and 70% of *N. unicornis* were larger than the median lengths of maturity estimated for populations in the region (Taylor et al. 2014; SPC unpublished data) (Figure 52).

Fisher perceptions

Fisher perceptions were collected during 39 surveys[3]. The majority (n=37) of fishers that perception data were collected from were male. The majority of fishers surveyed indicated that they had seen changes in the fishery in the last few years, with 77% of all respondents claiming they considered their catches had decreased compared to five years ago, and 87% of all respondents claiming sizes of fish had decreased compared to those five years ago (Figure 53). Variations in perceptions were evident among fishers from the different municipalities. For example, 86% of fishers from Kolonia and 50% of fishers from Kitti considered their catches had decreased relative to five years ago, while 100% of fishers from Kolonia and only 50% of fishers from Kitti felt the size of fish had decreased (Figure 53).

During the creel surveys fishers were asked their concerns. Main concerns were:

- Overfishing and too many fishers;
- Overly efficient fishing methods such as night spearfishing;
- Habitat destruction and geophysical changes on the reef;
- Climate change;
- Increased population.

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

Table 15 Data summary of creel surveys conducted at Pohnpei, March 2014.

Fishing method	**Gillnet (Kolonia)**	**Handline (Kolonia)**	**Day spearfishing (Kolonia)**	**Night spearfishing (Kolonia)**	**Night spearfishing (Kitti)**
No. surveys where method observed	7	27	3	13	14
Total number of fishers surveyed	19	50	6	17	22
Mean time spent fishing (hrs)	2.29±0.49	5.62±0.45	5.33±0.67	3.29±0.31	8.07±.067
Mean no. of fishers per trip	2.71±0.61	1.85±0.12	2.00±0.58	1.31±0.13	1.57±0.25
Average catch (number of fish) per trip	36.14±6.98	81.11±10.96	38.33±7.17	49.15±10.99	92.57±15.80
Average catch (kg) per trip	21.38±5.19	20.57±2.52	31.69±5.23	19.65±5.39	35.48±7.68
Average CPUE by abundance	17.14±2.85	10.34±1.75	5.33±3.09	11.51±1.36	9.26±1.77
Average CPUE by weight	9.47±2.01	2.61±0.41	3.80±1.58	4.50±1.36	3.19±0.40
No. of landings needed to survey to detect change in CPUE by abundance at precision of 0.2 (to 1 sig. fig.)	5	20	25	5	13
No. of landings needed to survey to detect change in CPUE by weight at precision of 0.2 (to 1 sig. fig.)	8	17	13	12	6

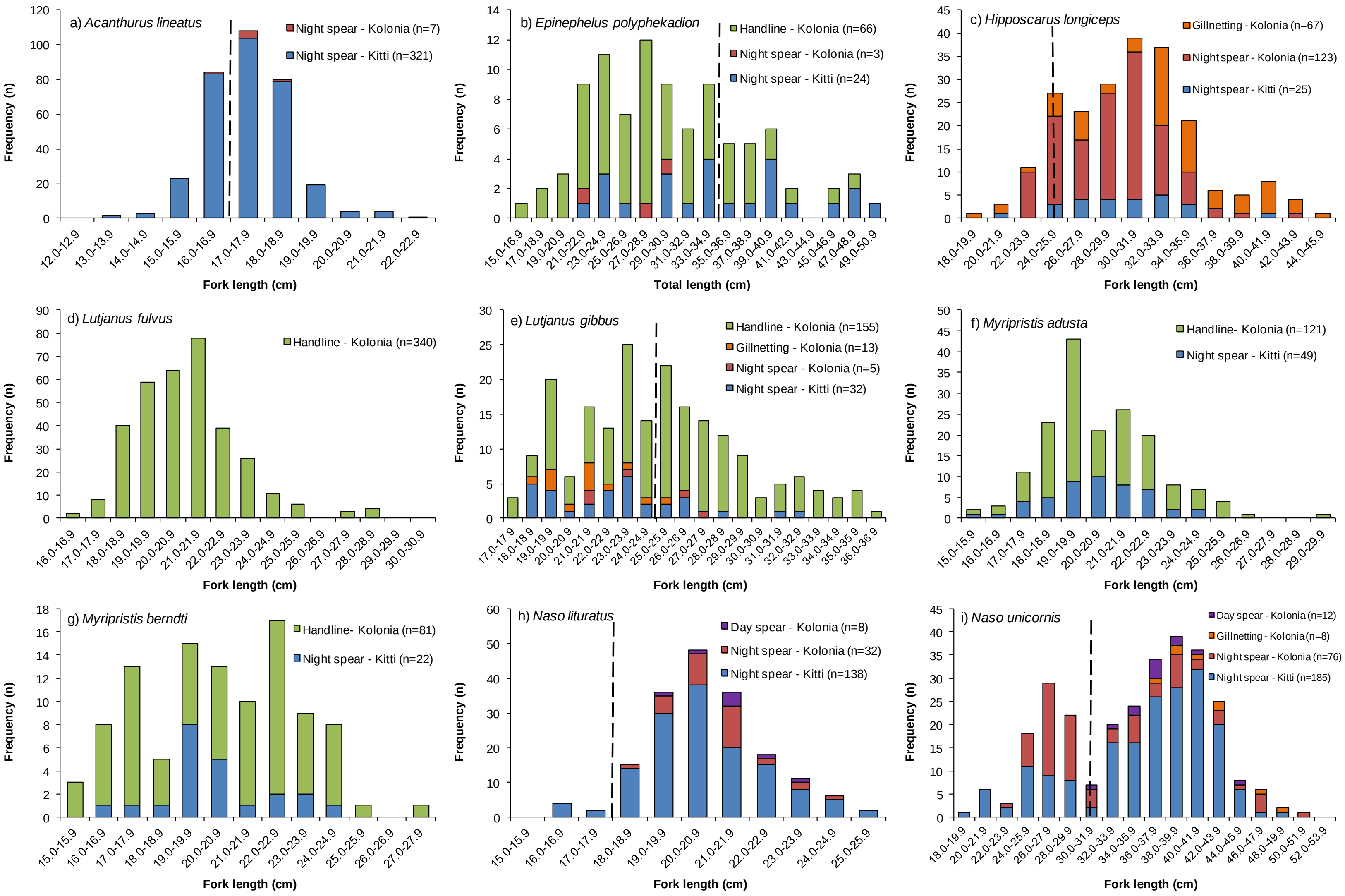

Figure 52 Length frequencies for nine of the most commonly observed finfish species during creel surveys at Kitti and Kolonia Provinces, February-March 2014. Dashed lines indicate estimated lengths at 50% maturity from: a) SPC unpublished data; b) Rhodes et al. 2011, c) SPC unpublished data; e) SPC unpublished data; h) & i) Taylor et al. 2014.

