Climate Change Baseline Assessment

Pohnpei
Federated States of Micronesia

March-April 2012

Brad Moore, Fulitua Siaosi, Watisoni Lalavanua, Kalo Pakoa, Being Yeeting, Franck Magron, Ian Bertram and Lindsay Chapman
Coastal Fisheries Science and Management Section
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ACRONYMS

ANOVA	Analysis of Variance
AusAID	Australian Agency for International Development
COTS	Crown-of-thorns starfish
CPC	Coral Point Count
CSP	Conservation Society of Pohnpei
DLNR-MCU	Department of Land and Natural Resources - Marine Conservation Unit
D-UVC	Distance-sampling Underwater Visual Census
EEZ	Exclusive Economic Zone
FSM	Federated States of Micronesia
FSM R&D	Federated States of Micronesia - Resource and Development
FSM OFA	Federated States of Micronesia Office of Fisheries and Aquaculture
GDP	Gross Domestic Product
GPS	Global Positioning System
GR	Government Revenue
ha	hectare
ICCAI	International Climate Change Adaptation Initiative (Australia)
IPCC	Intergovernmental Panel on Climate Change
IRD	Institut de Recherche pour le Développement
MCRMP	Millennium Coral Reef Mapping Project
MPA	Marine Protected Area
mt	metric tonne
NASA	National Aeronautics and Space Administration
NGO	Non-Government Organisation
PCA	Principle Component Analysis
PCCSP	Pacific Climate Change Science Program
PICT	Pacific Island Countries and Territories
PROCFish	Pacific Regional Oceanic and Coastal Fisheries Development Programme
RBT	Reef-benthos transect
SCUBA	Self-Contained Underwater Breathing Apparatus
SEAFRAME	Sea Level Fine Resolution Acoustic Measuring Equipment
SOPAC	Applied Geoscience and Technology Division of SPC
SPC	Secretariat of the Pacific Community
SE	Standard Error
SST	Sea-surface temperature
TL	Total length
USD	United States dollar(s)

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Introduction

Considering the concerns of climate change and its impacts on coastal fisheries resources, SPC is implementing the 'Monitoring the Vulnerability and Adaptation of Coastal Fisheries to Climate Change' project with funding assistance from the Australian Government's International Climate Change Adaptation Initiative (ICCAI). This project aims to assist Pacific Islands Countries and Territories (PICTs) to determine whether changes are occurring in the productivity of coastal fisheries and, if changes are found, to identify the extent to which such changes are due to climate change, as opposed to other causative factors. This report presents the results of baseline field surveys for the project conducted in Pohnpei, Federated States of Micronesia (FSM), between March and April 2012.

Survey Design

Survey work at Pohnpei covered four disciplines (water temperature monitoring, benthic habitat assessments and assessments of finfish and invertebrate resources), and was conducted by a team from SPC's Coastal Fisheries Science and Management Section, staff from FSM – Department of Resources & Development (FSM R&D), Office of Fisheries and Aquaculture – Pohnpei State (OFA), Marine Conservation Unit – Department of Land and Natural Resources – Pohnpei State (DLNR - MCU), and Conservation Society of Pohnpei (CSP). The fieldwork included capacity development of local counterparts by providing training in survey design and methodologies, data collection and entry, and data analysis.

Surveys were focused in and around the Kehpara Marine Sanctuary (Kehpara MPA) and the Pwudoi Mangrove Reserve (Pwudoi MPA), in the south-western corner of Pohnpei Island. Monitoring stations were established within the protected area (MPA sites) and within the surrounding area open to fishing (Open sites). This design allows for potential de-coupling of the effects of over-fishing and pollution from other causes (e.g. climate-related effects). For purposes of this report, comparisons were made among the MPA and Open sites, to explore functioning of the protected areas. The data presented here provides a quantitative baseline that will be analysed after future monitoring events to examine changes in coastal habitat and fishery resources over time.

Water Temperature

In October 2010, two RBR TR-1060 temperature loggers were deployed in Pohnpei: one on the outer reef and one in the lagoon, as part of a pilot study to test equipment and deployment methods. The loggers were housed in a PVC tube with holes to allow flow of water and encased in a concrete block and deployed at a depth of approximately 10 m.

Preliminary data show that water temperatures at both the outer-reef and in the lagoon were higher in 2011 than 2010. Further monitoring is required to assess temporal trends in water temperature.

Benthic Habitat Assessments

Benthic habitats of the Kehpara MPA and Kehpara Open sites were assessed via photoquadrat methodologies. Thirty-six benthic habitat assessment transects were established across the back-, lagoon- and outer-reef habitats of the Kehpara region, with 18 transects completed in the MPA site and 18 transects completed in the Open site. Up to 50 photographs of the benthos were taken per transect (with one photo taken approximately every metre) using a housed underwater camera and a quadrat frame measuring an area of 0.25 m^2. Photographs were analysed using SPC software. In general, the back-reef habitats of both the MPA and Open sites were characterised by high cover (> 40%) of sand and moderate cover of hard corals. Lagoon reefs within the MPA site were characterised by moderate cover of hard corals (dominated by members of the genus *Porites*), while the lagoon reefs of the Open site had high (> 60%) coral cover (dominated by *Porites* and *Porites-rus*), and low cover of sand. Outer-reef habitats of the MPA had moderate cover of hard corals and coralline algae (> 30%), while outer-reef habitats of the Open site had a comparatively low cover of hard coral (< 15%) and a moderate cover of coralline algae, sand and rubble.

Finfish Surveys

Finfish resources and their supporting habitats of the Kehpara MPA and Open sites were surveyed using distance-sampling underwater visual census (D-UVC) methodology. Thirty-six D-UVC monitoring transects were established across the back-, lagoon- and outer-reef habitats of the Kehpara region, with 18 transects completed at each of the MPA and Open sites, with six transects established in each habitat type at each site. Habitats supporting finfish at both the Kehpara MPA and Kehpara Open sites were largely similar to those recorded during the benthic habitat assessments, with back-reef habitats consisting of high cover of sand, lagoon-reefs consisting of high coral cover and comparatively low cover of sand, and outer-reef habitats consisting of moderate cover of hard corals. Finfish diversity was higher within the Kehpara MPA compared to the Open site for all three habitats examined. At the MPA site, the outer-reef habitats supported a greater density and slightly higher biomass of finfish than back- or lagoon-reef habitats, while no differences in finfish density or biomass were evident between the back- and lagoon-reefs. No differences in overall density or biomass of finfish resources were evident among the back-, lagoon- or outer-reef habitats of the Open site. Common families observed at all habitats of both the MPA and Open site were the Pomacentridae, Acanthuridae, Labridae, Chaetodontidae and Scaridae.

Invertebrate Surveys

Invertebrate resources and their supporting habitats were surveyed using three complementary approaches; a broad-scale method, which employed manta tows, and two fine-scale methods: reef-benthos transects (RBT) and soft-benthos transects (SBT). Two full manta tow monitoring stations (6 x 300 m replicates) were established within the Kehpara MPA, while four full stations were established within the Open site. An additional manta tow transect was divided between the MPA and Open sites. Species observed in the highest densities of both the MPA and Open sites during manta tow surveys included the sea cucumbers *Holothuria atra*, *H. edulis* and *Bohadschia argus*. Few differences were evident in the mean density of observed invertebrate species among sites, although the mean densities of the medium-value greenfish *Stichopus chloronotus* and the elongate giant clam *Tridacna maxima* were significantly higher at the MPA site than the Open sites. The crown-of-thorns starfish (*Acanthaster planci*) was observed at relatively low densities in manta tow transects within both the Kehpara MPA and Kehpara Open site.

To assess invertebrate resources associated with hard (reefal) substrates, reef-benthos transects (RBT) were used. Eight RBT monitoring stations (6 x 40 m replicates) were established within both the Kehpara MPA and Open site. The individual species observed in the highest mean densities during the RBT surveys within the MPA site were the gastropods *Dendropoma maximum* (22,098.96±6,825.72 individuals/ha), and *Tectus pyramis* (197.92±174.44 individual/ha), the sea cucumbers *Holothuria atra* (3,276.04±601.18 individuals/ha) and *H. edulis* (729.17±107.97 individuals/ha) and the starfish *Linckia laevigata* (1,182.29±125.97 individuals/ha). The individual species observed in the highest mean densities within the Kehpara Open site were the sea cucumbers *H. atra* (4,270.83±1,506.95 individuals/ha) and *H. edulis* (583.33±260.45 individuals/ha). RBT stations within the MPA site supported significantly higher densities of the sea cucumbers *Bohadschia vitiensis*, *Holothuria edulis* and *Stichopus chloronotus*, the gastropods *Coralliophora violacea*, *Dendropoma maximum* and *Conomurex luhuanus*, and the starfish *Acanthaster planci*, *Linckia laevigata* and *Linckia* sp. Crown-of-thorns starfish (COTS) were observed at seven of the eight RBT stations within the Kehpara MPA and three of the eight stations within the Open site. Densities of COTS within the Kehpara MPA ranged from 0 to 208.33 individuals/ha.

Soft-benthos transects (SBT) were used to assess invertebrate resources associated with soft (i.e. sand and mud) substrates. Four SBT stations (6 x 40 m replicates) were established in areas open to harvest, while a single SBT station was established within a protected area (the Pwudoi Mangrove Reserve). Species diversity and density was largely similar among sites, with the sea cucumber species *Bohadschia similis*, *Holothuria atra*, *H. edulis* and *Stichopus vastus* the most commonly observed species.

Recommendations for Future Monitoring

The following recommendations are proposed for future monitoring events:

- Many of the back-reef monitoring stations established during the baseline survey were established in shallow (< 1 m deep) water. Accordingly, these habitats will likely only support transient finfish communities due to tidal effects. For future surveys it is recommended that additional deeper water back-reef transects be established, where possible.
- Due to poor weather during this baseline study, manta tow surveys were conducted on back-and lagoon-reef habitats only. As various reef habitats, and the organisms they support, differ greatly in their vulnerability to climate change, it is recommended that additional manta tow monitoring stations be established on the outer reef of both Kehpara MPA and Kehpara Open sites. Inclusion of outer-reef habitats will also allow for comparison against the surveys of Tardy et al. (2009), providing an additional time series with which to assess temporal patterns in invertebrate resources and their habitats.
- For this baseline assessment, only one SBT station was established within a protected area (Pwudoi Mangrove Reserve), while four SBT stations were established in areas open to fishing. Additional SBT stations should be established within the Pwudoi MPA to balance the survey design.

1. Introduction

Project Background

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

The purpose of this project is to assist PICTs to:

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

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

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

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

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

The Approach

Monitoring impacts of climate change on coastal fisheries is a complex challenge. To facilitate this task, a set of monitoring methods was selected from the SPC expert workshop 'Vulnerability and Adaptation of Coastal Fisheries to Climate Change: Monitoring Indicators and Survey Design for Implementation in the Pacific' (Noumea, 19–22 April 2010) of scientists and representatives of many PICTs. These methods include monitoring of water temperature using temperature loggers, finfish and invertebrate resources using SPC resource assessment protocols, and photo quadrats for assessing benthic habitats supporting coastal fisheries. The methods were prioritised as they 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 including fish, invertebrate and socio-economic survey data from the Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish), multi-temporal images (aerial photographs and satellite images) from the Applied Geosciences and Technology Division of SPC (SOPAC), the presence of Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME), as well as their geographical location.

This report presents the results of baseline field surveys for the project conducted in Pohnpei, FSM, between March and April 2012, by a team from SPC's Coastal Fisheries Science and Management Section, and staff from FSM – Department of Resources & Development (FSM R&D), Office of Fisheries and Aquaculture – Pohnpei State (OFA), Marine Conservation Unit – Department of Land and Natural Resources – Pohnpei State (DLNR - MCU), and Conservation Society of Pohnpei (CSP). Recommendations for future monitoring events are also provided.

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.

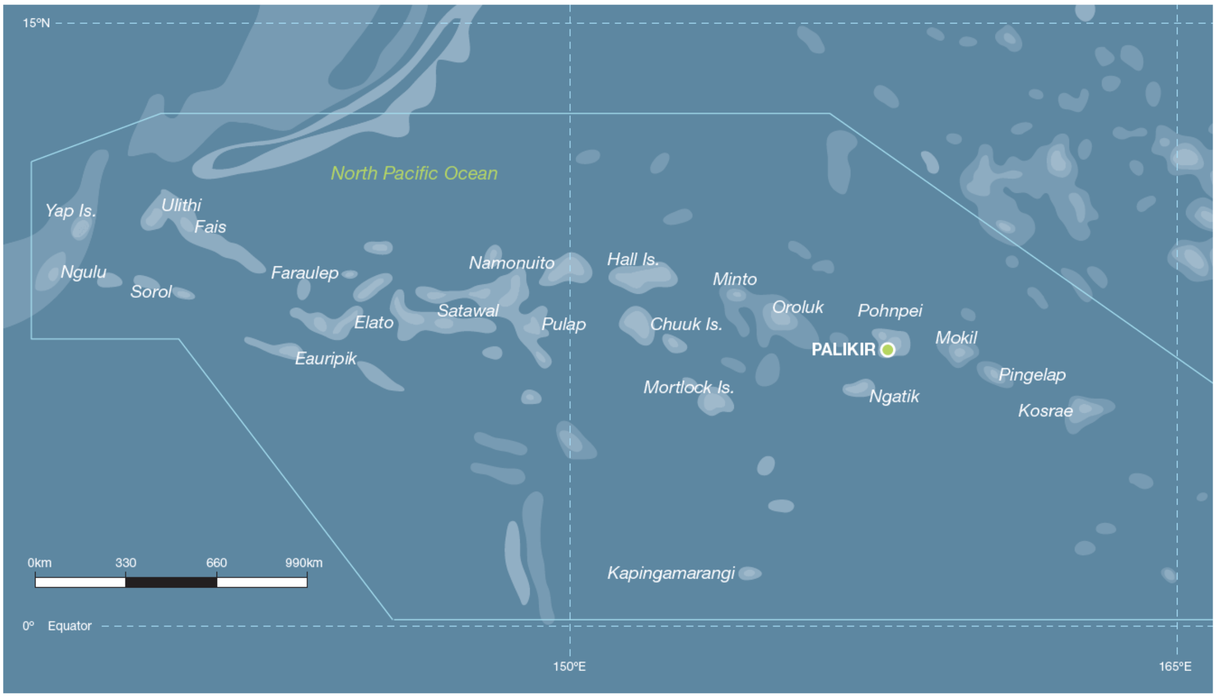

Figure 1 Federated States of Micronesia (from PCCSP 2011).

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 1). 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 are comprised of four broad-scale categories: demersal fish (bottom-dwelling fish associated with mangrove, seagrass and coral reef habitats), nearshore pelagic fish (including tuna, wahoo, mackerel, rainbow runner and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas (Bell et al. 2011). In 2007, the total annual catch of the coastal sector was estimated to be 12,600 tonnes, worth > USD 23.0 million (Gillet 2009) (Table 2). 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 2).

Table 1 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 2 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 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 3).