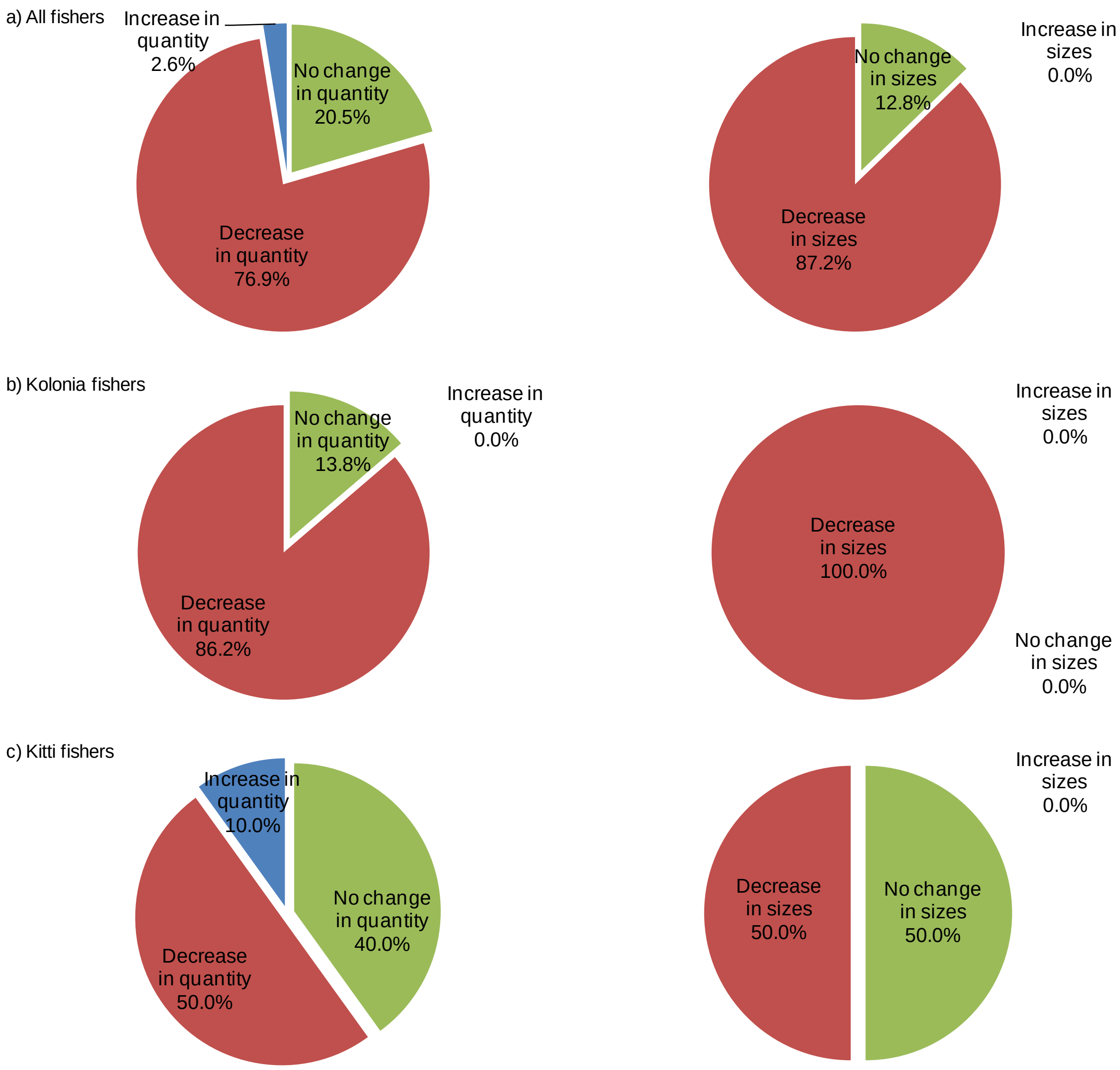

Figure 53 Responses of lead fishers to questions on perceptions on whether catch quantities (left) or fish sizes (right) have changed over the last five years.

8. Biological Monitoring of Selected Reef Fish Species

Methods

Sample collection

Biological monitoring of key reef fish species focused on five commercially harvested species: peacock grouper (*Cephalopholis argus*), striated surgeonfish (*Ctenochaetus striatus*), blacktail snapper (*Lutjanus fulvus*), humpback red snapper (*Lutjanus gibbus*) and orangespine unicornfish (*Naso lituratus*) and one 'control' species: redfin butterflyfish (*Chaetodon lunulatus*) which was included to control for the effects of fishing. Fish were collected from commercial 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. argus*, *C. striatus*, *L. fulvus*, *L. gibbus*, and *N. lituratus* were processed using standard sectioning protocols. Here, a single otolith from each individual was embedded in resin and sectioned on the transverse axis using a slow-speed diamond edge saw. Sections were approximately 300µm thick, and care was taken to ensure the primordium of the otolith was included in the sections. Sections were cleaned, dried and mounted onto clear glass microscope slides under glass coverslips using resin.

Otoliths from *C. lunulatus* were prepared using the single ground transverse sectioning method 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, 800, 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 each 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 *Lutjanus fulvus* (Shimose and Nanami 2014), *L. 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. A single VBGF was fitted for hermaphroditic species (*C. argus*), while sex-specific VBGFs were initially fitted for gonochoristic species (*C. lunulatus*, *C. striatus*, *L. fulvus*, *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 species with samples sizes ≥ 60. Catch curves were generated by fitting a linear regression to the natural log-transformed number of fish in each age class against fish age. The slope of this regression is an estimate of the rate of annual mortality. Regressions were fitted from the first modal age class, presumed to be the first age class fully selected by the sampling gear, to the oldest age class that was preceded by no more than two consecutive zero frequencies. Instantaneous natural mortality rates (M) were derived using the general regression equation of Hoenig (1983) for fish:

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

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

Thirty-three peacock grouper (*C. argus*) were collected from Pohnpei, with 31 of these aged to date. Estimated ages ranged from 3–15 years, with a modal age of 9 years (Figure 54). Although sample sizes were insufficient to calculate mortality rates, the wide range of age classes and relatively old modal age suggests fishing mortality on this species is currently low. Greater sampling of this species at Pohnpei is required to confirm this hypothesis.

Forty-four redfin butterflyfish (*C. lunulatus*) were collected by fisheries-independent spearfishing at Pohnpei, with 39 of these aged to date. Estimated ages ranged from 1–9 years, with a modal age of 4 years (Figure 54; Table 16). Growth was similar amongst sexes, and was rapid early in life, consistent with descriptions of growth elsewhere across the species' range (Figure 55) (Berumen et al. 2012). Due to low sample sizes, no mortality estimates were calculated for this species. Accordingly, greater sampling is required to develop mortality parameters for this species at Pohnpei.

Fifty-nine striated surgeonfish (*C. striatus*) were collected by fisheries-independent spearfishing at Pohnpei, with 55 of these aged to date. Estimated ages ranged from 0.5–11 years, with a modal age of 6 years (Figure 54). Little difference in growth was evident among sexes (Figure 55). Total (Z) and natural (M) rates of mortality were estimated as 0.259 and 0.246, respectively (Table 17). Fishing mortality was estimated as 0.012, well under the recommended maximum fishing mortality rate of 0.123 (Table 17).

Seventy-nine blacktail snapper (*L. fulvus*) were collected from commercial handline fishers at Pohnpei. Of these, 78 have been aged to date. Estimated ages ranged from 2–19 years, with a modal age of 5 years (Table 16; Figure 54). Growth differed among sexes, with females reaching a slightly greater length than males at a given age (Figure 55). Total (Z) and natural (M) rates of mortality were estimated as 0.295 and 0.220, respectively (Table 17). Fishing mortality was estimated as 0.075, which was lower than the recommended optimal fishing mortality rate of 0.110 (Table 17).

Ninety humpback red snapper (*L. gibbus*) were sampled from the commercial handline fishers of Pohnpei, all of which were successfully aged (Table 16). Estimated ages ranged from 1–16 years, with a modal age of 2 years (Figure 54). Growth differed markedly among sexes, with males reaching a greater length at a given age than females (Figure 55). Total (Z) and natural (M) rates of mortality were estimated as 0.431 and 0.262, respectively (Table 17). Fishing mortality was estimated as 0.169, exceeding the recommended optimal fishing mortality rate of 0.131 (Table 17). This indicates that this species is fished above its recommended level, suggesting management invention is required to reduce fishing pressure on this highly important resource.

Eighty orangespine unicornfish (*Naso lituratus*) were sampled by fisheries-dependent and fisheries-independent spearfishing at Pohnpei, with 71 of these aged to date (Table 16). Estimated ages ranged from 1–13 years, with a modal age of 2 years (Figure 54). Growth differed markedly among sexes, with males reaching a greater length at a given age than females (Figure 55).Total mortality (Z) and natural mortality were estimated as 0.270 and 0.209, respectively. Fishing mortality was calculated as 0.061, and was under the recommended optimal fishing mortality rate of 0.104 (Table 17).