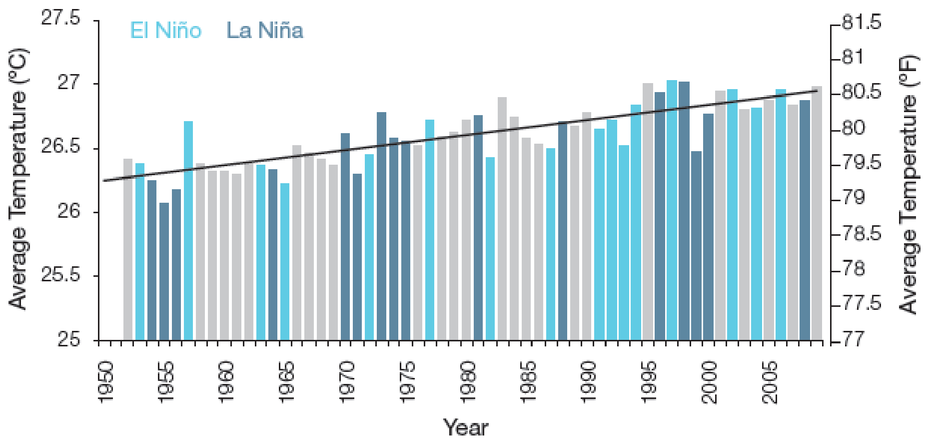

Figure 2 **Annual mean air temperature at Pohnpei (1950–2009) (from PCCSP 2011).**

Table 3 **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 4).

Table 4 **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 (Sea Level Fine Resolution Acoustic Measuring Equipment) 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 5). 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 6).

Table 5 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 6 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 (FFEM) 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).

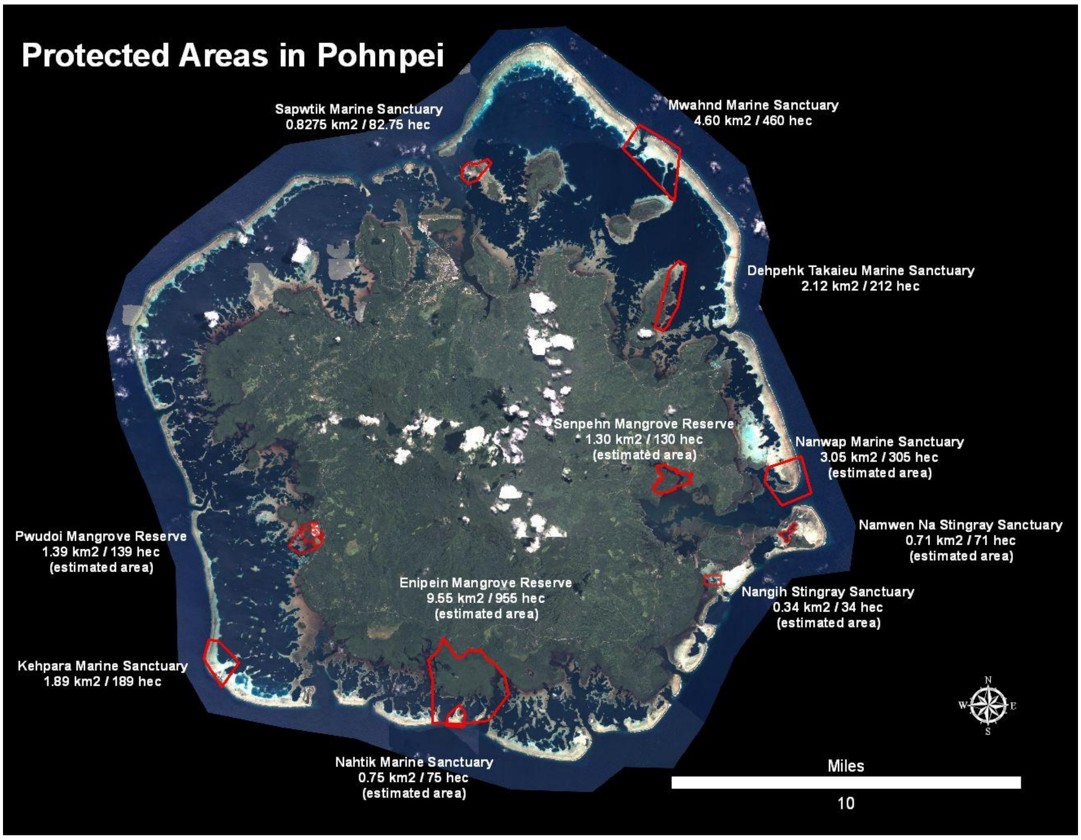

Figure 3 Map of Pohnpei indicating the Kehpara Marine Sanctuary (Kehpara MPA) and Pwudoi Mangrove Reserve (from the Conservation Society of Pohnpei).

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.

A Comparative Approach Only

The data collected provides a quantitative baseline that will be analysed after future monitoring events to examine temporal changes in coastal habitat and fishery resources. It should be stressed that due to the comparative design of the project, the methodologies used, and the number of sites and habitats examined, the data provided in this report should only be used in a comparative manner to explore differences in coastal fisheries productivity over time. These data should not be considered as indicative of the actual available fisheries resources.

3. Monitoring of Water Temperature

Methodologies

In October 2010, two RBR TR-1060 temperature loggers were deployed in Pohnpei: one on the outer reef and one in the lagoon (Table 7). 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. Data retrieval and battery replacement is planned after a period ranging from six months (initial trial) to two years. The collected data will be stored on SPC servers and made available to networks of researchers, governmental services and conservation NGOs.

Figure 4 Deployment of temperature loggers in Pohnpei, 2012.

Table 7 Details of temperature loggers deployed at Pohnpei Island.

Details	Pohnpei 1	Pohnpei 2
Deployment date	10/03/2012	14/03/2012
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

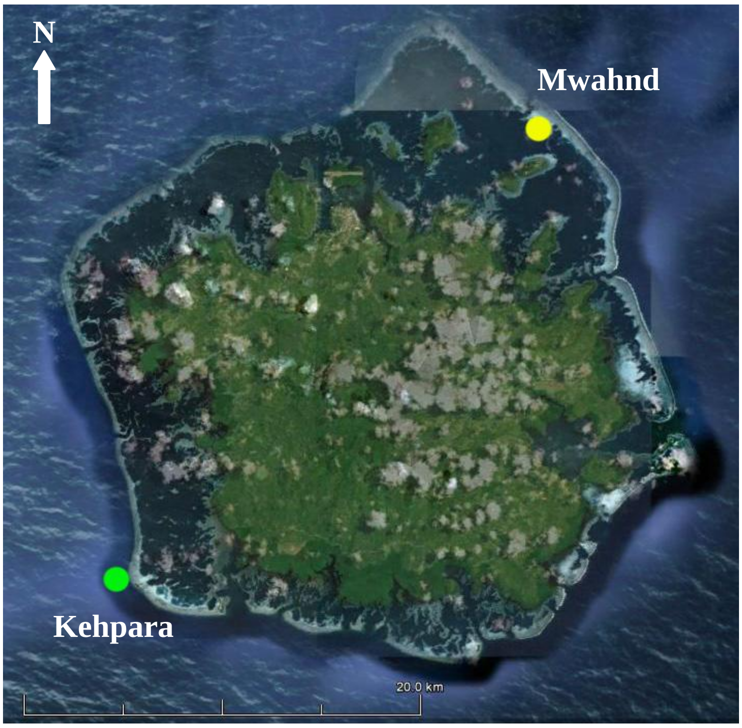

Figure 5 **Location of water temperature loggers deployed in Pohnpei, 2010.**

Results

Preliminary data show that water temperatures at both the outer-reef and in the lagoon were higher in 2011 than 2010 (Figure 6). Further monitoring of water temperature is required to assess whether these trends are consistent over time.

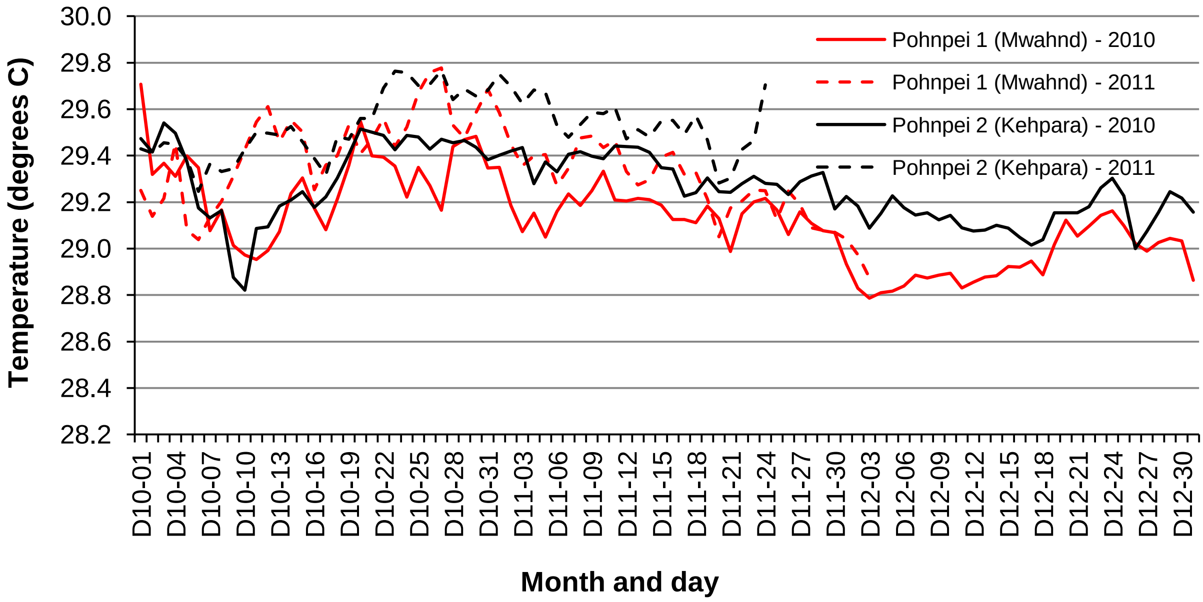

Figure 6 **Mean daily water temperature in the lagoon (Mwahnd) and outer-reef (Kehpara) of Pohnpei Island, Oct-Dec 2010 and 2011. See Figure 5 for logger locations.**

4. Benthic Habitat Assessment

Methodologies

Data collection

For the assessments of coral reef benthic habitat and finfish resources monitoring sites were established within and adjacent to the Kehpara MPA (i.e. Kehpara MPA and Kehpara Open). Assessments focused on three habitats: back-reefs, lagoon-reefs and outer-reefs with two monitoring stations established in each habitat at each site, and a target of three replicate 50 m transects in each habitat for each station (Figure 7). To assess benthic habitats, up to 50 photographs of the benthos were taken per transect (with one photo taken approximately every metre) using a housed underwater camera and a quadrat frame measuring approximately 1 m high that captured an area of 0.25 m^2. Photos were taken 1 m above the benthos. Transects were laid parallel to the reef. A GPS position was recorded at the beginning of each replicate transect. To maximise survey efficiency, the same transects were used for both the benthic habitat and finfish assessments.

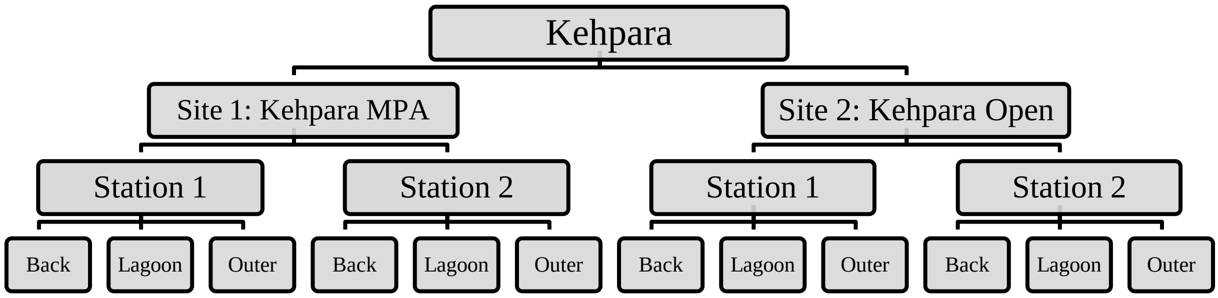

Figure 7 Survey design of the benthic habitat and finfish assessments in Pohnpei, FSM. Three replicate 50m transects were planned in each back-, lagoon- or outer-reef habitat.

Data processing and analysis

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

1. Hard coral – sum of the different types of hard coral, identified to genus level[1];
2. Other invertebrates – sum of invertebrate types including *Anemones*, *Ascidians*, *Cup sponge*, *Discosoma*, *Dysidea sponge*, *Gorgonians*, *Olive sponge*, *Terpios sponge*, *Other sponges*, *Soft coral*, *Zoanthids*, and *Other invertebrates* (other invertebrates not included in this list);

[1] Corals of the genus *Porites* were further divided into *Porites* (branching and encrusting forms), *Porites-rus* and *Porites*-massive categories.

3. Macroalgae – sum of different types of macroalgae *Asparagopsis*, *Blue-green algae*, *Boodlea*, *Bryopsis*, *Chlorodesmis*, *Caulerpa*, *Dicotyota*, *Dictosphyrea*, *Galaxura*, *Halimeda*, *Liagora*, *Lobophora*, *Mastophora*, *Microdictyton, Neomeris*, *Padina*, *Sargassum*, *Schizothrix*, *Turbinaria*, *Tydemania*, *Ulva*, and *Other macroalgae* (other macroalgae not included in this list);
4. Branching coralline algae – *Amphiroa*, *Jania*, *Branching coralline general*;
5. Crustose coralline algae;
6. Fleshy coralline algae;
7. Turf algae;
8. Seagrass – sum of seagrass genera *Enhalus*, *Halodule*, *Halophila*, *Syringodium*, *Thalassia*, *Thalassodendron*;
9. Chrysophytes;
10. Sand – 0.1 mm < hard particles < 30 mm;
11. Rubble – carbonated structures of heterogeneous sizes, broken and removed from their original locations; and
12. Pavement.

In addition, the status of corals (live, recently dead or bleached) was noted for each coral genera data point. Recently dead coral was defined as coral with newly exposed white skeletons with visible corallites and no polyps present, while bleached coral was defined as white coral with polyps still present. Resulting data were then summarized as percentages and extracted to MS Excel according to genus level and grouped into 12 broad-scale substrate categories (totalling to 100%). To assess broad-scale patterns in benthic habitat among sites and habitats, principle component analysis (PCA) was conducted on log(x+1) transformed mean percent cover values of each major substrate category, using Primer 6. To explore differences among sites and habitats, coverage data of each major benthic category in each individual transect were square-root transformed to reduce heterogeneity of variances and analysed by two-way analysis of variance (ANOVA) using Statistica 7.1, with site (Kehpara MPA and Kehpara Open) and habitat (back-reef, lagoon-reef, and outer-reef) as fixed factors in the analysis. While data for some categories (other invertebrates, macroalgae, crustose coralline algae and turf algae) failed Cochran's C test for homogeneity of variances ($P < 0.05$), the results of the ANOVA were still deemed useful as the design was balanced (Underwood 1997). Tukey-Kramer post-hoc pairwise tests were used to identify specific differences between factors at $P = 0.05$. Summary graphs of mean percentage cover (± SE) were generated to further explore patterns of each major substrate category by habitat.

Results

Survey coverage

A total of 36 benthic habitat assessment transects were completed across the back-, lagoon- and outer-reef habitats of the Kehpara region, with 18 transects completed in each of the Kehpara MPA and Kehpara Open sites (Figure 8; Table 8). A list of GPS positions for each benthic habitat assessment transect is presented as Appendix 1.

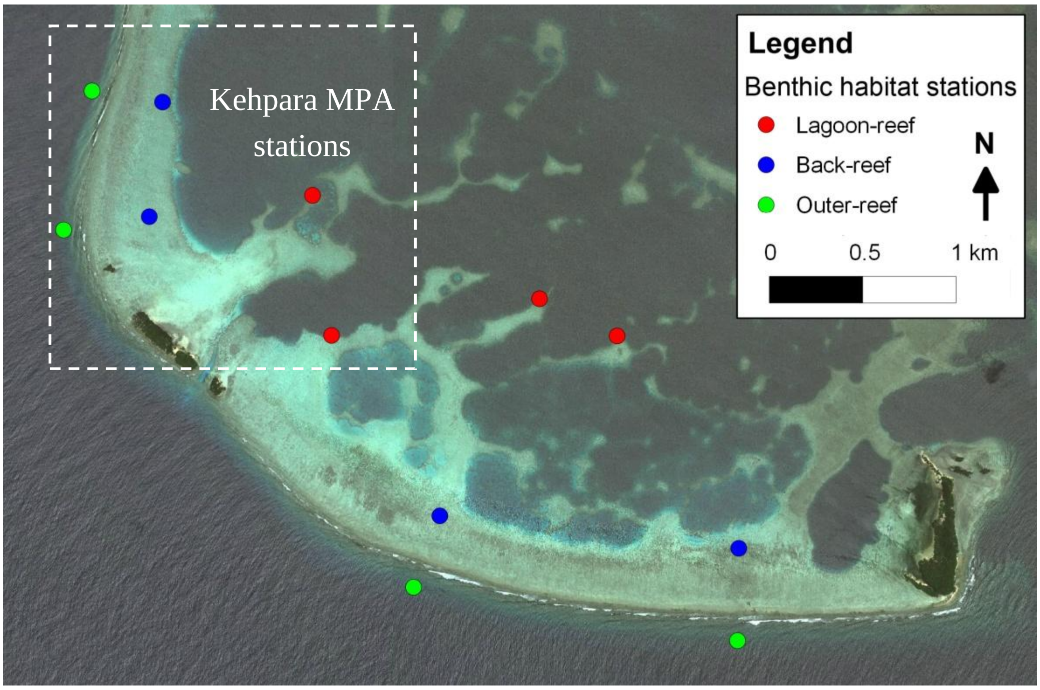

Figure 8 **Location of benthic habitat assessment stations established in the Kehpara region, 2012.**

Table 8 **Summary of benthic habitat assessment transects within the Kehpara MPA and Kehpara Open monitoring sites, 2012**

Site	Station	Habitat	No. of transects
Kehpara MPA	Kehpara MPA 1	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3
	Kehpara MPA 2	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3
Kehpara Open	Kehpara Open 1	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3
	Kehpara Open 2	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3

Back-reef habitats

Back-reef habitats of both the Kehpara MPA and Kehpara Open monitoring stations typically differed from lagoon- and outer-reef habitats by a relatively high percent cover of sand and low hard coral cover (Figure 9). Among sites, the cover of crustose coralline algae and macroalgae was significantly higher within the back-reef habitats of the Kehpara MPA than the Open site (P < 0.001 and P = 0.049, respectively), with *Turbinaria*, *Halimeda* and blue-green algae (cyanobacteria) the dominant types, while the cover of seagrass was significantly higher within back-reef habitats of the Kehpara Open stations (P = 0.008) (Figure 10).

Hard coral diversity was higher within the Kehpara MPA site, where a total of 11 types of hard coral were recorded, compared to seven within the Kehpara Open site (Figure 10). Hard coral cover was low at both sites; with hard corals constituting 21.5±2.2% and 25.5±3.6% of overall cover at the MPA and Open sites, respectively, and did differ significantly among sites (Figure 10). In terms of cover, *Porites*-massive was the most common coral type of back-reefs within the Kehpara MPA site, representing 16.4±3.2% of overall cover, respectively, while *Acropora* and *Porites*-massive were the most common coral types of the Kehpara Open site, representing 16.1±4.2% and 6.9±2.1% of overall cover, respectively (Figure 10). No bleached corals were observed in the back-reef habitats of either site. The percentage cover of recently dead corals at both sites was low, constituting 0.1±0.1% and 0.2±0.1% of overall mean cover of hard corals at the Kehpara MPA and Open sites, respectively.

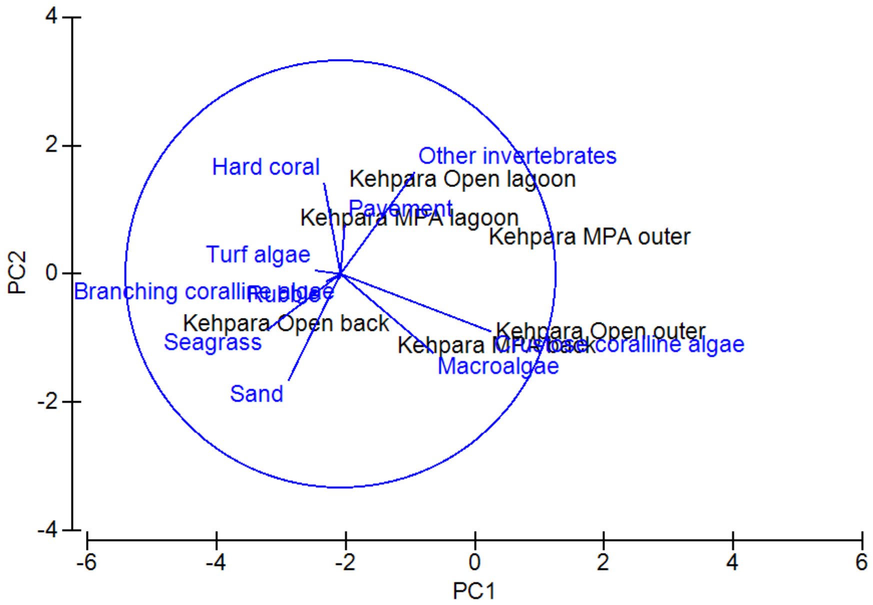

Figure 9 **Principle Component Analysis (PCA) of each major benthic substrate category for each site and habitat. Sites separate along a gradient of crustose coralline algae versus turf (PC1) and hard coral versus sand (PC2).**

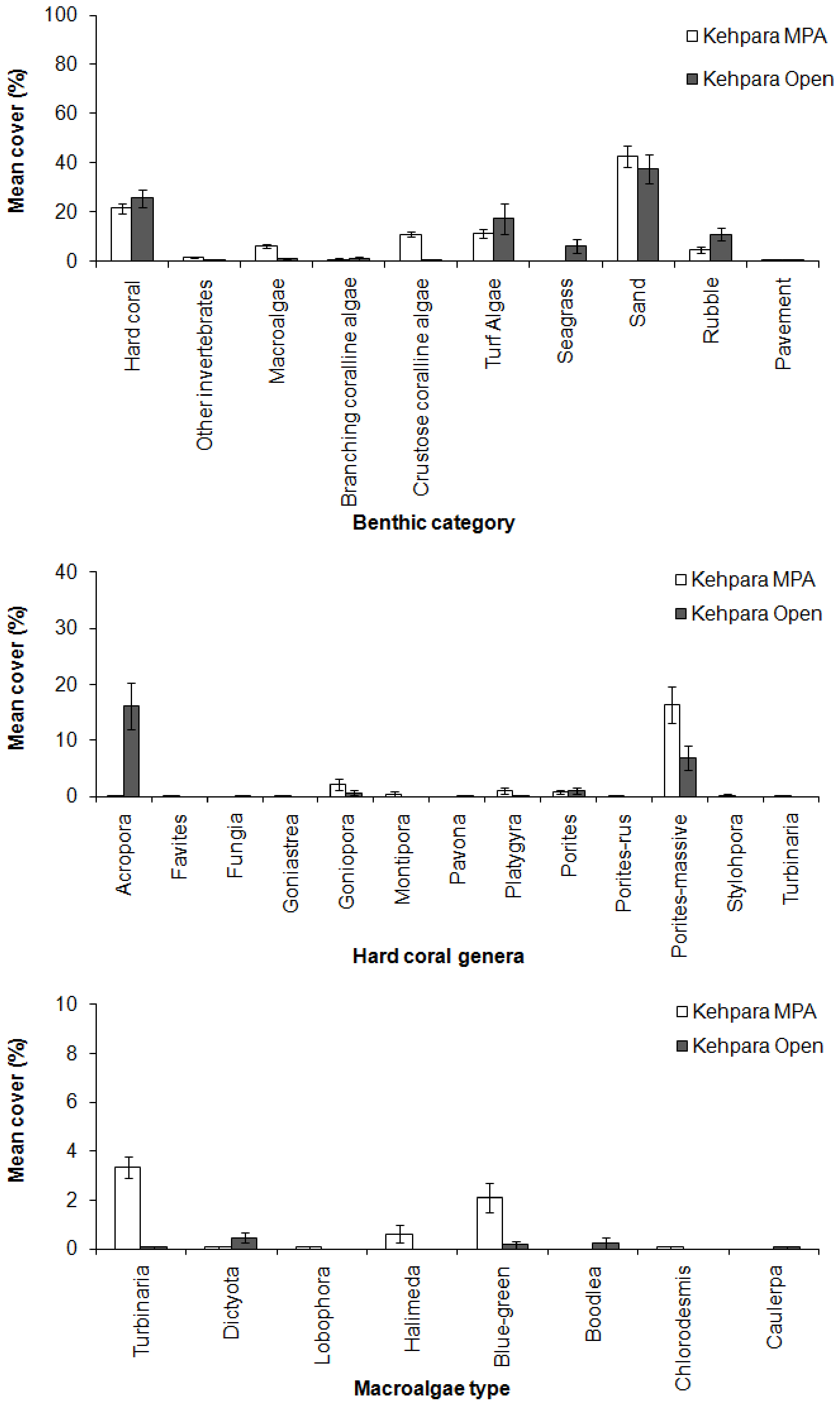

Figure 10 **Mean cover (+/- SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at back-reef habitats during benthic habitat assessments at Kehpara MPA and Open sites, 2012.**

Lagoon-reef habitats

Lagoon-reef habitats of both the Kehpara MPA and Kehpara Open monitoring stations differed from back- and outer-reef habitats by the presence of relatively high hard coral cover and relatively low cover of macroalgae (Figure 11). Lagoon-reefs of the Kehpara MPA site had a significantly lower mean percent cover of hard coral (36.8±4.5% vs. 65.8±4.3%; $P = 0.003$), and significantly higher mean percent cover of sand (28.4±6.1% vs. 6.0±1.6%; $P = 0.013$), than the lagoon-reefs at the Kehpara Open site. The cover of macroalgae was low (< 5%) at both sites (Figure 11).

Hard coral diversity was slightly higher within the lagoon-reef habitats of the Kehpara MPA site, where a total of 13 types of hard coral were recorded, compared to 12 types observed within the lagoon-reefs of the Kehpara Open site (Figure 11). In terms of cover, *Porites*-massive, *Porites*-rus and *Porites* were the most common hard coral types within the lagoon-reefs of both the Kehpara MPA and Open sites, representing 10.8±2.1%, 9.2±3.0% and 7.8±2.7% of overall cover at the MPA site, and 4.9±1.5%, 24.8±3.4% and 26.4±5.6% of overall cover at the Open site, respectively (Figure 11). The percent cover of bleached corals was low within the Kehpara MPA (0.1±0.1%), while no bleached corals were observed in the lagoon-reef habitats of the Kehpara Open site. The percentage cover of recently dead corals at both sites was low, constituting 0.1±0.1% and 1.5±0.4% of overall mean cover of hard corals at the Kehpara MPA and Open sites, respectively.

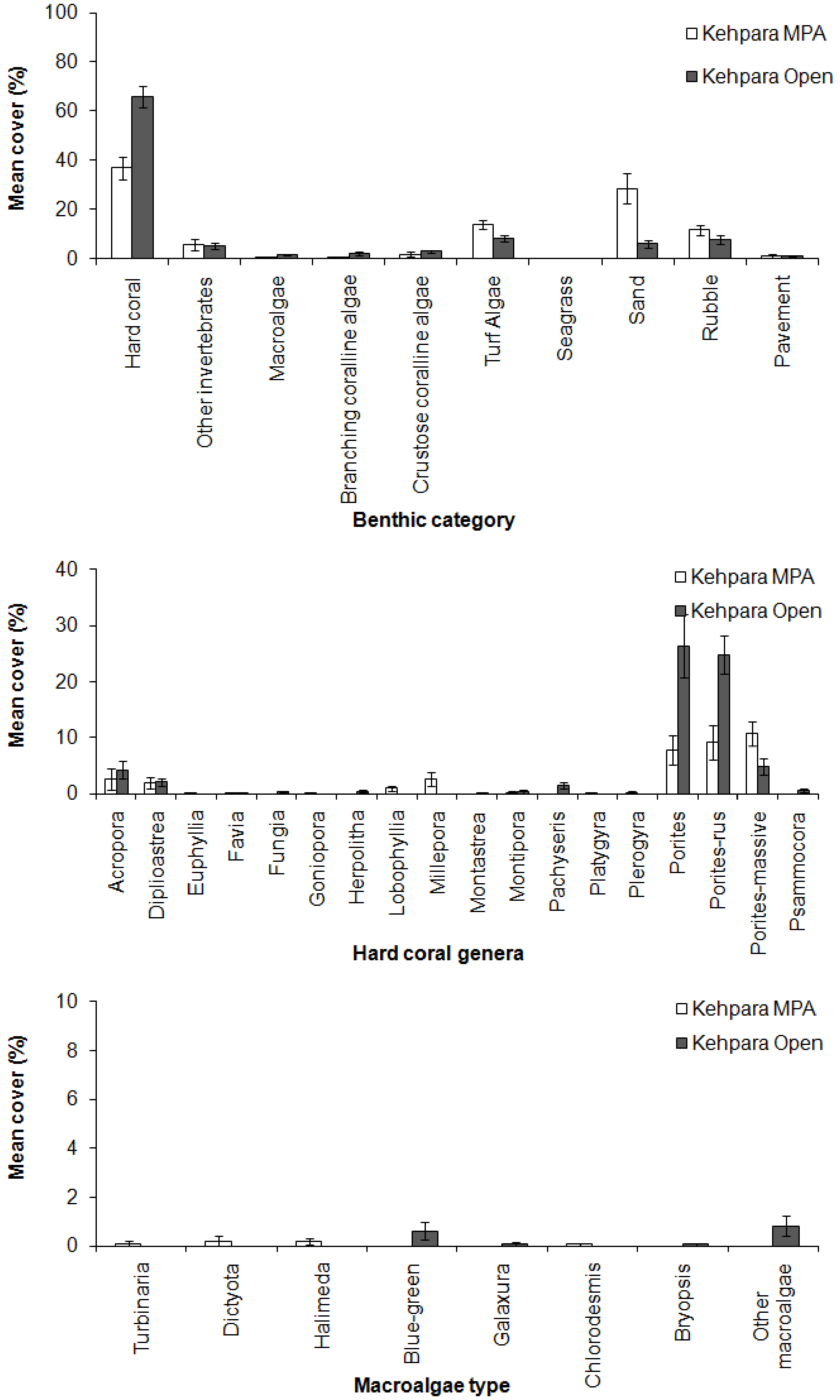

Figure 11 **Mean cover (± SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at lagoon-reef habitats during benthic habitat assessments at Kehpara MPA and Open sites, 2012.**

Outer-reef habitats

Outer-reef habitats of both the Kehpara MPA and Kehpara Open monitoring stations differed from back- and lagoon-reef habitats by the presence of a relatively high percent cover of crustose coralline algae and macroalgae (Figure 9). Outer-reef transects within the Kehpara MPA monitoring stations had a significantly higher mean cover of hard corals ($P = 0.001$) and a significantly lower mean cover of rubble ($P = 0.023$) than those within the Kehpara Open stations (Figure 12). The cover of macroalgae on outer-reef habitats was relatively low, with *Halimeda* the most common macroalgae observed at both sites (Figure 12).