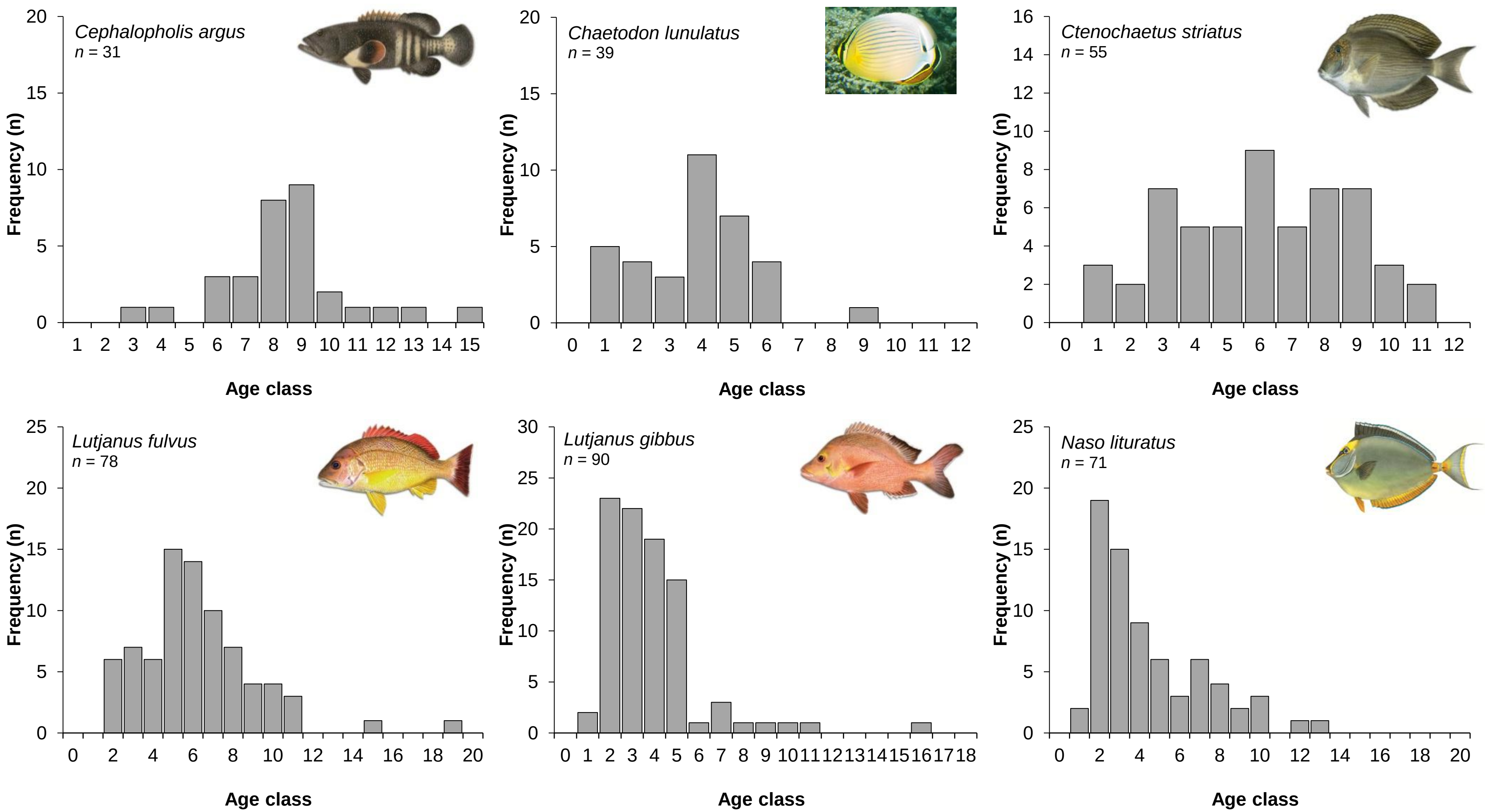

Figure 54 Age class frequencies for the six monitored finfish species at Pohnpei, February–March 2014.

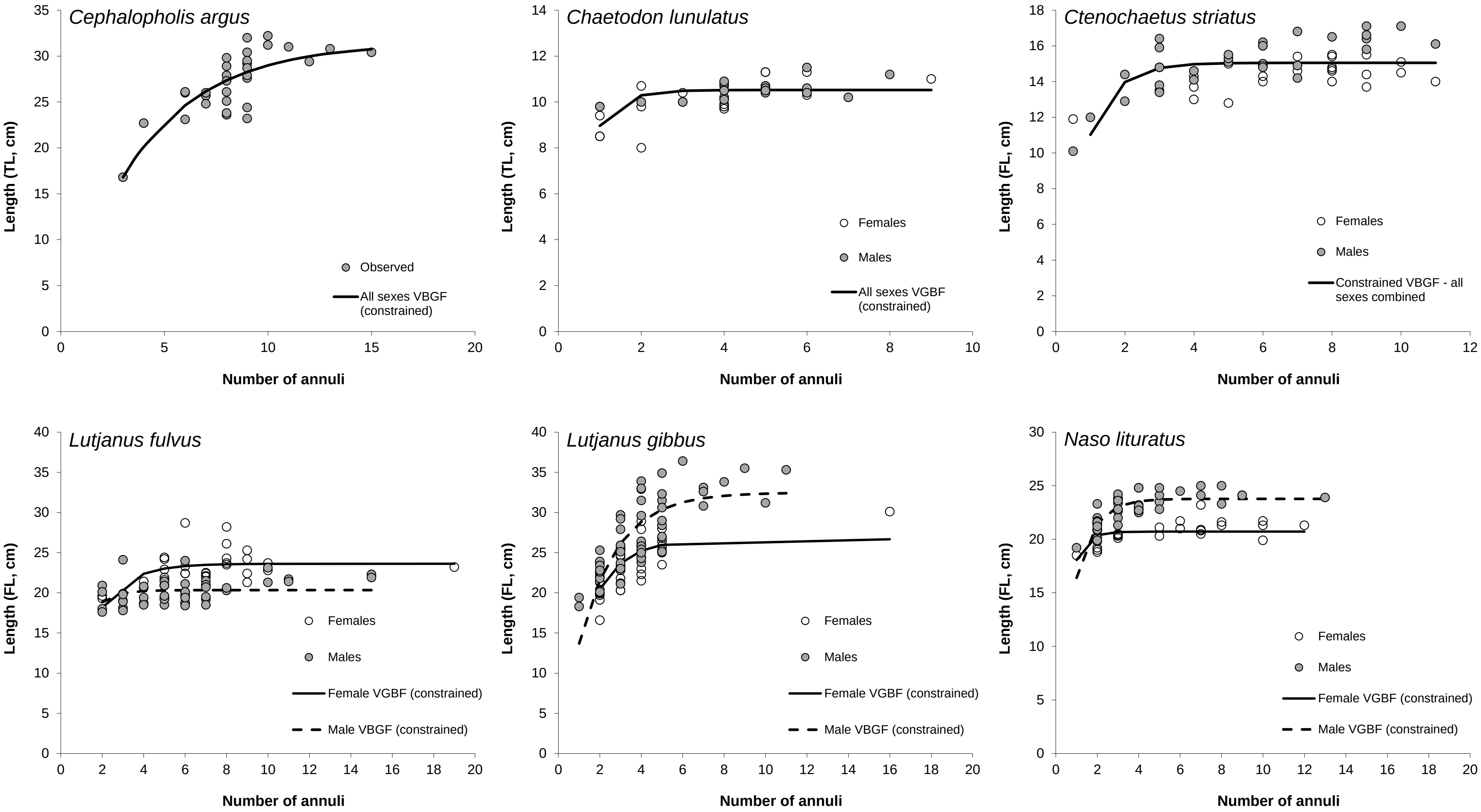

Figure 55 von Bertalanffy growth function curves for the six monitored finfish species at Pohnpei, February–March 2014.

Table 16 Demographic parameter estimates for selected reef fish species from Pohnpei, Federated States of Micronesia, February–March 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)
Cephalopholis argus	33	31	16.8–32.2	3–15	31.44	0.255
Chaetodon lunulatus	44	39	8.0-11.5	1–9	10.52	1.910
Ctenochaetus striatus	58	55	10.1–17.1	1–11	15.05	1.318
Lutjanus fulvus	79	78	17.6–28.7	2–19	20.34 / 23.62	1.306 / 0.735
Lutjanus gibbus	90	90	16.6–36.4	1–16	32.48 / 26.67	0.547 / 0.729
Naso lituratus	80	71	18.5–25.0	1–13	23.77 / 20.72	1.171 / 2.055

Table 17 Estimates of mortality for monitored 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
Ctenochaetus striatus	17 (Trip et al. 2008, Kavieng)	6–11	0.259	0.246	0.012	0.123
Lutjanus fulvus	19 (this study)	5–11	0.295	0.220	0.075	0.110
Lutjanus gibbus	16 (this study)	2–11	0.434	0.262	0.172	0.131
Naso lituratus	20 (Moore et al. 2014)	2–13	0.270	0.209	0.061	0.104

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

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

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 Pohnpei to both long-term (e.g. climate change) and short-term (e.g. overfishing) stressors. Many of the approaches recommended here will also be of relevance to other FSM states. This list is by no means intended to be exhaustive; rather it provides salient information on the key recommendations.

1) **Increase enforcement of fisheries management regulations.** In the present survey few consistent differences were observed in resource abundance or habitat health between the MPA sites and sites open to fishing. It is highly likely that illegal fishing is a significant contributing factor behind these patterns. During the field survey, several boats were seen fishing in the vicinity of the Kehpara Marine Sanctuary, while no enforcement was observed in the area during the five weeks of fieldwork. For the protected areas of Pohnpei to be effective, greater enforcement of illegal fishing needs to occur.

2) **Expand the network of Marine Protected Areas.** To maintain biodiversity, ecosystem functioning and resilience, and confer benefits to adjacent fisheries, in accordance with the objectives of the Micronesia Challenge, it is highly recommended that the reserve network within Pohnpei be expanded. While the creation of MPAs in Pohnpei is commendable, the small sizes of many of the MPAs precludes the combination and connectivity of essential habitat types needed for many species during their life history development and does not account home range sizes or migratory behaviours into account (Rhodes et al. 2008). Larger scale MPAs that link essential habitats for a broad range of species are recommended. The design, monitoring and enforcement of the MPA network in Pohnpei should involve community input and take into account conservation targets, socio-ecological and economic interests, and the home ranges of species the MPA is intended to protect (Rhodes et al. 2008; Green et al. 2013). Green et al. (2013) provide a guide to designing marine protected areas to achieve conservation objectives in tropical ecosystems. As a general rule of thumb, they recommend the following:
    a. that MPAs represent 20–40% of the available area of each habitat;
    b. that protected areas are established across widely separated areas, to minimise the risk that all areas will be adversely impacted by the same disturbance; and
    c. that MPAs be twice the size of the minimum home range of the species they are implemented to protect. For example, most species of browsing or scraping herbivores, considered to be key for reducing overgrowth of coral by macroalgae (and thus preventing coral-algae regime shifts) have home ranges in the order of 500 m to 2 km (Green et al. 2013).