A total of 10 types of hard coral were recorded on the outer-reef habitat of the Kehpara MPA monitoring stations, while 11 types were recorded within the Kehpara Open site (Figure 12). Hard coral cover was significantly higher within the Kehpara MPA compared to the Open site ($P = 0.001$), with hard corals constituting 33.5±3.2% of overall cover within the MPA and 13.6±3.6% of overall cover within the Open site. In terms of cover, *Porites*-massive, *Montipora* and *Porites*-rus were the most common hard coral types within the outer-reefs of the Kehpara MPA, representing 19.2±2.1%, 6.0±1.5% and 5.2±1.5% of overall cover, respectively, while *Porites*-massive and *Platygyra* were the most common corals on the outer-reef of the Kehpara Open site, representing 6.0±1.4% and 3.1±2.1% of overall cover at the Open site, respectively (Figure 12). No bleached coral was observed on the outer-reefs on either site. Similarly, no recently dead corals were observed on the outer-reef at the Kehpara Open site, while the percentage cover of recently dead corals at the MPA site was low, constituting 0.1±0.1% of the overall mean cover of hard corals, respectively.

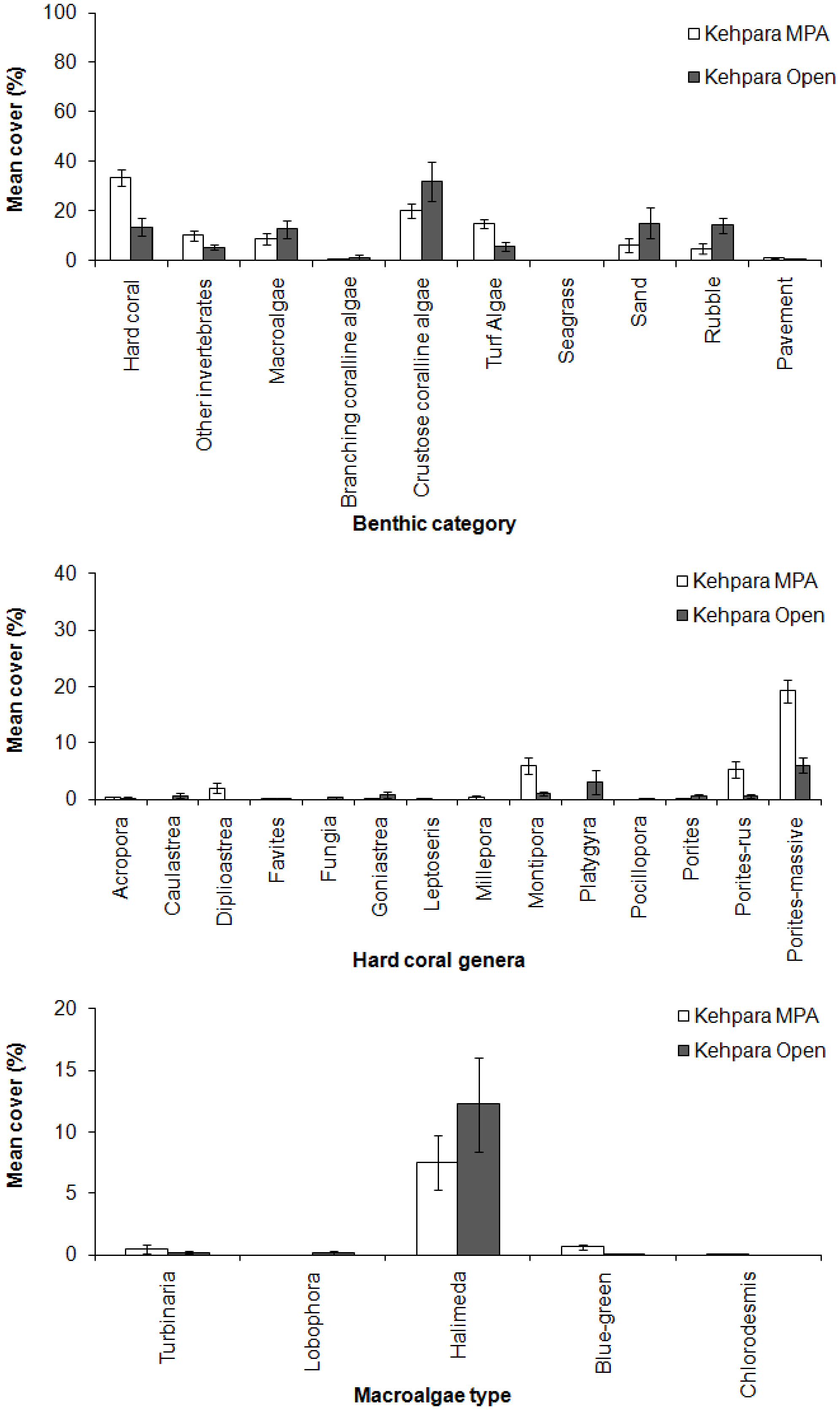

Figure 12 **Mean cover (± SE) of each major benthic category (top), hard coral type (middle) and macroalgae type (bottom) present at outer-reef habitats during benthic habitat assessments at Kehpara MPA and Open sites, 2012.**

5. Finfish surveys

Methods and Materials

Data collection

Finfish surveys

Fish on reef habitats of the Kehpara region were surveyed using distance-sampling underwater visual census (D-UVC) methodology. As per the benthic habitat assessments, three replicate 50 m transects were planned to be surveyed in outer-reef, back-reef and lagoon-reef habitats at each of two stations within the Kehpara MPA and Kehpara Open monitoring sites (Figure 13). Each transect census was completed by two SCUBA divers who recorded the species name, abundance and total length (TL) of all fish observed (Appendix 2). The distance of the fish from the transect line was also recorded. Two distance measurements were recorded for a school of fish belonging to the same species and size: the distance from the transect tape to the nearest individual (D1) and the distance from the transect tape to the furthest individual (D2), while for individual fish only one distance was recorded (D1) (Figure 13). Regular review of identification books and cross-checks between divers after the dive ensured that accurate and consistent data were collected.

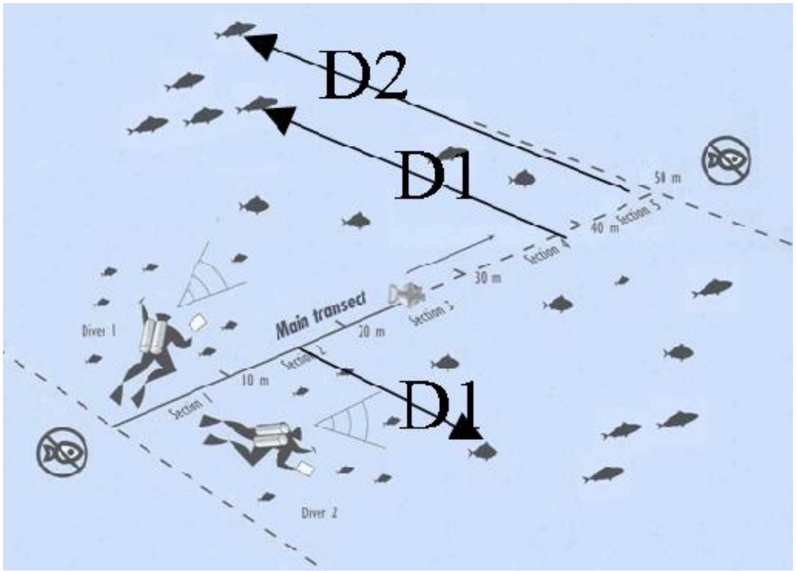

Figure 13 Diagram portraying the D-UVC method.

Habitats supporting finfish

Habitats supporting finfish were documented after the finfish survey using a modified version of the medium scale approach of Clua et al (2006). This component uses a separate form (Appendix 3) from that of the finfish assessment, 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 meter transect.

The substrate types were grouped into the following six categories:

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

Data Analysis

Finfish surveys

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

1) richness – the number of families, genera and species counted in D-UVC transects;
2) diversity – total number of observed species per habitat and site divided by the number of transects conducted in each individual habitat and site;
3) community structure – overall mean density and biomass compared among habitats and sites;
4) mean density (fish/m^2) – estimated from fish abundance in D-UVC, calculated at a family, trophic group and individual species level;
5) mean biomass (g/m^2) – obtained by combining densities, size, and weight–size ratios, calculated at a family, trophic group and individual species level;
6) weighted mean size (cm total length) – direct record of fish size by D-UVC, calculated at a family, trophic group and individual species level;
7) weighted mean size ratio (%) – the ratio between fish size and maximum reported size of the species, calculated at a family, trophic group and individual species

level. This ratio can range from nearly zero when fish are very small to 100% when a given fish has reached the maximum size reported for the species;

8) trophic structure – density, size and biomass of trophic groups compared among habitats and sites. Trophic groups were based on accounts from published literature. Each species was classified into one of five broad trophic groups: 1) carnivore (feed predominantly on zoobenthos), 2) herbivore (feed predominantly on plants and algae), 3) piscivore (feed predominantly on nekton, other fish and cephalopods), 4) planktivore (feed predominantly on zooplankton), and 5) detritivore (feeding predominantly on detritus. More details on fish diet can be found online at:
http://www.fishbase.org/manual/english/FishbaseThe_FOOD_ITEMS_Table.htm.

To account for differences in visibility among sites and habitats, only fish recorded within five metres of the transect line were included in the analysis. While all observed finfish species were recorded, including both commercial and non-commercial species, for the purposes of this report results of analyses of density, biomass, size, size ratio, and trophic structure are presented based on data for 18 selected families, namely Acanthuridae, Balistidae, Chaetodontidae, Ephippidae, Haemulidae, Holocentridae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Mullidae, Nemipteridae, Pomacanthidae, Pomacentridae, Scaridae, Serranidae, Siganidae and Zanclidae. These families were selected as they comprise the dominant finfish families of tropical reefs (and are thus most likely to indicate changes where they occur), and constitute species with a wide variety of trophic and habitat requirements. Other families abundant on reefs, such as Blennidae and Gobiidae, were not analysed due to the difficulties in enumerating these cryptic species.

Given the baseline nature of this report, relationships between environmental parameters and finfish resources have not been fully explored. Rather, the finfish resources are described and compared amongst habitats within sites and between the Kehpara MPA and Kehpara Open sites to explore functioning of the MPA. To examine differences among sites and reef environments, habitat category data and density, biomass, mean size and mean size ratio data of each of the 18 indicator finfish families and five trophic groups in each individual transect were square-root transformed to reduce heterogeneity of variances and analysed by two-way analysis of variance (ANOVA) using Statistica 7.1, with site (Kehpara MPA and Kehpara Open) and habitat (back-reef, lagoon-reef, and outer-reef) as fixed factors in the analysis. A square-root transformation was used as preliminary analyses revealed it provided the greatest homogeneity of variances as compared to other transformation methods (e.g. log(x+1), 4^{th}-root). While Cochran's C tests revealed that homogeneity of data was not always achieved, results of the ANOVA were still considered valid as the design was balanced (Underwood 1997). Tukey-Kramer post-hoc pairwise tests were used to identify specific differences between factors at $P = 0.05$.

Results

Coverage

A total of 36 D-UVC transects were completed during the baseline monitoring program, with three replicate transects conducted in each lagoon-, back- and outer-reef monitoring station (Figure 14; Table 9). A list of GPS coordinates for each transect is presented as Appendix 4.

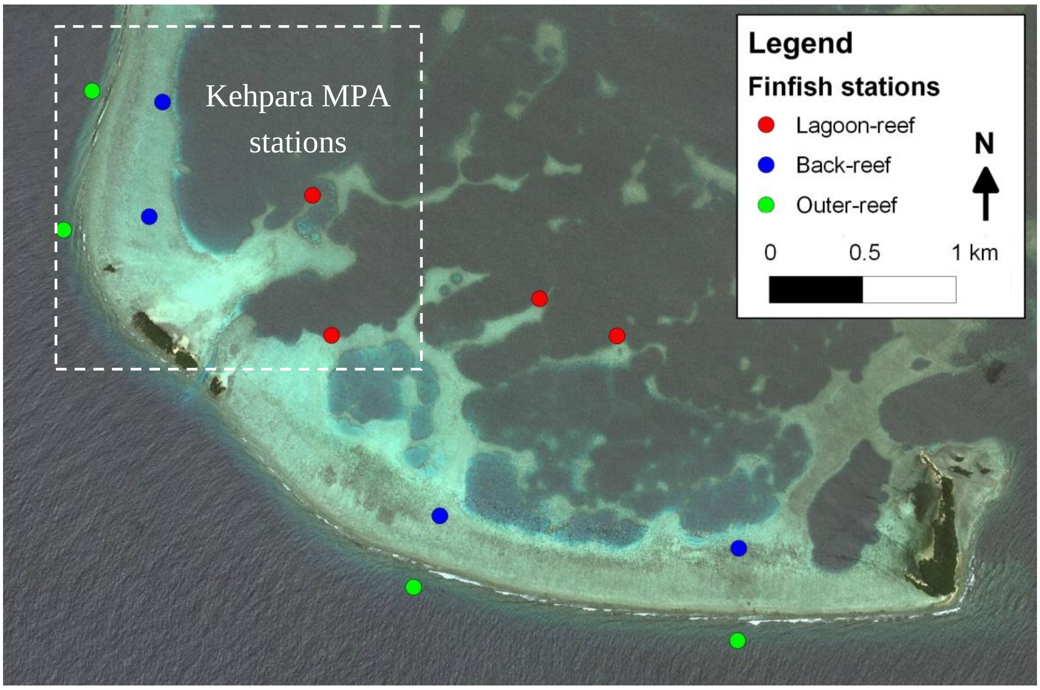

Figure 14 Location of finfish assessment stations established in the Kehpara region, 2012.

Table 9 Summary of distance underwater visual census (D-UVC) transects among habitats for the Kehpara MPA and Kehpara Open monitoring sites.

Site	Station	Habitat	No. of transects
Kehpara MPA	Kehpara MPA 1	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3
	Kehpara MPA 2	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3
Kehpara Open	Kehpara Open 1	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3
	Kehpara Open 2	Back-reef	3
		Lagoon-reef	3
		Outer-reef	3

Finfish Surveys

Overall

A total of 25 families, 68 genera, 176 species and 15,441 individual fish were recorded from the 36 transects. Of these, 24 families, 63 genera, 144 species and 6,942 individual fish were recorded from the Kehpara MPA monitoring stations, while 21 families, 54 genera, 132 species and 8,499 individual fish were recorded from the Kehpara Open monitoring stations (see Appendices 5–8 for a full list of families species recorded at both Kehpara MPA and Kehpara Open sites). Finfish diversity was higher within the MPA than the Open site for all habitats (Table 10). Overall mean density was higher in the Kehpara Open sites than the Kehpara MPA sites for back- and lagoon-reef habitats, but showed no difference between Kehpara MPA and Kehpara Open sites for outer-reef habitats (Figure 15). Within the Kehpara MPA, overall mean density was higher within the outer-reef compared to the lagoon- or back-reef habitats. Within the Kehpara Open stations, no difference in mean density was apparent among habitats (Figure 15). In terms of overall mean biomass, no difference was observed among the Kehpara MPA and Kehpara Open sites for lagoon- or outer-reef habitats, while mean biomass within the back-reef habitats at Kehpara MPA stations appeared slightly higher than those within the Kehpara Open stations. No difference in mean biomass was observed among any of the three habitats (back-, lagoon- and outer-reefs) within either the Kehpara MPA or Kehpara Open sites (Figure 16).

Table 10 Total number of families, genera and species, and diversity of finfish observed at back-, lagoon- and outer-reef habitats of Kehpara MPA and Kehpara Open monitoring stations, 2012.

Parameter	Back-reef		Lagoon-reef		Outer-reef	
	Kehpara MPA	Kehpara Open	Kehpara MPA	Kehpara Open	Kehpara MPA	Kehpara Open
No. of families	16	10	22	17	21	19
No. of genera	36	25	50	42	56	43
No. of species	78	49	94	82	120	94
Diversity	13.0	8.2	15.7	13.7	20	15.7

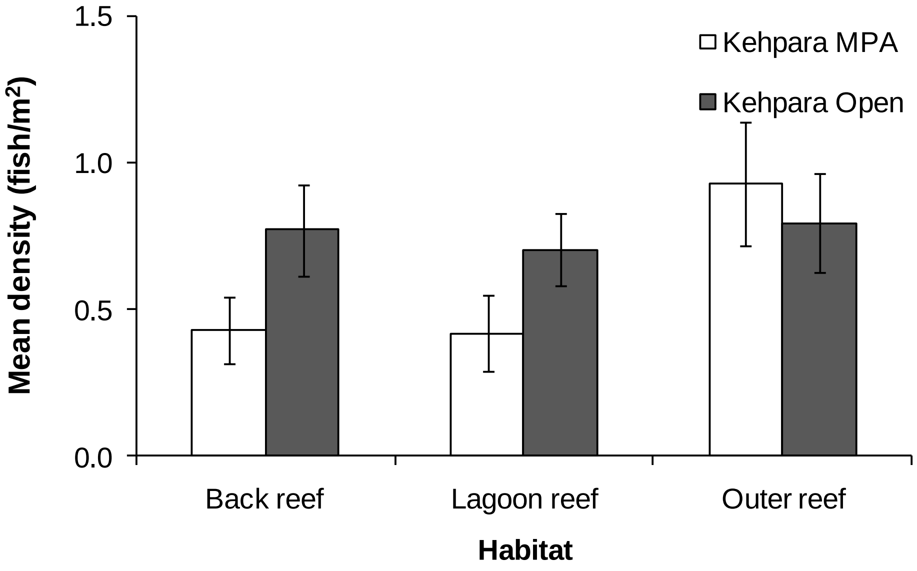

Figure 15 **Overall mean density of finfish (± SE) within back-, lagoon and outer-reef habitats within the Kehpara MPA and Kehpara Open monitoring sites, 2012.**

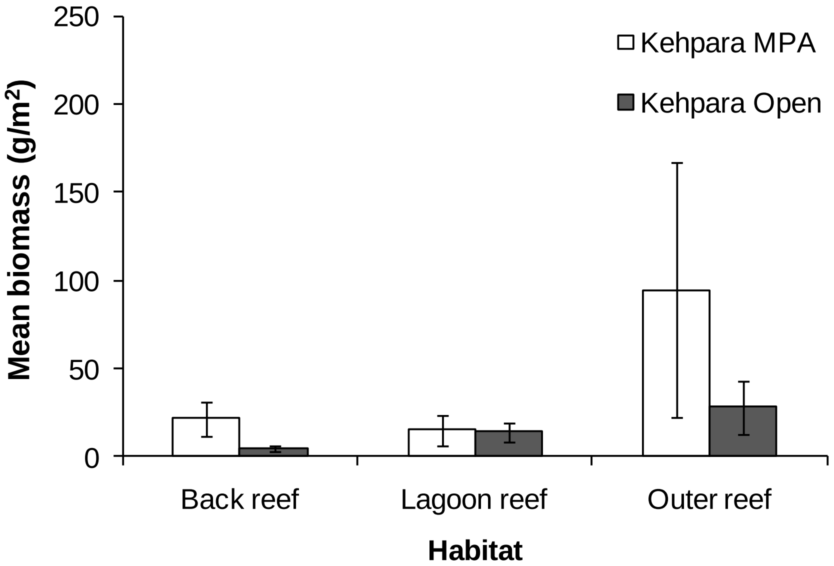

Figure 16 **Overall mean biomass of finfish (± SE) within back-, lagoon and outer-reef habitats within the Kehpara MPA and Kehpara Open monitoring sites, 2012.**

Back-reef habitats

Habitats supporting finfish

Sand was the dominant substrate type for the back-reefs of both the Kehpara MPA and Open sites (Figure 17). Live hard coral cover was moderate at both sites, constituting 33.2±8.4% and 27.1±8.5% of overall cover at the MPA and Open sites, respectively. Of the corals present, massives and sub-massives were the most common growth forms present at the Kehpara MPA sites, while branching coral was the most common growth form at the Kehpara Open site. No significant differences were observed in the depth, topography, or complexity of the D-UVC transects among on the back-reefs of the MPA or Open sites ($P = 0.05$). Of the substrate categories, only the cover of branching corals differed among sites ($P < 0.001$), with back-reefs of the Kehpara Open site having a greater percent cover of branching corals compared to those within the MPA (Figure 17).

Finfish

A total of 16 families, 36 genera, 78 species and 1,583 individuals were recorded from back-reef habitats of the Kehpara MPA monitoring stations, while 10 families, 25 genera, 49 species and 2,769 individual fishes were recorded from back-reef habitats of the Kehpara Open monitoring stations (Table 10). For the 18 selected 'indicator' families, mean density within the back-reef environments of the Kehpara MPA stations was dominated by the family Acanthuridae, with 0.208±0.034 fish/m^2 (49.3% of the mean observed density). Pomacentridae was the dominant family in terms of density for the Kehpara Open stations, with 0.645±0.104 fish/m^2, representing 83.6% of the mean observed density. For back-reef habitats, mean densities of Acanthuridae ($P < 0.001$) and Mullidae ($P = 0.029$) were significantly higher at Kehpara MPA stations than Kehpara Open stations (Figure 18). In contrast, the mean density of Pomacentridae was significantly higher in Kehpara Open stations than stations within the Kehpara MPA ($P < 0.001$) (Figure 18). The individual species observed in the highest densities within the back-reef habitats of Kehpara MPA site were the acanthurids *Ctenochaetus striatus*, *Acanthurus nigroris* and *Acanthurus nigrofuscus*, the pomacentrid *Stegastes nigricans* and the scarid *Chlorurus sordidus* (Table 11). The species observed in the highest densities within the back-reef habitats of the Kehpara Open site were the pomacentrids *Dascyllus aruanus*, *Stegastes nigricans*, *Dascyllus melanurus*, *Chromis viridis* and *Chrysiptera unimaculata* (Table 11). A full list of densities by family and individual species can be found in Appendices 5–8).

For back-reef habitats of the Kehpara MPA stations, members of the Acanthuridae had the greatest biomass with 14.620±6.351 g/m^2, comprising 66.9% of the mean observed biomass at this site, followed by members of the families Scaridae (3.089±1.009 g/m^2, 14.2% of mean biomass) and Labridae (0.797±0.160 g/m^2, 3.6% of mean observed biomass). In accordance with their high density, members of the Pomacentridae had the greatest biomass in back-reef habitats for the Kehpara Open monitoring stations

(3.093±1.013 g/m^2, representing 65.2% of the mean observed biomass. Consistent with their greater density, the observed mean biomass of Acanthuridae was significantly higher within Kehpara MPA stations than Kehpara Open stations (P = 0.006), while, mean biomass of Pomacentridae was significantly higher in Kehpara Open stations than stations within the Kehpara MPA (P = 0.005) (Figure 18). The individual species with the greatest biomass within the back-reef habitats of Kehpara MPA sites were the acanthurids *Ctenochaetus striatus*, *Acanthurus nigrofuscus*, *Acanthurus gahhm*, and *Acanthurus nigroris* and the scarid *Chlorurus sordidus* (Table 12). Consistent with their high densities, the species with the greatest biomass within the back-reef habitats of Kehpara Open sites were the pomacentrids *Dascyllus aruanus*, *Stegastes nigricans*, *Dascyllus melanurus*, *Dascyllus trimaculatus* and *Chrysiptera unimaculata* (Table 12). A full list of biomass by family and individual species can be found in Appendices 5–8.

Few differences were observed in the mean size and mean size ratio (a function of average maximum size) among sites, with only the mean size and mean size ratio of Acanthuridae being significantly larger within the Kehpara MPA stations than the Kehpara Open stations (P = 0.0132 and P = 0.009, respectively) (Figure 18).

In terms of trophic group, herbivores (0.308±0.036 fish/m^2) occurred in the greatest mean density within the back-reef habitats of the Kehpara MPA, followed by carnivores (0.092±0.013 fish/m^2). Planktivores (0.463±0.061 fish/m^2) and herbivores (0.225±0.069 fish/m^2) were the dominant trophic groups in terms of density within the Kehpara Open stations, resulting from the high densities of pomacentrids observed at this site. The density of planktivores was significantly greater in Kehpara Open transects than Kehpara MPA transects ($P < 0.001$) (Figure 19). In terms of mean biomass, herbivores (18.316±7.080 g/m^2) and carnivores (3.039±0.887 g/m^2) were the dominant trophic groups within the Kehpara MPA transects, while planktivores (2.122±0.856 g/m^2) had the greatest biomass within the Kehpara Open sites. The mean biomass of herbivores was significantly higher in the Kehpara MPA compared to the Kehpara Open site (P = 0.013) (Figure 19). Similarly, the mean size of herbivores was higher in the Kehpara MPA compared to the Kehpara Open stations (P = 0.004). The size ratio of all trophic groups was low (typically below 50% of average maximum values) for both the Kehpara MPA and Kehpara Open stations (Figure 19).

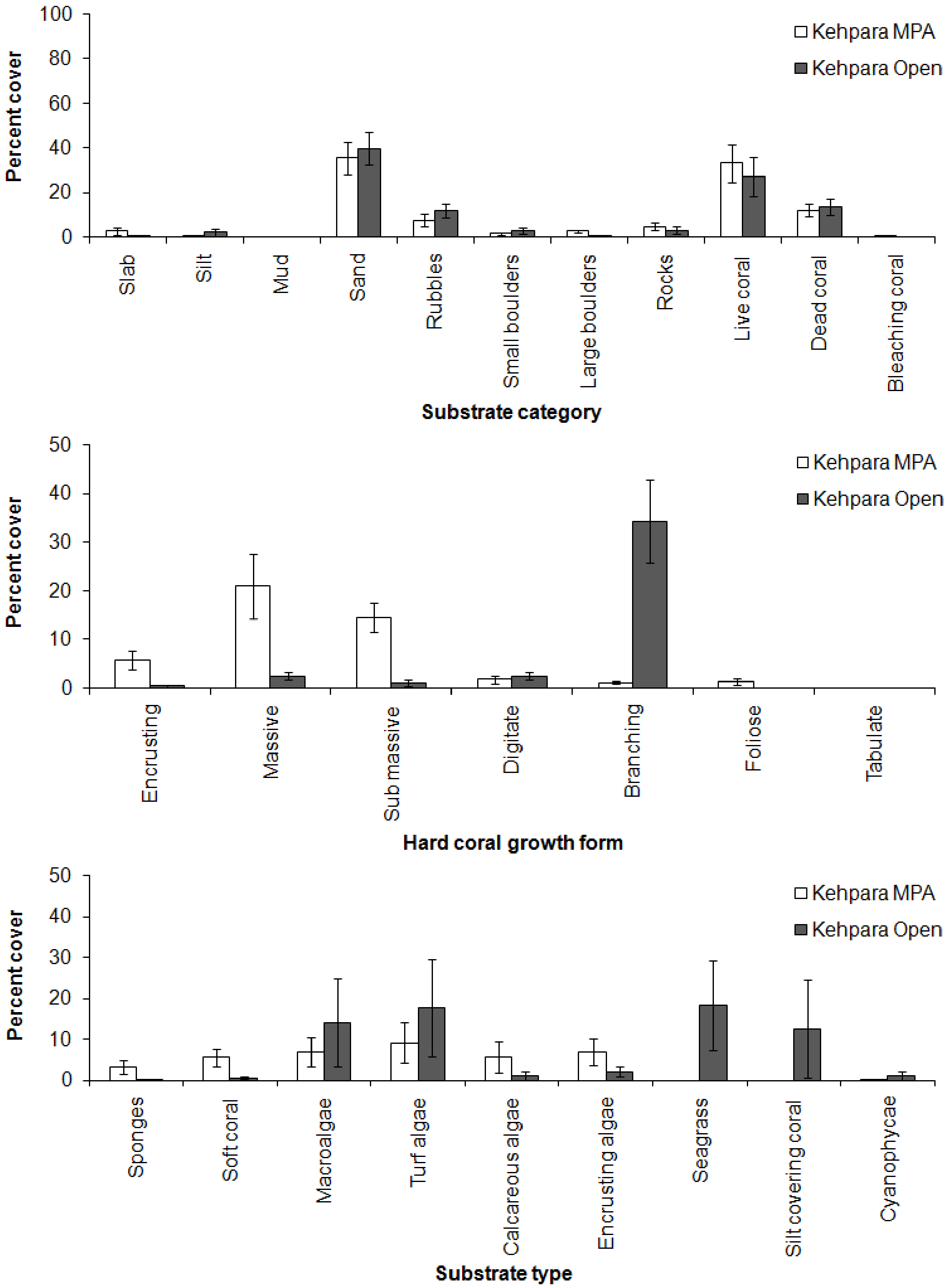

Figure 17 **Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate type (bottom) present at back-reef habitats during finfish surveys at the Kehpara MPA and Kehpara Open monitoring sites, 2012.**