3) **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.

4) **Maintain the closure of sea cucumber fisheries.** A ban on the commercial harvest of sea cucumbers is currently in place in Pohnpei due to concerns regarding the over-harvesting of stocks. However, Pohnpei is currently experiencing pressure from interested traders to re-open the sea cucumber fishery. Surveys conducted in 2008 by the SPC and OFA considered the densities of sea cucumber populations of Pohnpei to be insufficient to permit commercial harvest (Tardy et al. 2009), a finding that is consistent with the results of the present study. In June 2013, a state-wide assessment of the status of sea cucumber populations was survey was conducted by SPC, OFA, CSP and the Pohnpei Environmental Protection Agency. We strongly recommend that the closure is maintained until at least such a time when the results of this recent assessment are reviewed to maintain stock recovery and the ecological functioning sea cucumbers provide.

5) **Protect sharks and other iconic and ecologically-significant species.** In addition to bumphead parrotfish, which the taking by any means is prohibited in Pohnpei, protection should be offered to other ecologically significant species, in particular sharks and humphead wrasse, *Cheilinus undulatus.* 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 moratorium be placed on the shark-fin fishery until such time as a shark-fin management plan is in place. Similarly, the humphead wrasse is listed as Endangered on the IUCN Red List in recognition of its slow population turnover and vulnerability to fishing, in particular 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. undulatus*, at least at the state level, and ideally the national level.

6) **Maintain healthy catchments on mainland Pohnpei.** Due to their close proximity the reefs of Pohnpei are highly susceptible to land-use practices. Destruction of catchments by mining and logging operations will result in increased eutrophication and sediment loads on reefs, resulting in further stress to already strained systems. We recommend that implications on downstream ecological communities be factored into decisions regarding changes to catchments. Mangrove forests in particular should be afforded protection due to both their

value as nursery habitats for a large number of fish and invertebrates, but also due to their roles as sediment traps.

7) **Strengthen stakeholder awareness programs and exchange of information on coastal fisheries, the marine environment and climate change.** It cannot be expected that citizens and key stakeholders of Pohnpei 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 traditional and scientific knowledge in management processes and strategies to mitigate their impacts. OFA, FSM Department of Resources and Development and the Conservation Society of Pohnpei should play a central role in facilitating these programs.

8) **Strengthen collaborations with National, State and Municipal governments, NGOs, fishing communities and clan leaders.** While some management measures, such as gear restrictions, monthly sales ban and size limits can be effectively implemented by state marine resource management agencies to reduce fishing pressure, many of the issues threatening the coastal fisheries resources and marine ecosystems of Pohnpei are best addressed by other groups or are outside the mandate of fisheries agencies. Accordingly, greater collaboration among partners is required to address and manage the many fishing and non-fishing related local threats to the coastal ecosystems of Pohnpei. Such a cooperative approach would be more effective if steered jointly by authorities responsible for governance, resource management and key stakeholders, such as municipal governments, communities and clan leaders.

9) **Develop a coastal fisheries management plan.** Ultimately, a comprehensive coastal fisheries management plan is needed. This plan should address various fishing activities (e.g. fishing gears and practices), restrictions on species' harvests (e.g. size limits, seasonal closures during spawning season), the export of coastal resources, and community management practices.

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 the FSM D&R, Pohnpei State OFA and CSP. 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 Kitti and Kolonia municipalities represent a single 'snapshot' of fisher behavior, fishing patterns and catches at the time of survey. Previous surveys at Pohnpei have revealed considerable difference among catches during and outside of the March-April sales ban on serranids, with significant increases in the catches of parrotfishes, emperors and goatfishes during the ban (Rhodes et al. 2008). Ongoing creel surveys are recommended to explore spatial and temporal variations in these parameters. Monitoring catch patterns both during and outside of the March-April sales ban on groupers is highly recommended.

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Appendix 1 GPS positions of finfish and benthic habitat assessment transects

Station ID	Habitat	Transect name	Latitude (N)	Longitude (E)
Kehpara MPA 1	Back reef	T16	6.807567	158.116567
	Back reef	T17	6.806617	158.116483
	Back reef	T18	6.805350	158.116200
	Lagoon reef	T1	6.801467	158.124250
	Lagoon reef	T2	6.801033	158.123383
	Lagoon reef	T3	6.800317	158.122783
	Outer reef	T13	6.806483	158.113267
	Outer reef	T14	6.805550	158.113017
	Outer reef	T15	6.804683	158.112750
Kehpara MPA 2	Back reef	T34	6.801000	158.115767
	Back reef	T35	6.800450	158.116067
	Back reef	T36	6.799250	158.116383
	Lagoon reef	T19	6.795083	158.123550
	Lagoon reef	T20	6.794750	158.124350
	Lagoon reef	T21	6.794700	158.125217
	Outer reef	T22	6.800200	158.111817
	Outer reef	T23	6.799150	158.111683
	Outer reef	T24	6.798283	158.112150
Kehpara Open 1	Back reef	T10	6.786900	158.128233
	Back reef	T11	6.786567	158.129083
	Back reef	T12	6.785933	158.129967
	Lagoon reef	T31	6.794717	158.138717
	Lagoon reef	T32	6.794217	158.138000
	Lagoon reef	T33	6.793833	158.137400
	Outer reef	T7	6.783100	158.126850
	Outer reef	T8	6.782683	158.127717
	Outer reef	T9	6.782383	158.128917
Kehpara Open 2	Back reef	T28	6.784333	158.144683
	Back reef	T29	6.784300	158.145550
	Back reef	T30	6.784200	158.146500
	Lagoon reef	T25	6.794717	158.138717
	Lagoon reef	T26	6.794217	158.138000
	Lagoon reef	T27	6.793833	158.137400
	Outer reef	T4	6.779867	158.144600
	Outer reef	T5	6.779850	158.145533
	Outer reef	T6	6.779850	158.147183

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** |__|__| **Transect** |__|__|__|

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

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

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

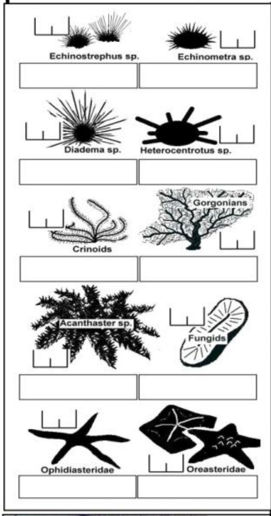
	current	oceanic influence	terrigenous influence
none	☐	☐	☐
medium	☐	☐	☐
strong	☐	☐	☐

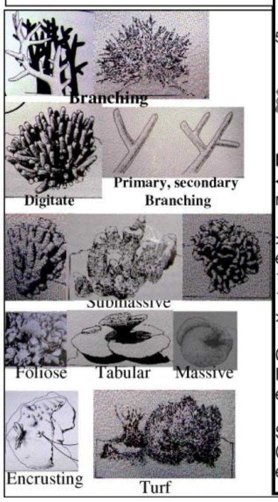
draw profile including estimate of slope in degree
Flat ☐ Floor ☐
Gentle slope ☐ Steep slope ☐

Remarks:

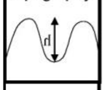
	Quadrat limits	0–10	10–20	20–30	30–40	40–50	%
	Depth of transect line (m)						
	Slope only: Depth of crest (m)						
	Slope only: Depth of floor (m)						
	Line of sight visibility (m)						
	Topography (1-5)						
	Complexity (1-5)						
1st layer	Hard substrate						100
	Soft substrate						
2nd layer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

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

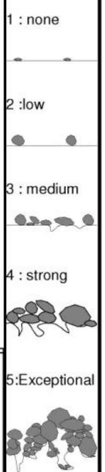




Topography



Complexity



Depth :
<10m : measure it ;