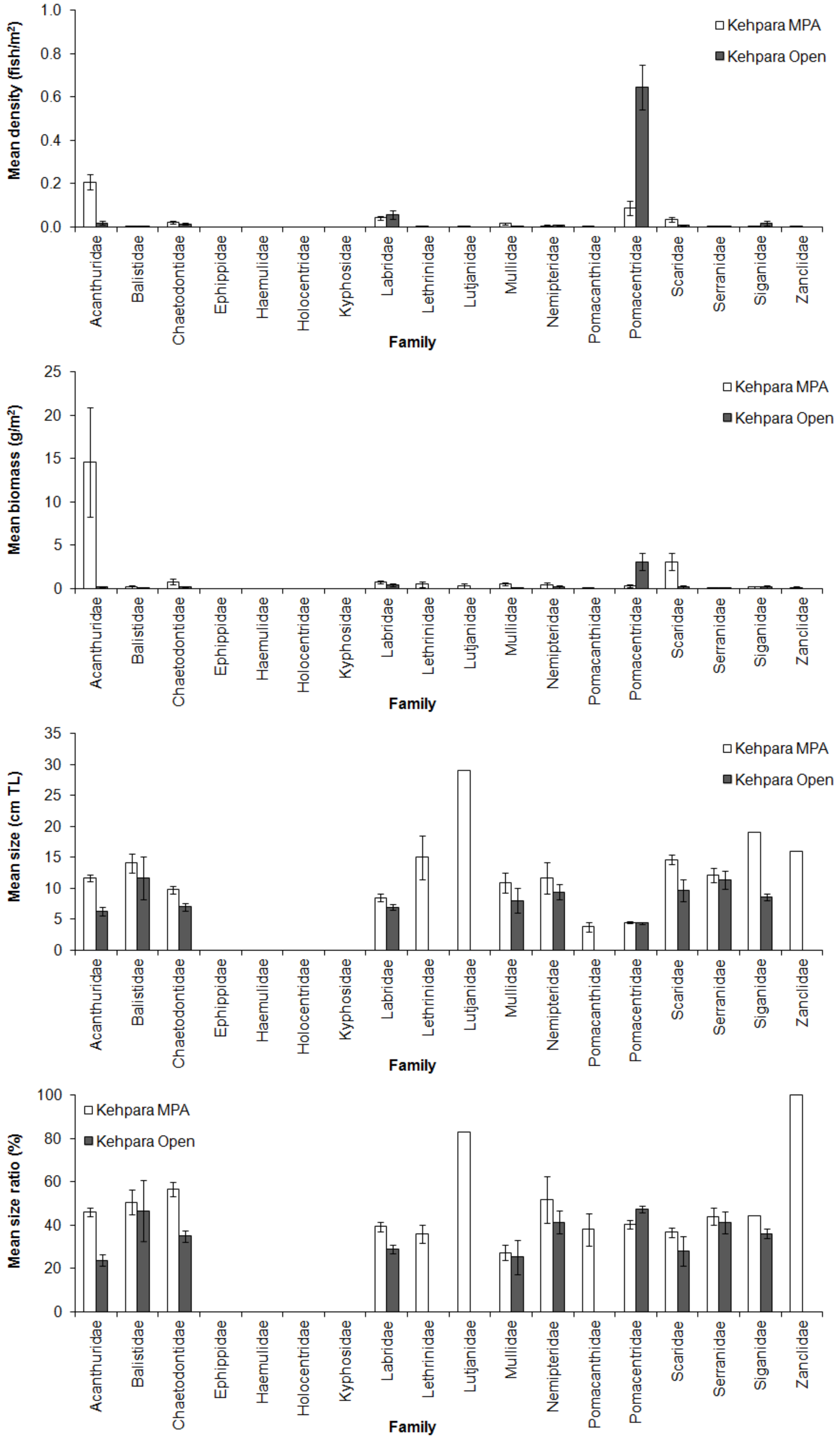

Figure 18 **Profile of finfish indicator families in back-reef habitats of the Kehpara MPA and Kehpara Open monitoring sites, 2012.**

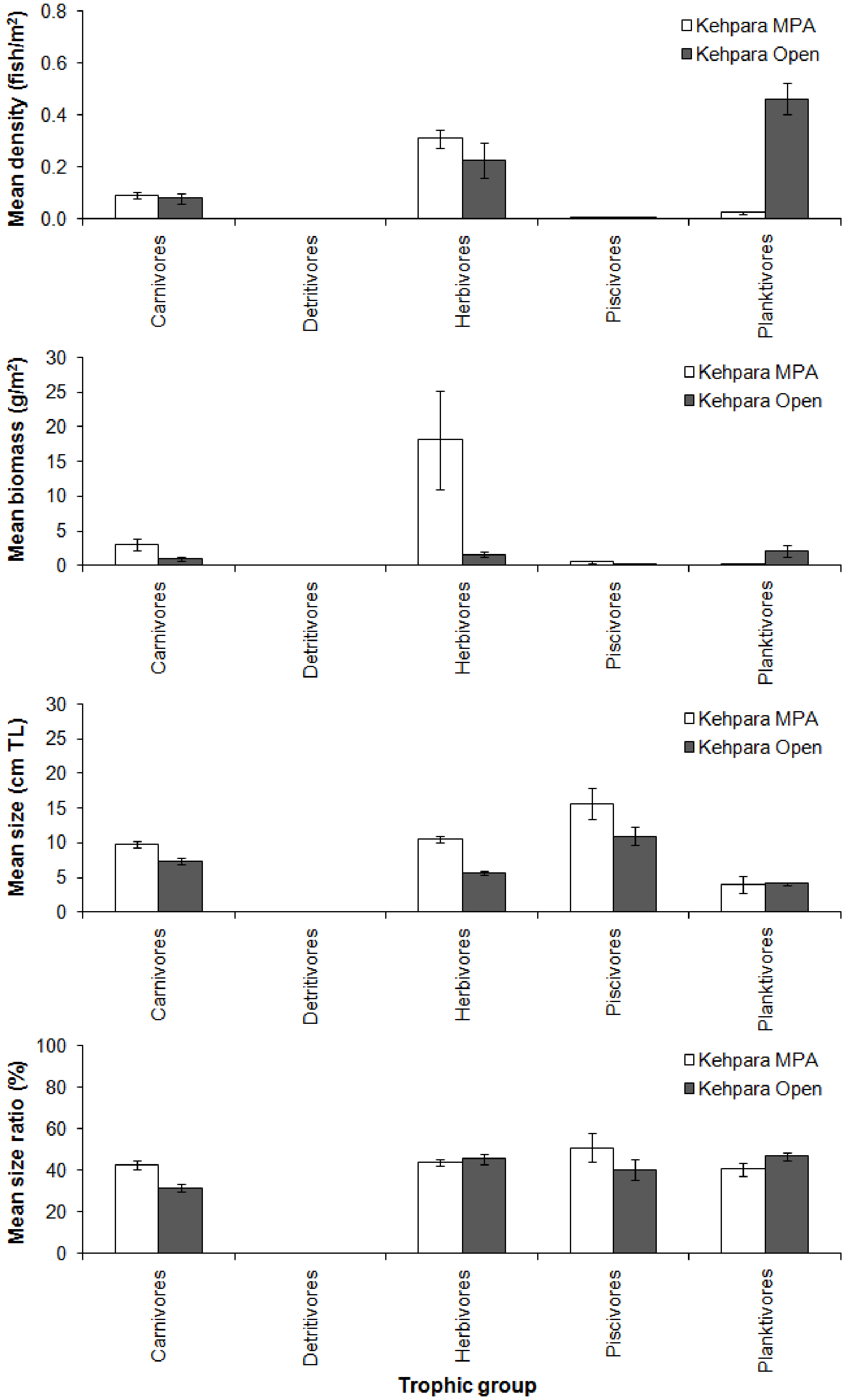

Figure 19 **Profile of finfish by trophic level in back-reef habitats of the Kehpara MPA and Kehpara Open monitoring sites, 2012.**

Table 11 Finfish species observed in the highest densities in back-reef habitats of the Kehpara MPA and Kehpara Open monitoring sites, 2012. See Appendix 7 and 8 for a full list of densities of individual fish species observed at each monitoring site.

Site	Species	Family	Density (fish/m^2±SE)
Kehpara MPA	*Ctenochaetus striatus*	Acanthuridae	0.099±0.042
	Acanthurus nigroris	Acanthuridae	0.053±0.039
	Stegastes nigricans	Pomacentridae	0.038±0.023
	Acanthurus nigrofuscus	Acanthuridae	0.028±0.015
	Chlorurus sordidus	Scaridae	0.027±0.011
Kehpara Open	*Dascyllus aruanus*	Pomacentridae	0.325±0.043
	Stegastes nigricans	Pomacentridae	0.079±0.037
	Dascyllus melanurus	Pomacentridae	0.064±0.036
	Chromis viridis	Pomacentridae	0.042±0.018
	Chrysiptera unimaculata	Pomacentridae	0.036±0.028

Table 12 Finfish species with the highest biomass in back-reef habitats of the Kehpara MPA and Kehpara Open monitoring sites, 2012. See Appendix 7 and 8 for a full list of biomass of individual fish species observed at each monitoring site.

Site	Species	Family	Biomass (g/m^2±SE)
Kehpara MPA	*Ctenochaetus striatus*	Acanthuridae	9.600±6.767
	Acanthurus nigrofuscus	Acanthuridae	2.224±1.621
	Chlorurus sordidus	Scaridae	2.150±0.598
	Acanthurus gahhm	Acanthuridae	0.827±0.693
	Acanthurus nigroris	Acanthuridae	0.723±0.466
Kehpara Open	*Dascyllus aruanus*	Pomacentridae	1.163±0.493
	Stegastes nigricans	Pomacentridae	0.552±0.324
	Dascyllus melanurus	Pomacentridae	0.461±0.387
	Dascyllus trimaculatus	Pomacentridae	0.397±0.321
	Chrysiptera unimaculata	Pomacentridae	0.237±0.216

Lagoon-reef habitats

Habitats supporting finfish

Lagoon-reefs habitats of both Kehpara MPA and Kehpara Open sites were dominated by hard corals (both live and dead) and sand (Figure 20). Live hard coral cover was relatively high at both sites, constituting 42.1±7.2% and 66.5±5.7% of overall cover of the lagoon-reef habitats at the MPA and Open sites, respectively. Of the corals present, massives, sub-massives and branching corals were the most common growth forms within the Kehpara MPA, while branching and sub-massives were the most common growth forms at the Kehpara Open site (Figure 20). No significant differences were observed in the depth, topography, or complexity of the D-UVC transects among the lagoon-reefs of the Kehpara Open and Kehpara MPA sites ($P = 0.05$). Of the major substrate categories, only the cover of large boulders ($P = 0.036$) differed significantly among sites, with lagoon-reefs at Kehpara MPA having a greater percent cover compared to Kehpara Open sites (Figure 20).

Finfish

A total of 22 families, 50 genera, 94 species and 1,735 individual fish were recorded from lagoon-reef habitats of the Kehpara MPA monitoring stations, while 17 families, 42 genera, 82 species and 2,554 individuals were recorded from lagoon-reef habitats of the Kehpara Open monitoring stations (Table 10). Of the 18 selected 'indicator' families, the family Pomacentridae occurred in the greatest mean density within the lagoon-reef environments of both Kehpara MPA and Kehpara Open, followed to a lesser extent by members of the families Acanthuridae, Labridae, Scaridae and Chaetodontidae (Figure 21). For the Kehpara MPA stations, these families comprised 54.0%, 14.7%, 8.3%, 5.8% and 5.5% of the mean density, respectively, while at the Kehpara Open stations these families comprised 73.5%, 7.6%, 5.2%, 4.6% and 3.9% of the mean density, respectively. The mean density of Pomacentridae was significantly greater within the Kehpara Open monitoring stations than the Kehpara MPA ($P = 0.033$) (Figure 21). The species observed in the highest densities within the lagoon-reef habitats of Kehpara MPA sites were the pomacentrids *Amblyglyphidodon curacao*, *Chromis viridis* and *Dascyllus aruanus*, the acanthurid *Ctenochaetus striatus* and the scarid *Chlorurus sordidus* (Table 13). Similarly, the species observed in the highest densities within the lagoon-reef habitats of Kehpara Open sites were the pomacentrids *Amblyglyphidodon curacao*, *Chromis viridis* and *Abudefduf vaigiensis*, the scarid *Chlorurus sordidus* and the acanthurid *Ctenochaetus striatus* (Table 13). A full list of densities by family and individual species can be found in Appendices 5–8.

Considerable variability in mean biomass was observed for most indicator families within both the Kehpara MPA and Kehpara Open monitoring stations, evidenced by the large standard error bars in Figure 20. For lagoon-reef habitats of the Kehpara MPA stations, members of the Acanthuridae had the greatest biomass (3.843±1.187 g/m^2), comprising

25.3% of the mean observed biomass, followed by members of the families Scaridae (2.390±1.724 g/m^2, 15.7% of mean observed biomass), Mullidae (1.722±1.025 g/m^2, 11.3% of mean observed biomass), Labridae (1.714±0.922 g/m^2, 11.3% of mean observed biomass), Chaetodontidae (1.537±0.974 g/m^2, 10.1% of total observed biomass) and Pomacentridae (0.716±0.196 g/m^2, 4.7% of mean observed biomass). Similarly, members of the Acanthuridae had the greatest biomass in lagoon-reef habitats for the Kehpara Open monitoring stations (3.270±0.997 g/m^2), comprising 23.4% of mean observed biomass, followed by members of the families Pomacentridae (2.913±1.243 g/m^2, 20.8% of mean observed biomass), Scaridae (2.418±0.599 g/m^2, 17.3% of mean observed biomass), Labridae (1.505±0.431 g/m^2, 10.8% of mean observed biomass), and Chaetodontidae (1.344±0.335 g/m^2, 9.6% of mean observed biomass). No significant differences in mean biomass were evident for any of the 18 indicator families among lagoon-reef habitats of the Kehpara MPA and Kehpara Open stations (Figure 21). The species that had the greatest biomass within the lagoon-reef habitats of Kehpara MPA sites were the acanthurid *Ctenochaetus striatus*, the scarid *Chlorurus sordidus*, the labrid *Cheilinus fasciatus*, the mullid *Parupeneus bifasciatus* and the pomacentrid *Amblyglyphidodon curacao* (Table 14). The species with the greatest biomass within the lagoon-reef habitats of Kehpara Open sites were the pomacentrid *Amblyglyphidodon curacao*, the acanthurids *Ctenochaetus striatus* and *Acanthurus nigrofuscus*, the scarid *Chlorurus sordidus* and the zanclid *Zanclus cornutus* (Table 14). A full list of biomass by family and individual species can be found in Appendices 5–8.

No significant difference was observed in mean size or mean size ratio of any of the 18 indicator families among the Kehpara MPA and Kehpara Open sites.

In terms of trophic group, planktivores occurred in the greatest mean density within the lagoon-reef habitats of both the Kehpara MPA and Kehpara Open monitoring sites, with 0.211±0.051 fish/m^2 and 0.514±0.076 fish/m^2, respectively. The density of planktivores was significantly greater in Kehpara Open transects than Kehpara MPA transects (P = 0.009), while no difference was observed in density of carnivores, herbivores or piscivores among the sites (Figure 22). Herbivores (6.678±2.810 g/m^2) and carnivores (6.160±3.370 g/m^2) had the greatest mean biomass within the Kehpara MPA transects, while herbivores (6.454±1.217 g/m^2), carnivores (3.852±0.782 g/m^2) and planktivores (3.069±1.393 g/m^2) had the greatest mean biomass within the Kehpara Open site. No significant differences in mean biomass, mean size or mean size ratio were observed among any trophic group among sites. As with back-reef habitats, the mean size ratio of all trophic groups was low (typically below 50% of average maximum values) for both the Kehpara MPA and Kehpara Open stations (Figure 22).