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

Crest side : Floor=transect depth

Slope side : Crest=transect depth

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

Site + habitat	Variable tested	Outcome	t	P	Unique perms
Kehpara MPA back reef	Mean total density	2014 > 2012	4.1926	0.013	412
Kehpara MPA back reef	Mean total biomass	2014 > 2012	2.5629	0.032	402
Kehpara MPA back reef	Mean density - Labridae	2014 > 2012	3.1302	0.011	312
Kehpara MPA back reef	Mean density - Scaridae	2014 > 2012	4.9443	0.005	407
Kehpara MPA back reef	Mean biomass - Chaetodontidae	2014 > 2012	2.4270	0.030	402
Kehpara MPA back reef	Mean biomass - Labridae	2014 > 2012	9.4664	0.002	403
Kehpara MPA back reef	Mean biomass - Mullidae	2014 > 2012	2.3415	0.014	415
Kehpara MPA back reef	Mean biomass - Pomacanthidae	2014 < 2012	2.7415	0.001	56
Kehpara MPA back reef	Mean biomass - Pomacentridae	2014 > 2012	2.8209	0.013	418
Kehpara MPA back reef	Mean density – Micro-carnivores	2014 > 2012	3.6253	0.019	229
Kehpara MPA back reef	Mean density – Scrapers	2014 > 2012	4.9443	0.006	410
Kehpara MPA back reef	Mean biomass – Corallivores	2014 > 2012	2.8247	0.018	309
Kehpara MPA back reef	Mean biomass – Macro-carnivores	2014 > 2012	2.5582	0.032	407
Kehpara MPA back reef	Mean biomass – Micro-carnivores	2014 > 2012	5.5855	0.004	392
Kehpara MPA lagoon reef	Mean total density	2014 > 2012	4.2017	0.004	414
Kehpara MPA lagoon reef	Mean total biomass	2014 > 2012	3.574	0.015	404
Kehpara MPA lagoon reef	Mean density - Acanthuridae	2014 > 2012	3.0902	0.020	309
Kehpara MPA lagoon reef	Mean density - Chaetodontidae	2014 > 2012	2.9744	0.018	308
Kehpara MPA lagoon reef	Mean density - Holocentridae	2014 > 2012	3.8522	0.002	86
Kehpara MPA lagoon reef	Mean density - Labridae	2014 > 2012	2.2909	0.046	308
Kehpara MPA lagoon reef	Mean density - Pomacentridae	2014 > 2012	3.0807	0.017	409
Kehpara MPA lagoon reef	Mean density - Scaridae	2014 > 2012	2.2214	0.043	414
Kehpara MPA lagoon reef	Mean biomass - Acanthuridae	2014 > 2012	3.2066	0.016	406
Kehpara MPA lagoon reef	Mean biomass - Holocentridae	2014 > 2012	4.7359	0.003	119
Kehpara MPA lagoon reef	Mean biomass - Labridae	2014 > 2012	2.3489	0.044	401
Kehpara MPA lagoon reef	Mean biomass - Pomacentridae	2014 > 2012	4.3520	0.007	416
Kehpara MPA lagoon reef	Mean biomass - Scaridae	2014 > 2012	3.3354	0.016	411
Kehpara MPA lagoon reef	Mean density - Corallivores	2014 > 2012	2.8682	0.008	173
Kehpara MPA lagoon reef	Mean density - Grazers	2014 > 2012	3.0407	0.020	422
Kehpara MPA lagoon reef	Mean density – Macro-carnivores	2014 > 2012	2.3676	0.011	311
Kehpara MPA lagoon reef	Mean density – Micro-carnivores	2014 > 2012	2.2852	0.049	412
Kehpara MPA lagoon reef	Mean density – Planktivores	2014 > 2012	3.3625	0.014	408
Kehpara MPA lagoon reef	Mean density – Scrapers	2014 > 2012	2.2214	0.032	412
Kehpara MPA lagoon reef	Mean biomass - Corallivores	2014 > 2012	2.7275	0.020	408
Kehpara MPA lagoon reef	Mean biomass - Grazers	2014 > 2012	3.2571	0.019	410

Site + habitat	Variable tested	Outcome	t	P	Unique perms
Kehpara MPA lagoon reef	Mean biomass – Macro-carnivores	2014 > 2012	2.9171	0.016	414
Kehpara MPA lagoon reef	Mean biomass – Planktivores	2014 > 2012	3.8132	0.010	412
Kehpara MPA lagoon reef	Mean biomass – Scrapers	2014 > 2012	3.3354	0.014	401
Kehpara MPA lagoon reef	Mean biomass – Farmers	2014 > 2012	2.6213	0.007	306
Kehpara MPA outer reef	Mean total density	2014 > 2012	2.4283	0.047	410
Kehpara MPA outer reef	Mean density - Acanthuridae	2014 > 2012	2.2786	0.037	406
Kehpara MPA outer reef	Mean density - Chaetodontidae	2014 > 2012	3.8584	0.006	206
Kehpara MPA outer reef	Mean density - Labridae	2014 > 2012	3.1983	0.028	312
Kehpara MPA outer reef	Mean density - Scaridae	2014 > 2012	2.9092	0.019	405
Kehpara MPA outer reef	Mean density - Serranidae	2014 > 2012	2.0784	0.037	234
Kehpara MPA outer reef	Mean density - Siganidae	2014 > 2012	2.5281	0.031	107
Kehpara MPA outer reef	Mean biomass - Labridae	2014 > 2012	3.3939	0.012	412
Kehpara MPA outer reef	Mean biomass - Pomacentridae	2014 > 2012	2.2428	0.042	403
Kehpara MPA outer reef	Mean biomass - Scaridae	2014 > 2012	3.9295	0.006	409
Kehpara MPA outer reef	Mean biomass - Serranidae	2014 > 2012	3.4007	0.006	303
Kehpara MPA outer reef	Mean density - Browsers	2014 > 2012	2.3067	0.008	171
Kehpara MPA outer reef	Mean density - Corallivores	2014 > 2012	2.8792	0.023	409
Kehpara MPA outer reef	Mean density - Scrapers	2014 > 2012	2.9092	0.014	409
Kehpara MPA outer reef	Mean biomass - Corallivores	2014 > 2012	2.6484	0.034	401
Kehpara MPA outer reef	Mean biomass - Scrapers	2014 > 2012	3.9295	0.009	409
Kehpara MPA outer reef	Mean biomass - Farmers	2014 > 2012	3.3115	0.016	314
Kehpara Open back reef	Mean total biomass	2014 > 2012	3.0452	0.016	414
Kehpara Open back reef	Mean density - Balistidae	2014 > 2012	2.0680	0.038	42
Kehpara Open back reef	Mean density - Labridae	2014 > 2012	3.7716	0.012	401
Kehpara Open back reef	Mean density - Scaridae	2014 > 2012	4.1856	0.005	230
Kehpara Open back reef	Mean biomass - Labridae	2014 > 2012	5.0619	0.007	404
Kehpara Open back reef	Mean biomass - Scaridae	2014 > 2012	2.4877	0.038	307
Kehpara Open back reef	Mean density – Micro-carnivores	2014 > 2012	4.0083	0.006	410
Kehpara Open back reef	Mean density – Scrapers	2014 > 2012	4.1856	0.006	231
Kehpara Open back reef	Mean biomass – Micro-carnivores	2014 > 2012	5.2285	0.003	406
Kehpara Open back reef	Mean biomass – Scrapers	2014 > 2012	2.4877	0.031	307
Kehpara Open back reef	Mean biomass – Farmers	2014 > 2012	2.3644	0.039	403
Kehpara Open lagoon reef	Mean total density	2014 > 2012	3.1636	0.016	409
Kehpara Open lagoon reef	Mean total biomass	2014 > 2012	2.9271	0.018	415
Kehpara Open lagoon reef	Mean density - Acanthuridae	2014 > 2012	2.5669	0.026	407
Kehpara Open lagoon reef	Mean density - Chaetodontidae	2014 > 2012	2.9503	0.007	235
Kehpara Open lagoon reef	Mean density - Pomacentridae	2014 > 2012	2.2505	0.048	404
Kehpara Open lagoon reef	Mean biomass - Chaetodontidae	2014 > 2012	2.1099	0.042	403

Site + habitat	Variable tested	Outcome	t	P	Unique perms
Kehpara Open lagoon reef	Mean biomass - Pomacentridae	2014 > 2012	3.3544	0.013	400
Kehpara Open lagoon reef	Mean density - Corallivores	2014 > 2012	3.3605	0.010	234
Kehpara Open lagoon reef	Mean density - Farmers	2014 > 2012	2.5338	0.021	177
Kehpara Open lagoon reef	Mean biomass - Corallivores	2014 > 2012	3.4801	0.009	415
Kehpara Open lagoon reef	Mean biomass - Grazers	2014 > 2012	2.2348	0.046	404
Kehpara Open lagoon reef	Mean biomass - Planktivores	2014 > 2012	3.1731	0.016	410
Kehpara Open lagoon reef	Mean biomass - Farmers	2014 > 2012	3.3317	0.003	315
Kehpara Open outer reef	Mean total density	2014 > 2012	2.9214	0.015	404
Kehpara Open outer reef	Mean density - Acanthuridae	2014 > 2012	2.9846	0.021	401
Kehpara Open outer reef	Mean density - Balistidae	2014 > 2012	2.2856	0.049	110
Kehpara Open outer reef	Mean density - Chaetodontidae	2014 > 2012	4.2774	0.008	226
Kehpara Open outer reef	Mean density - Lutjanidae	2014 > 2012	1.2882	0.012	8
Kehpara Open outer reef	Mean density - Pomacanthidae	2014 > 2012	2.3197	0.008	125
Kehpara Open outer reef	Mean density - Serranidae	2014 > 2012	2.1667	0.014	62
Kehpara Open outer reef	Mean biomass - Labridae	2014 > 2012	2.3306	0.046	401
Kehpara Open outer reef	Mean biomass - Lutjanidae	2014 > 2012	1.7200	0.012	16
Kehpara Open outer reef	Mean biomass - Scaridae	2014 > 2012	3.0572	0.015	413
Kehpara Open outer reef	Mean biomass - Serranidae	2014 > 2012	2.6064	0.045	62
Kehpara Open outer reef	Mean density - Corallivores	2014 > 2012	2.6751	0.031	128
Kehpara Open outer reef	Mean density - Grazers	2014 > 2012	2.7271	0.028	413
Kehpara Open outer reef	Mean density – Macro-carnivores	2014 > 2012	2.9178	0.031	169
Kehpara Open outer reef	Mean biomass – Macro-carnivores	2014 > 2012	2.5496	0.035	318
Kehpara Open outer reef	Mean biomass – Micro-carnivores	2014 > 2012	2.6875	0.025	412
Kehpara Open outer reef	Mean biomass – Scrapers	2014 > 2012	3.0572	0.017	409
Kehpara Open outer reef	Mean biomass – Farmers	2014 > 2012	3.6136	0.004	407
Kehpara MPA vs Open – back	Mean density - Acanthuridae	MPA > Open	5.0653	0.004	405
Kehpara MPA vs Open – back	Mean density - Chaetodontidae	MPA > Open	2.5515	0.003	313
Kehpara MPA vs Open – back	Mean density - Mullidae	MPA > Open	5.3253	0.002	171
Kehpara MPA vs Open – back	Mean density - Pomacanthidae	MPA > Open	2.8113	0.002	10
Kehpara MPA vs Open – back	Mean density - Pomacentridae	Open > MPA	2.6442	0.022	400
Kehpara MPA vs Open – back	Mean density - Scaridae	MPA > Open	4.3260	0.004	408
Kehpara MPA vs Open – back	Mean total biomass	MPA > Open	3.4381	0.011	398
Kehpara MPA vs Open – back	Mean biomass - Acanthuridae	MPA > Open	12.971	0.004	401
Kehpara MPA vs Open – back	Mean biomass - Chaetodontidae	MPA > Open	4.3890	0.002	306
Kehpara MPA vs Open – back	Mean biomass - Mullidae	MPA > Open	4.2262	0.004	304
Kehpara MPA vs Open – back	Mean biomass - Pomacanthidae	MPA > Open	2.8966	0.003	10
Kehpara MPA vs Open – back	Mean biomass - Pomacentridae	Open > MPA	2.9971	0.016	406
Kehpara MPA vs Open – back	Mean biomass - Scaridae	MPA > Open	4.1844	0.007	413

Site + habitat	Variable tested	Outcome	t	P	Unique perms
Kehpara MPA vs Open – lagoon	Mean density - Holocentridae	MPA > Open	4.0122	0.003	47
Kehpara MPA vs Open – lagoon	Mean density - Pomacanthidae	MPA > Open	3.5028	0.013	51
Kehpara MPA vs Open – lagoon	Mean biomass - Holocentridae	MPA > Open	7.0554	0.005	63
Kehpara MPA vs Open – lagoon	Mean biomass - Pomacanthidae	MPA > Open	3.9328	0.012	201
Kehpara MPA vs Open – outer	Mean density - Chaetodontidae	MPA > Open	3.0919	0.019	402
Kehpara MPA vs Open – outer	Mean biomass - Scaridae	MPA > Open	3.0770	0.020	402

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

Site + habitat	Variable tested	Outcome	t	P	Unique perms
Broad-scale surveys					
Kehpara MPA inner	Dead coral	2014 < 2012	5.4907	0.001	872
Kehpara MPA inner	Coralline algae	2014 > 2012	7.8228	0.001	109
Kehpara Open outer	Coralline algae	2014 > 2012	2.9334	0.016	59
Fine-scale surveys					
Kehpara MPA back reef	Rubble	2014 > 2012	2.7457	0.011	413
Kehpara Open back reef	Live hard coral	2014 < 2012	3.1443	0.014	403
Kehpara Open back reef	Macroalgae	2014 > 2012	7.5089	0.005	116
Kehpara Open lagoon reef	Branching coralline algae	2014 < 2012	2.7517	0.016	63
Kehpara Open lagoon reef	Turf	2014 < 2012	2.9005	0.014	305

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 Kehpara MPA and Kehpara Open monitoring sites, 2014

Site	Station ID	Replicate	Start Latitude (N)	Start Longitude (E)
Kehpara MPA 2014	Manta_Inner_3	1	6.798933	158.120083
Kehpara MPA 2014	Manta_Inner_3	2	6.799983	158.117667
Kehpara MPA 2014	Manta_Inner_3	3	6.801050	158.121983
Kehpara MPA 2014	Manta_Inner_3	4	6.802650	158.118083
Kehpara MPA 2014	Manta_Inner_3	5	6.805300	158.117450
Kehpara MPA 2014	Manta_Inner_3	6	6.808283	158.117533
Kehpara MPA 2014	Manta_Inner_4	1	6.796467	158.120483
Kehpara MPA 2014	Manta_Inner_4	2	6.798050	158.122833
Kehpara MPA 2014	Manta_Inner_4	3	6.798117	158.126000
Kehpara MPA 2014	Manta_Inner_4	4	6.799900	158.124333
Kehpara MPA 2014	Manta_Inner_4	5	6.800333	158.123233
Kehpara MPA 2014	Manta_Inner_4	6	6.800867	158.123383
Kehpara MPA 2014	Manta_Inner_5	1	6.793517	158.123867
Kehpara MPA 2014	Manta_Inner_5	2	6.794783	158.123300
Kehpara MPA 2014	Manta_Inner_5	3	6.794817	158.120867
Kehpara MPA 2014	Manta_Outer_9	1	6.794567	158.113917
Kehpara MPA 2014	Manta_Outer_9	2	6.797300	158.112800
Kehpara MPA 2014	Manta_Outer_9	3	6.799883	158.111900
Kehpara MPA 2014	Manta_Outer_9	4	6.802617	158.112050
Kehpara MPA 2014	Manta_Outer_9	5	6.806167	158.113267
Kehpara MPA 2014	Manta_Outer_9	6	6.809300	158.114200
Kehpara Open 2014	Manta_Inner_1	1	6.793317	158.155767
Kehpara Open 2014	Manta_Inner_1	2	6.794350	158.158467
Kehpara Open 2014	Manta_Inner_1	3	6.794900	158.156633
Kehpara Open 2014	Manta_Inner_1	4	6.797550	158.156983
Kehpara Open 2014	Manta_Inner_1	5	6.799583	158.155233
Kehpara Open 2014	Manta_Inner_1	6	6.800150	158.153083
Kehpara Open 2014	Manta_Inner_2	1	6.808233	158.117717
Kehpara Open 2014	Manta_Inner_2	2	6.810183	158.119250
Kehpara Open 2014	Manta_Inner_2	3	6.812133	158.118200
Kehpara Open 2014	Manta_Inner_2	4	6.815083	158.118650
Kehpara Open 2014	Manta_Inner_2	5	6.817733	158.118483
Kehpara Open 2014	Manta_Inner_2	6	6.820333	158.117850
Kehpara Open 2014	Manta_Inner_5	1	6.790517	158.126150
Kehpara Open 2014	Manta_Inner_5	2	6.791017	158.124000
Kehpara Open 2014	Manta_Inner_5	3	6.791783	158.121400

Site	Station ID	Replicate	Start Latitude (N)	Start Longitude (E)
Kehpara Open 2014	Manta_Inner_6	1	6.783450	158.150050
Kehpara Open 2014	Manta_Inner_6	2	6.784517	158.148317
Kehpara Open 2014	Manta_Inner_6	3	6.785183	158.143917
Kehpara Open 2014	Manta_Inner_6	4	6.785333	158.141550
Kehpara Open 2014	Manta_Inner_6	5	6.786100	158.146433
Kehpara Open 2014	Manta_Inner_6	6	6.787083	158.148367
Kehpara Open 2014	Manta_Inner_7	1	6.784483	158.138600
Kehpara Open 2014	Manta_Inner_7	2	6.784750	158.135633
Kehpara Open 2014	Manta_Inner_7	3	6.786417	158.134100
Kehpara Open 2014	Manta_Inner_7	4	6.789617	158.132367
Kehpara Open 2014	Manta_Inner_7	5	6.792100	158.131467
Kehpara Open 2014	Manta_Inner_7	6	6.794033	158.130050
Kehpara Open 2014	Manta_Outer_10	1	6.780233	158.139500
Kehpara Open 2014	Manta_Outer_10	2	6.780717	158.136850
Kehpara Open 2014	Manta_Outer_10	3	6.781133	158.133883
Kehpara Open 2014	Manta_Outer_10	4	6.781900	158.131300
Kehpara Open 2014	Manta_Outer_10	5	6.782750	158.128733
Kehpara Open 2014	Manta_Outer_10	6	6.783700	158.126117
Kehpara Open 2014	Manta_Outer_8	1	6.816067	158.114933
Kehpara Open 2014	Manta_Outer_8	2	6.818817	158.114883
Kehpara Open 2014	Manta_Outer_8	3	6.821300	158.114600
Kehpara Open 2014	Manta_Outer_8	4	6.823900	158.114150
Kehpara Open 2014	Manta_Outer_8	5	6.826500	158.113883
Kehpara Open 2014	Manta_Outer_8	6	6.829100	158.113183