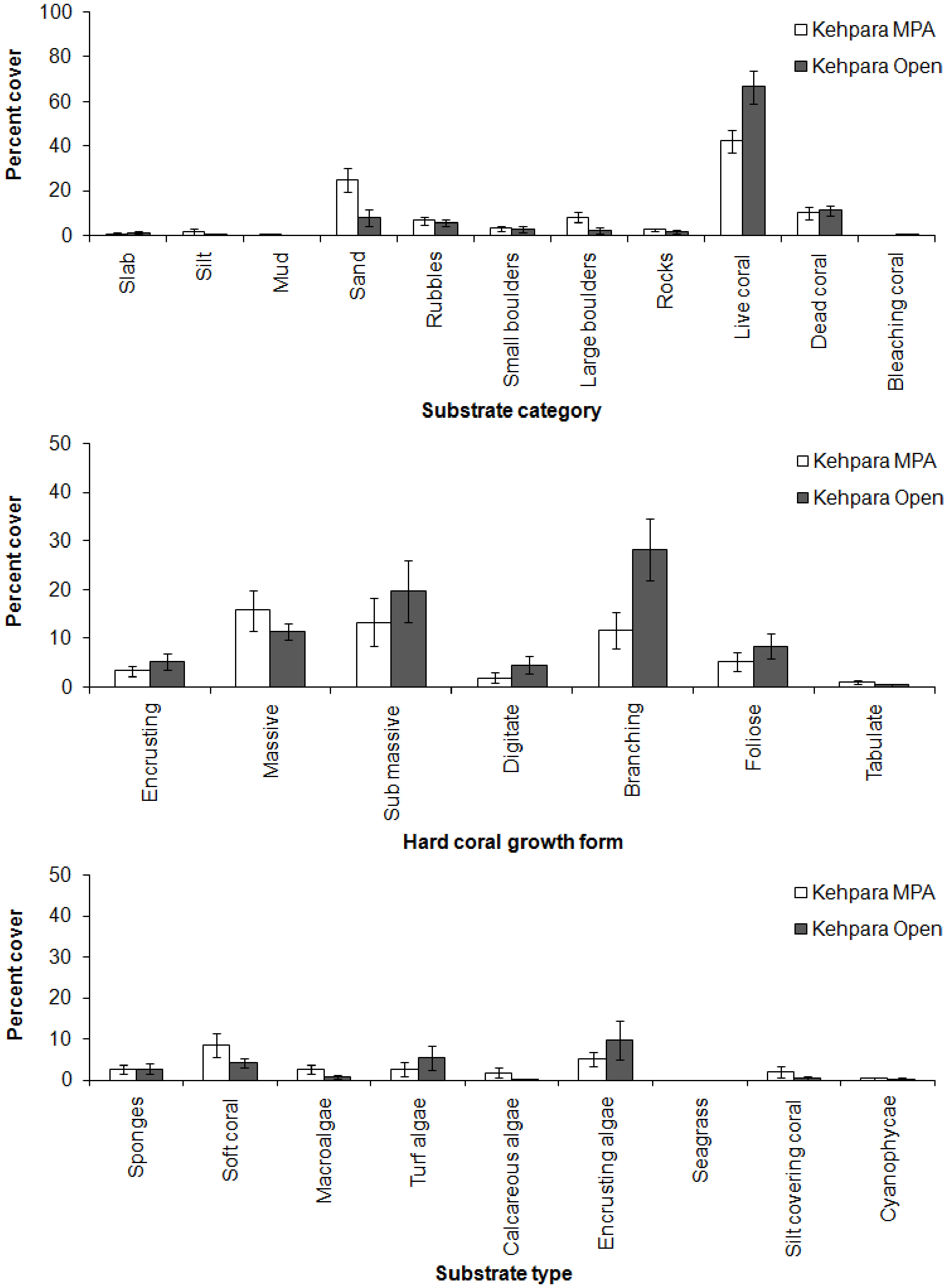

Figure 20 **Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate type (bottom) present at lagoon-reef habitats during finfish surveys at the Kehpara MPA and Kehpara Open monitoring sites, 2012.**

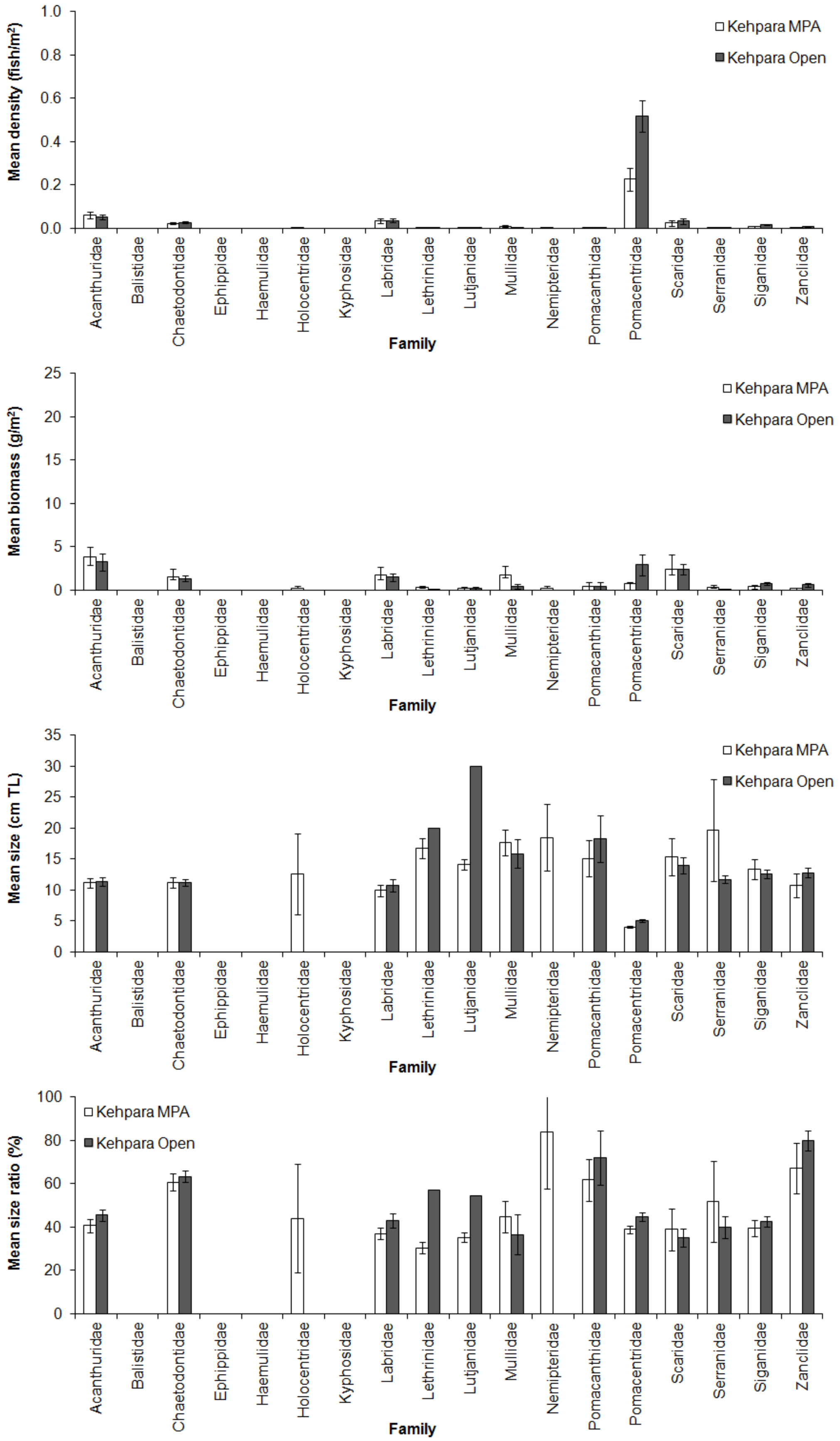

Figure 21 **Profile of finfish indicator families in lagoon-reef habitats of the Kehpara MPA and Kehpara Open monitoring sites, 2012.**

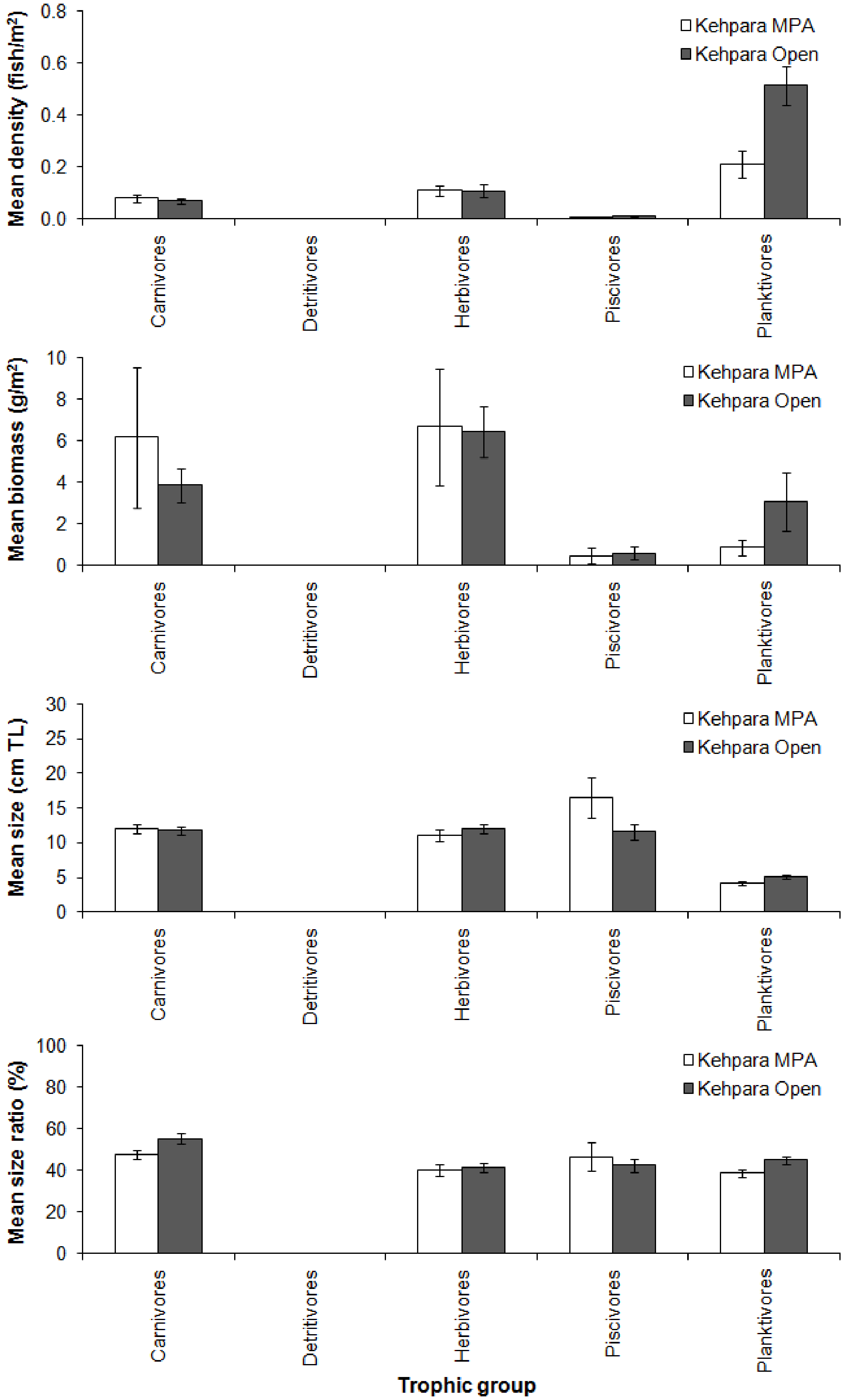

Figure 22 **Profile of finfish by trophic level in lagoon-reef habitats of the Kehpara MPA and Kehpara Open monitoring sites, 2012.**

Table 13 Finfish species observed in highest densities in lagoon-reef habitats of the Kehpara MPA and Kehpara Open monitoring sites, 2012. See Appendix 7 and 8 for a full list of densities of individual fish species observed at each monitoring site.

Site	Species	Family	Density (fish/m^2±SE)
Kehpara MPA	*Amblyglyphidodon curacao*	Pomacentridae	0.132±0.018
	Chromis viridis	Pomacentridae	0.029±0.021
	Ctenochaetus striatus	Acanthuridae	0.027±0.012
	Dascyllus aruanus	Pomacentridae	0.026±0.020
	Chlorurus sordidus	Scaridae	0.021±0.012
Kehpara Open	*Amblyglyphidodon curacao*	Pomacentridae	0.355±0.073
	Chromis viridis	Pomacentridae	0.063±0.026
	Abudefduf vaigiensis	Pomacentridae	0.045±0.029
	Chlorurus sordidus	Scaridae	0.024±0.013
	Ctenochaetus striatus	Acanthuridae	0.024±0.012

Table 14 Finfish species with the highest biomass in lagoon-reef habitats of the Kehpara MPA and Kehpara Open monitoring sites, 2012. See Appendix 7 and 8 for a full list of biomass of individual fish species observed at each monitoring site.

Site	Species	Family	Biomass (g/m^2±SE)
Kehpara MPA	*Ctenochaetus striatus*	Acanthuridae	2.388±1.422
	Chlorurus sordidus	Scaridae	1.755±1.372
	Cheilinus fasciatus	Labridae	1.276±0.676
	Parupeneus bifasciatus	Mullidae	0.731±0.684
	Amblyglyphidodon curacao	Pomacentridae	0.533±0.201
Kehpara Open	*Amblyglyphidodon curacao*	Pomacentridae	1.855±0.843
	Ctenochaetus striatus	Acanthuridae	1.408±0.576
	Chlorurus sordidus	Scaridae	1.374±0.637
	Zanclus cornutus	Zanclidae	0.597±0.210
	Acanthurus nigrofuscus	Acanthuridae	0.539±0.369

Outer-reef habitats

Habitats supporting finfish

Of the three habitat types, outer-reef habitats had the greatest mean percent cover of hard substrate (comprised of slab and hard corals), and consequently the lowest percent of soft substrate. Live hard coral cover was relatively high at both sites, representing 60.3±5.0% and 37.6±8.5% of overall cover at Kehpara MPA and Kehpara Open sites, respectively (Figure 23). Of the corals present, encrusting, massive and sub-massive growth forms were the most common growth forms on the outer-reefs of both sites (Figure 23). No significant differences were observed in the depth, topography, or complexity of the D-UVC transects among the outer-reefs of the MPA or Open sites (P = 0.05). Of the habitat categories and substrate types, only the cover of slab (P = 0.022) differed significantly among outer-reef habitats, with outer-reefs at Kehpara Open having a slightly higher cover of slab than those at the MPA (Figure 23).

Finfish

Outer-reef habitats supported the greatest diversity of finfish, with 21 families, 56 genera, 120 species and 3,624 individual fishes recorded from outer-reef habitats of the Kehpara MPA monitoring stations, while 19 families, 43 genera, 94 species and 3,176 individual fishes were recorded from outer-reef habitats of the Kehpara Open monitoring stations (Table 10). Consistent with lagoon- and back-reef habitats, the family Pomacentridae occurred in the greatest mean density within the outer-reef environments of both Kehpara MPA and Kehpara Open sites, followed to a lesser extent by members of the families Acanthuridae, Chaetodontidae, Labridae and Scaridae (Figure 24). The mean density of Mullidae was significantly higher in outer-reef habitats of the Kehpara MPA than those of the Kehpara Open site (P = 0.023). The species observed in the highest densities within the outer-reef habitats of Kehpara MPA site were the pomacentrids *Chromis margaritifer*, *Chromis xanthura* and *Chrysiptera traceyi*, and the acanthurids *Ctenochaetus striatus* and *Acanthurus nigrofuscus* (Table 15). The individual species observed in the highest densities within the outer-reef habitats of the Kehpara Open site were the pomacentrids *Chromis margaritifer* and *Chromis xanthura* and the acanthurids *Ctenochaetus striatus*, *Acanthurus nigrofuscus* and *Zebrasoma scopas* (Table 15). A full list of densities by family and individual species can be found in Appendices 5–8.