Appendix 8 GPS positions of reef benthos transect (RBt) stations at the Kehpara MPA and Kehpara Open monitoring sites

Site	Station ID	Latitude (N)	Longitude (E)
Kehpara MPA	RBt 1	6.808367	158.117617
Kehpara MPA	RBt 2	6.806717	158.117200
Kehpara MPA	RBt 3	6.804950	158.117217
Kehpara MPA	RBt 4	6.804083	158.117300
Kehpara MPA	RBt 5	6.802483	158.117450
Kehpara MPA	RBt 6	6.801417	158.117167
Kehpara MPA	RBt 7	6.798733	158.118333
Kehpara MPA	RBt 8	6.798600	158.118433
Kehpara Open	RBt 9	6.823083	158.117117
Kehpara Open	RBt 10	6.783983	158.150550
Kehpara Open	RBt 11	6.784117	158.138450
Kehpara Open	RBt 12	6.788983	158.132933
Kehpara Open	RBt 13	6.796117	158.129467
Kehpara Open	RBt 14	6.794700	158.138767
Kehpara Open	RBt 15	6.789600	158.148733
Kehpara Open	RBt 16	6.783950	158.146850

Appendix 9 GPS positions of soft benthos transect (SBt) stations at the Pwudoi MPA and Pwudoi Open monitoring sites

Site	Station ID	Latitude (N)	Longitude (E)
Pwudoi Open	SBt 1	6.813517	158.153867
Pwudoi Open	SBt 2	6.802500	158.166300
Pwudoi Open	SBt 3	6.817717	158.155267
Pwudoi Open	SBt 4	6.827617	158.151650
Pwudoi MPA	SBt 5	6.848333	158.153383
Pwudoi MPA	SBt 6	6.847467	158.153633
Pwudoi MPA	SBt 7	6.849183	158.153000
Pwudoi MPA	SBt 8	6.849967	158.152533

Appendix 10 Form used for creel surveys at Pohnpei

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

Slice C1 basic information on fishers

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

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

C3 Species sizes and C4 Species weights

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

C5 Effort data for CPUE

How many hours spent fishing today?	hrs

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

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

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

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

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

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

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

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

What kind of boat used today?

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

If "Other", What kind of boat?

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

C6 Catch prices

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

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

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

C7 Perceptions of fishers

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

Appendix 11 Number of individuals observed from various fishing methods during creel surveys at Pohnpei, Feb–March 2014, and relative percent contribution to the catch of that method+site

Fishing method	Species	Number observed	% contribution by abundance	% contribution by weight
Gillnetting - Kolonia	*Acanthurus nigricauda*	3	1.19	1.08
	Acanthurus triostegus	1	0.40	0.08
	Acanthurus xanthopterus	2	0.79	1.37
	Carangoides orthogrammus	2	0.79	1.93
	Caranx melampygus	14	5.53	5.12
	Caranx sexfasciatus	7	2.77	6.39
	Cetoscarus ocellatus	1	0.40	0.18
	Chlorurus bleekeri	2	0.79	0.85
	Chlorurus microrhinos	1	0.40	0.50
	Hipposcarus longiceps	67	26.48	35.41
	Kyphosus cinerascens	19	7.51	11.27
	Kyphosus vaigiensis	4	1.58	2.59
	Lethrinus erythropterus	6	2.37	0.93
	Lethrinus harak	4	1.58	0.55
	Lethrinus obsoletus	6	2.37	0.78
	Lethrinus xanthochilus	4	1.58	0.88
	Lutjanus gibbus	13	5.14	1.81
	Monotaxis grandoculis	5	1.98	1.15
	Naso lituratus	8	3.16	0.89
	Naso unicornis	8	3.16	8.34
	Parupeneus barberinus	18	7.11	3.94
	Plectorhinchus lineatus	1	0.40	1.33
	Plectropomus areolatus	1	0.40	0.21
	Rhinecanthus aculeatus	1	0.40	0.09
	Sargocentron tiere	1	0.40	0.08
	Scarus dimidiatus	2	0.79	0.70
	Scarus flavipectoralis	1	0.40	0.23
	Scarus ghobban	1	0.40	0.43
	Scarus globiceps	3	1.19	3.18
	Scarus rivulatus	1	0.40	0.17
	Siganus argenteus	17	6.72	2.79
	Siganus doliatus	12	4.74	1.39
	Siganus lineatus	1	0.40	0.31
	Siganus puellus	8	3.16	0.82
	Siganus punctatus	8	3.16	2.23

Fishing method	**Species**	**Number observed**	**% contribution by abundance**	**% contribution by weight**
Handline - Kolonia	*Acanthurus mata*	4	0.18	0.43
	Acanthurus xanthopterus	1	0.05	0.40
	Anyperodon leucogrammicus	1	0.05	0.20
	Aphareus furca	3	0.14	0.15
	Aphareus rutilans	2	0.09	0.25
	Carangoides ferdau	3	0.14	0.59
	Carangoides orthogrammus	13	0.59	1.49
	Caranx lugubris	12	0.55	1.99
	Caranx melampygus	10	0.46	0.91
	Caranx papuensis	4	0.18	0.42
	Caranx sexfasciatus	148	6.76	9.49
	Cephalopholis argus	3	0.14	0.19
	Cephalopholis sexmaculata	1	0.05	0.08
	Cephalopholis urodeta	8	0.37	0.11
	Decapterus macarellus	78	3.56	2.09
	Elagatis bipinnulata	2	0.09	0.81
	Epinephelus coeruleopunctatus	9	0.41	1.51
	Epinephelus fuscoguttatus	3	0.14	0.30
	Epinephelus hexagonatus	5	0.23	0.14
	Epinephelus maculatus	21	0.96	1.75
	Epinephelus merra	9	0.41	0.13
	Epinephelus polyphekadion	66	3.01	5.21
	Gerres longirostris	1	0.05	0.02
	Gnathodentex aureolineatus	3	0.14	0.09
	Hemigymnus melapterus	1	0.05	0.06
	Lethrinus erythropterus	66	3.01	2.60
	Lethrinus harak	17	0.78	0.90
	Lethrinus obsoletus	12	0.55	0.73
	Lethrinus ornatus	3	0.14	0.10
	Lethrinus rubrioperculatus	1	0.05	0.03
	Lethrinus xanthochilus	5	0.23	0.75
	Lutjanus bohar	11	0.50	2.80
	Lutjanus fulviflamma	19	0.87	0.75
	Lutjanus fulvus	340	15.53	10.77
	Lutjanus gibbus	155	7.08	10.31
	Lutjanus kasmira	21	0.96	0.41
	Lutjanus monostigma	43	1.96	3.02

Fishing method	Species	Number observed	% contribution by abundance	% contribution by weight
	Lutjanus semicinctus	15	0.68	0.78
	Megalops cyprinoides	1	0.05	0.13
	Monodactylus argenteus	7	0.32	0.20
	Monotaxis grandoculis	1	0.05	0.24
	Myripristis adusta	121	5.53	4.87
	Myripristis berndti	81	3.70	2.08
	Myripristis pralinia	1	0.05	0.02
	Myripristis vittata	19	0.87	0.34
	Naso vlamingii	2	0.09	0.37
	Parupeneus cyclostomus	1	0.05	0.08
	Platax teira	1	0.05	0.16
	Plectorhinchus lineatus	1	0.05	0.22
	Plectropomus areolatus	2	0.09	0.17
	Plectropomus oligacanthus	1	0.05	0.15
	Priacanthus hamrur	21	0.96	0.88
	Rhinecanthus aculeatus	1	0.05	0.03
	Sargocentron spiniferum	24	1.10	1.16
	Sargocentron tiere	22	1.00	0.50
	Sargocentron tiereoides	19	0.87	0.36
	Selar crumenophthalmus	724	33.06	21.85
	Siganus punctatus	1	0.05	0.04
	Sphyraena barracuda	1	0.05	1.39
	Sphyraena forsteri	15	0.68	1.78
	Upeneus vittatus	2	0.09	0.05
	Variola louti	2	0.09	0.15
Day spearing - Kolonia	*Acanthurus nigricauda*	2	1.74	0.65
	Acanthurus xanthopterus	27	23.48	17.31
	Caranx melampygus	7	6.09	9.97
	Caranx papuensis	2	1.74	2.31
	Cephalopholis argus	1	0.87	0.57
	Cetoscarus ocellatus	2	1.74	1.73
	Chlorurus bleekeri	2	1.74	1.03
	Chlorurus microrhinos	9	7.83	10.55
	Gymnocranius euanus	1	0.87	0.97
	Gymnosarda unicolor	1	0.87	2.09
	Hipposcarus longiceps	1	0.87	0.39
	Kyphosus cinerascens	3	2.61	1.48

Fishing method	Species	Number observed	% contribution by abundance	% contribution by weight
	Kyphosus vaigiensis	9	7.83	6.52
	Lethrinus erythropterus	1	0.87	0.38
	Lutjanus monostigma	2	1.74	1.44
	Lutjanus semicinctus	1	0.87	0.53
	Monotaxis grandoculis	3	2.61	2.96
	Naso lituratus	8	6.96	1.92
	Naso unicornis	12	10.43	13.90
	Parupeneus barberinus	2	1.74	1.22
	Plectorhinchus albovittatus	1	0.87	1.85
	Plectorhinchus lineatus	7	6.09	9.54
	Plectorhinchus vittatus	1	0.87	1.23
	Plectropomus areolatus	3	2.61	4.80
	Scarus ghobban	2	1.74	1.37
	Scarus rubroviolaceus	2	1.74	1.23
	Scomberoides lysan	1	0.87	1.26
	Siganus doliatus	1	0.87	0.29
	Siganus spinus	1	0.87	0.50
Night spearing (Kolonia)	*Acanthurus lineatus*	7	1.10	0.43
	Acanthurus mata	10	1.56	2.98
	Acanthurus nigricauda	31	4.85	2.51
	Acanthurus xanthopterus	24	3.76	4.46
	Arothron hispidus	1	0.16	0.19
	Carangoides orthogrammus	4	0.63	0.27
	Caranx papuensis	1	0.16	0.05
	Caranx sexfasciatus	3	0.47	0.48
	Cephalopholis argus	1	0.16	0.10
	Cetoscarus ocellatus	3	0.47	0.79
	Cheilinus undulatus	2	0.31	0.93
	Chlorurus bleekeri	5	0.78	0.84
	Chlorurus microrhinos	2	0.31	0.31
	Chlorurus sordidus	3	0.47	0.38
	Ctenochaetus striatus	17	2.66	0.40
	Epinephelus coeruleopunctatus	1	0.16	0.12
	Epinephelus fuscoguttatus	4	0.63	2.12
	Epinephelus maculatus	5	0.78	0.62
	Epinephelus polyphekadion	3	0.47	0.40
	Hipposcarus longiceps	123	19.25	24.50

Fishing method	Species	Number observed	% contribution by abundance	% contribution by weight
	Kyphosus cinerascens	1	0.16	0.20
	Kyphosus vaigiensis	3	0.47	0.48
	Lethrinus erythropterus	3	0.47	0.27
	Lethrinus obsoletus	2	0.31	0.25
	Lethrinus xanthochilus	2	0.31	0.29
	Lutjanus gibbus	5	0.78	0.57
	Lutjanus semicinctus	2	0.31	0.31
	Monotaxis grandoculis	2	0.31	0.78
	Naso lituratus	32	5.01	2.54
	Naso unicornis	76	11.89	22.82
	Neoniphon sammara	1	0.16	0.12
	Parupeneus barberinus	37	5.79	6.09
	Parupeneus crassilabris	1	0.16	0.20
	Parupeneus cyclostomus	4	0.63	0.69
	Plectorhinchus lineatus	1	0.16	0.21
	Plectropomus areolatus	8	1.25	1.27
	Priacanthus hamrur	2	0.31	0.14
	Pseudobalistes flavimarginatus	1	0.16	0.65
	Sargocentron spiniferum	6	0.94	0.68
	Scarus chameleon	7	1.10	1.13
	Scarus dimidiatus	14	2.19	1.48
	Scarus flavipectoralis	2	0.31	0.30
	Scarus globiceps	1	0.16	0.44
	Scarus rivulatus	13	2.03	1.74
	Scarus rubroviolaceus	3	0.47	0.36
	Siganus argenteus	16	2.50	1.24
	Siganus doliatus	33	5.16	2.22
	Siganus lineatus	4	0.63	0.57
	Siganus puellus	55	8.61	3.95
	Siganus punctatus	48	7.51	4.99
	Siganus spinus	1	0.16	0.07
	Siganus vulpinus	1	0.16	0.05
	Stegastes fasciolatus	2	0.31	0.05
Day spearing (Kitti)	*Acanthurus blochii*	4	0.31	0.36
	Acanthurus lineatus	321	24.77	8.36
	Acanthurus nigricauda	83	6.40	2.47
	Acanthurus nigrofuscus	1	0.08	0.01

Fishing method	**Species**	**Number observed**	**% contribution by abundance**	**% contribution by weight**
	Acanthurus olivaceus	1	0.08	0.03
	Anyperodon leucogrammicus	1	0.08	0.04
	Caesio caerulaurea	6	0.46	0.29
	Caranx ignobilis	1	0.08	0.71
	Caranx melampygus	5	0.39	1.73
	Caranx sexfasciatus	1	0.08	0.09
	Cephalopholis argus	9	0.69	0.75
	Cetoscarus ocellatus	2	0.15	0.18
	Cheilinus chlorourus	1	0.08	0.18
	Cheilinus trilobatus	2	0.15	0.21
	Chlorurus bleekeri	9	0.69	0.52
	Chlorurus microrhinos	1	0.08	0.21
	Chlorurus sordidus	10	0.77	0.66
	Ctenochaetus striatus	3	0.23	0.08
	Epinephelus coeruleopunctatus	1	0.08	0.08
	Epinephelus cyanopodus	1	0.08	0.19
	Epinephelus fuscoguttatus	3	0.23	0.85
	Epinephelus hexagonatus	1	0.08	0.05
	Epinephelus maculatus	33	2.55	2.33
	Epinephelus polyphekadion	24	1.85	4.03
	Epinephelus spilotoceps	3	0.23	0.12
	Hipposcarus longiceps	25	1.93	2.53
	Kyphosus cinerascens	4	0.31	0.39
	Kyphosus vaigiensis	33	2.55	4.26
	Lethrinus erythropterus	21	1.62	2.12
	Lethrinus harak	1	0.08	0.06
	Lethrinus obsoletus	7	0.54	0.30
	Lethrinus olivaceus	2	0.15	0.45
	Lethrinus xanthochilus	2	0.15	0.33
	Lutjanus gibbus	32	2.47	1.86
	Lutjanus monostigma	2	0.15	0.31
	Lutjanus semicinctus	4	0.31	0.24
	Macolor macularis	5	0.39	0.70
	Monotaxis grandoculis	15	1.16	2.19
	Myripristis adusta	49	3.78	2.01
	Myripristis berndti	22	1.70	0.52
	Myripristis violacea	8	0.62	0.18

Fishing method	Species	Number observed	% contribution by abundance	% contribution by weight
	Naso lituratus	138	10.65	5.26
	Naso lopezi	1	0.08	0.05
	Naso unicornis	185	14.27	37.27
	Neoniphon opercularis	1	0.08	0.03
	Parupeneus barberinus	15	1.16	0.77
	Parupeneus cyclostomus	6	0.46	0.34
	Parupeneus trifasciatus	3	0.23	0.14
	Platax orbicularis	1	0.08	0.29
	Platax teira	1	0.08	0.20
	Plectorhinchus lineatus	1	0.08	0.15
	Plectorhinchus vittatus	3	0.23	0.72
	Plectropomus areolatus	14	1.08	2.23
	Pomacanthus xanthometopon	2	0.15	0.19
	Priacanthus hamrur	1	0.08	0.04
	Sargocentron spiniferum	2	0.15	0.14
	Scarus altipinnis	5	0.39	0.48
	Scarus frenatus	6	0.46	0.23
	Scarus oviceps	7	0.54	0.42
	Scarus psittacus	3	0.23	0.20
	Scarus rivulatus	21	1.62	1.34
	Scarus rubroviolaceus	6	0.46	0.61
	Scarus schlegeli	4	0.31	0.22
	Siganus argenteus	12	0.93	0.35
	Siganus doliatus	58	4.48	1.62
	Siganus lineatus	1	0.08	0.03
	Siganus puellus	2	0.15	0.05
	Siganus punctatus	31	2.39	1.26
	Siganus spinus	1	0.08	0.06
	Sphyraena barracuda	1	0.08	0.23
	Variola louti	5	0.39	2.10