Considerable variability in mean biomass was observed for most families at outer-reef habitats for both Kehpara MPA and Kehpara Open monitoring stations, evidenced by the large standard error values in Figure 24. For outer-reef habitats of the Kehpara MPA stations, members of the Haemulidae had the greatest biomass (31.665±31.665 g/m^2, comprising 33.5% of the total observed biomass), followed by the families Acanthuridae (21.792±10.831 g/m^2, 23.1% of mean biomass) and Lutjanidae (17.081±16.801 g/m^2, 18.1% of mean observed biomass). In contrast to their high density, members of the

Pomacentridae contributed only 1% of the mean observed biomass at this site. Acanthuridae had the greatest biomass in outer-reef habitats for the Kehpara Open monitoring stations (12.516±4.026 g/m2, comprising 44.7% of the mean observed biomass). Given the large amount of variability in biomass, few differences were observed in terms of mean biomass by family between the sites, with the mean biomass of only Mullidae appearing significantly higher within Kehpara MPA stations than Kehpara Open stations (P = 0.009) (Figure 24). The individual species that occurred in the greatest biomass within the outer-reef habitats of Kehpara MPA sites were the haemulid *Plectorhinchus albovittatus*, the lutjanid *Lutjanus gibbus*, the acanthurid *Ctenochaetus striatus* and the scarids *Scarus altipinnis* and *Chlorurus sordidus* (Table 16). The species with the greatest biomass within the outer-reef habitats of Kehpara Open sites were the acanthurids *Ctenochaetus striatus*, *Zebrasoma scopas*, *Acanthurus nigrofuscus* and *Acanthurus nigricans* and the scarid *Chlorurus sordidus* (Table 16). A full list of biomass by family and individual species can be found in Appendices 5–8.

As with the back- and lagoon-reef habitats, few differences were observed in the mean size and mean size ratio (a function of average maximum size) among sites. The mean size and mean size ratio of Serranidae was significantly higher within the Kehpara Open stations than the Kehpara MPA (P = 0.004 and P < 0.001, respectively).

In terms of trophic group, planktivores occurred in the greatest mean density within the outer-reef habitats of the Kehpara MPA and Kehpara Open stations, with 0.423±0.068 fish/m^2 and 0.400±0.074 fish/m2, respectively, followed by herbivores (0.322±0.042 fish/m^2 and 0.275±0.031 fish/m^2, respectively). No difference in mean density was observed for any trophic group among the Kehpara MPA and Kehpara Open sites. In terms of mean biomass, carnivores (56.039±50.293 g/m^2) and herbivores (29.332±10.220 g/m^2) were the dominant trophic groups within the Kehpara MPA transects, while herbivores (15.273±3.979 g/m^2) had the greatest biomass within the Kehpara Open sites. No significant difference in mean biomass, mean size or mean size ratio was observed for any trophic group among sites (Figure 25). As with the both the back- and lagoon-reef habitats, the size ratio of all trophic groups was low relative to average maximum sizes for both the Kehpara MPA and Kehpara Open stations (Figure 25).

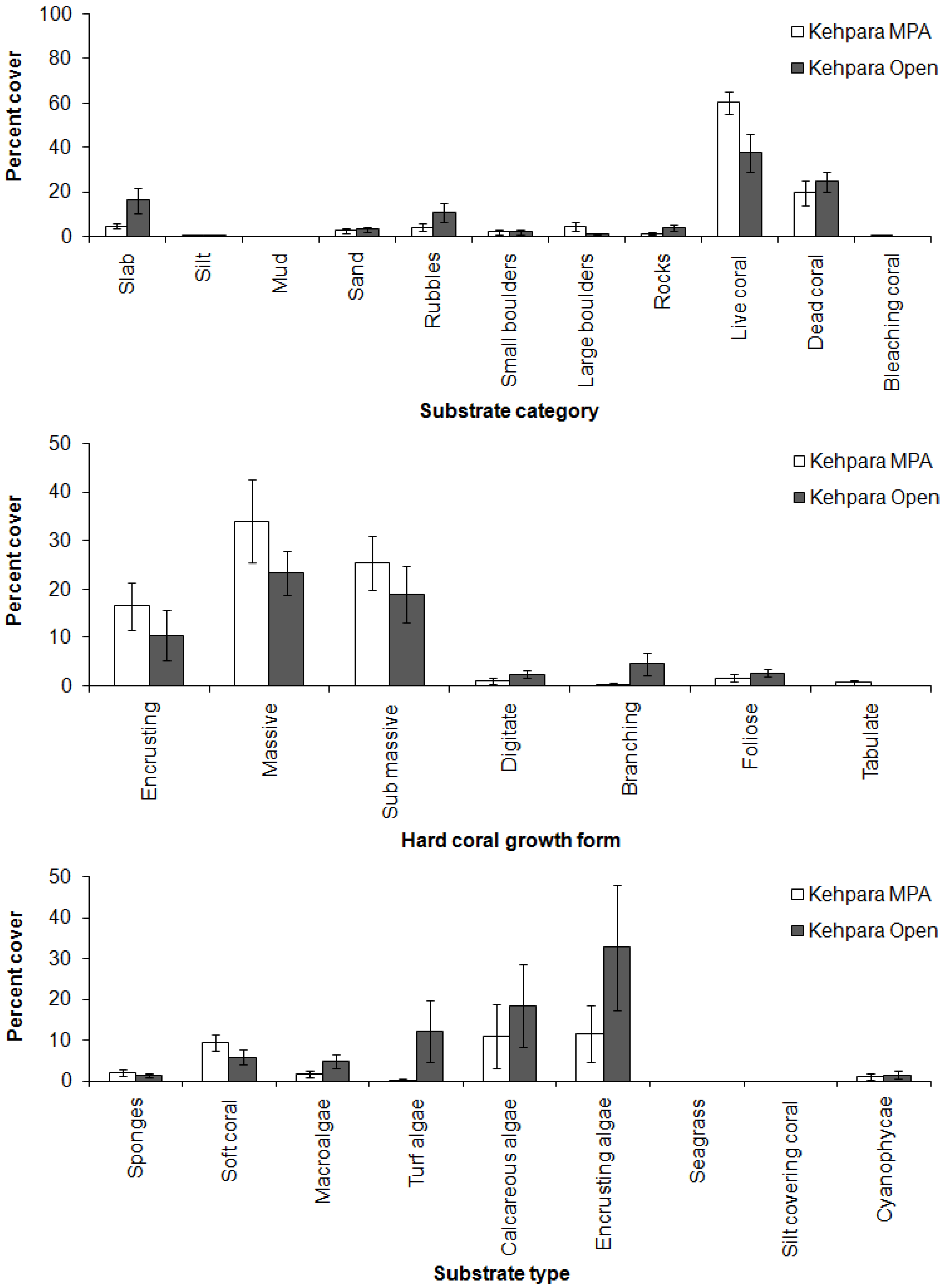

Figure 23 **Mean cover (± SE) of each major substrate category (top), hard coral growth form (middle) and 'other' substrate type (bottom) present at outer-reef habitats during finfish surveys at the Kehpara MPA and Kehpara Open monitoring sites, 2012.**

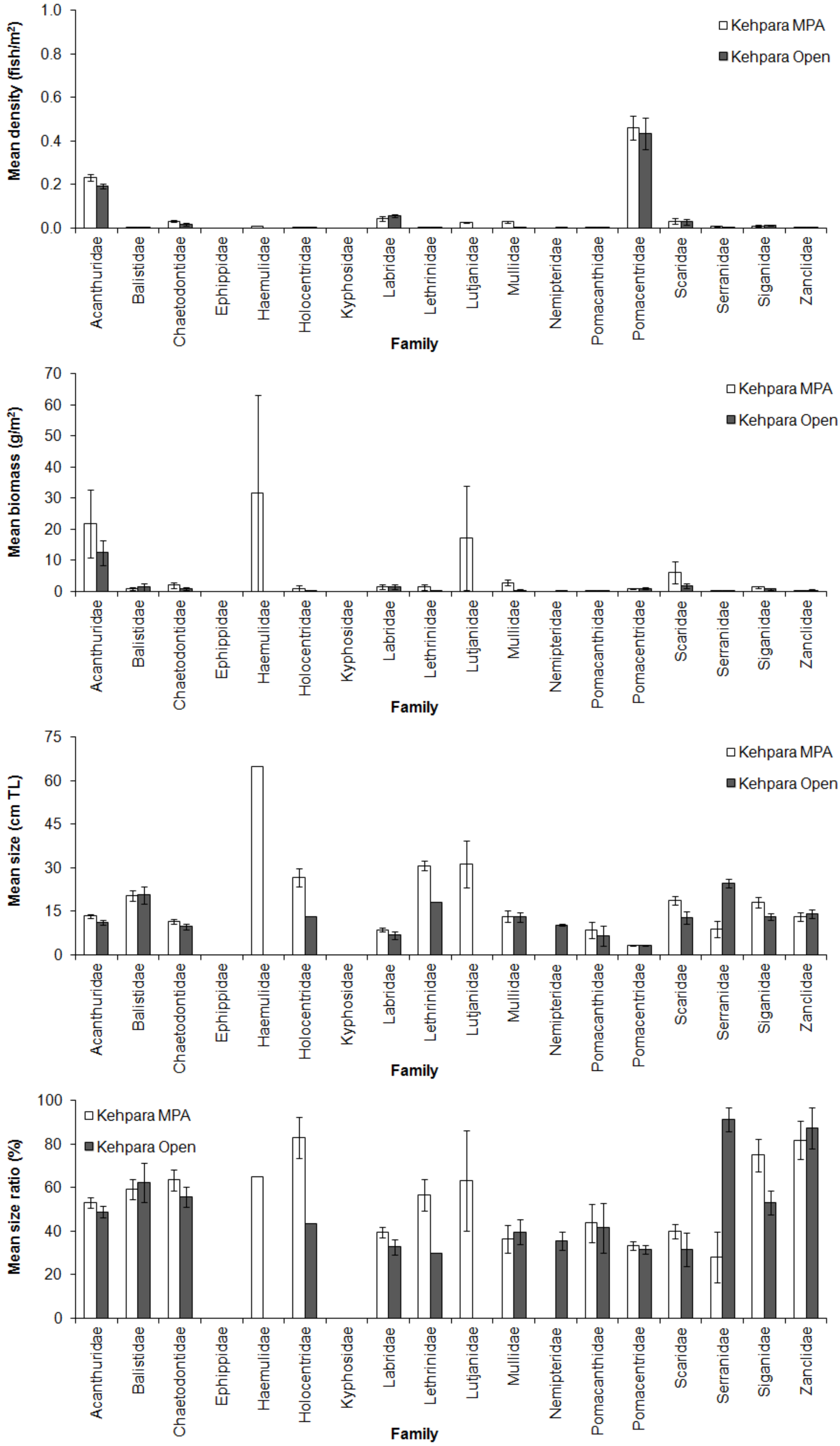

Figure 24 Profile of finfish indicator families in outer-reef habitats of the Kehpara MPA and Kehpara Open monitoring stations, 2012.

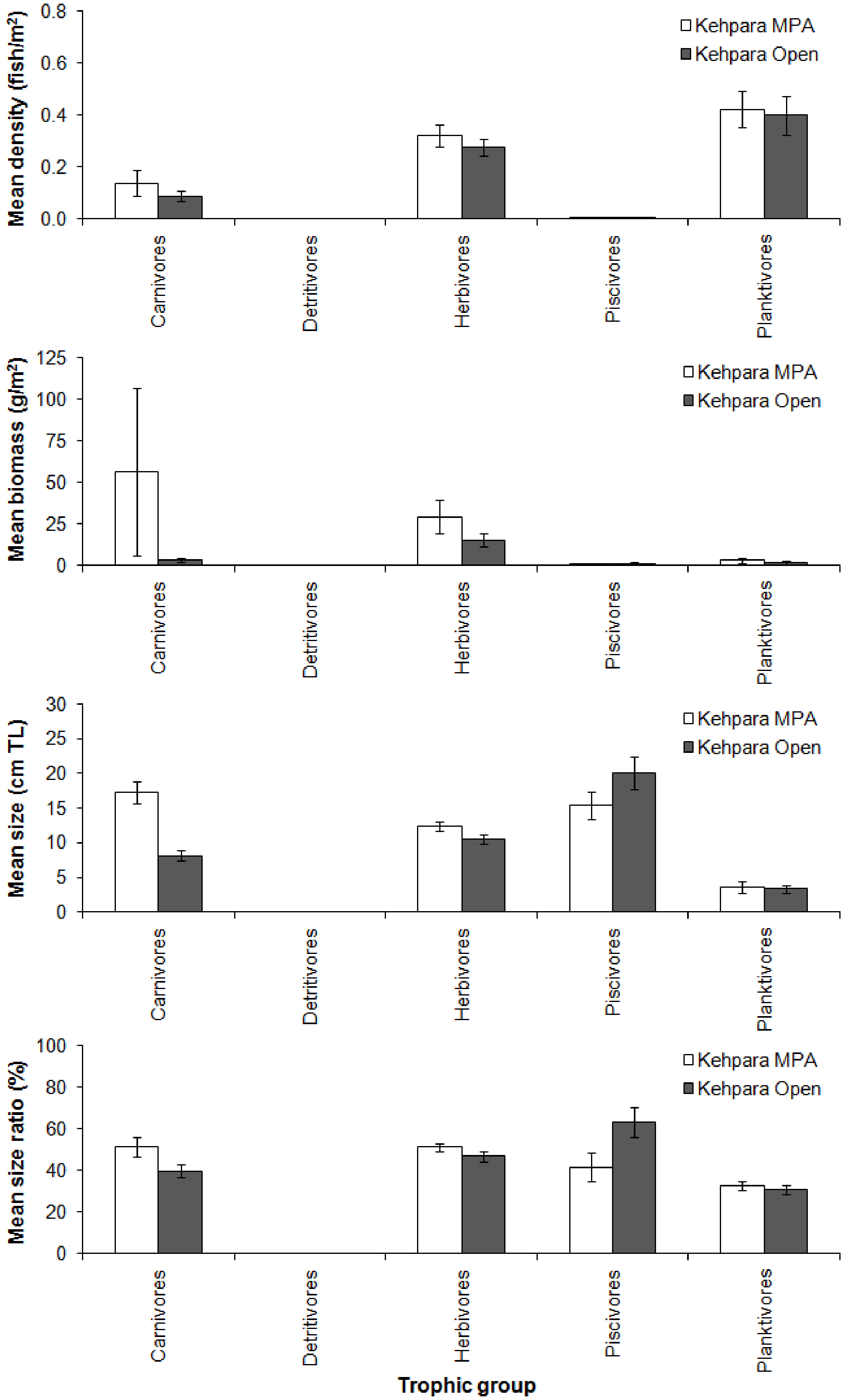

Figure 25 Profile of finfish by trophic level in outer-reef habitats of the Kehpara MPA and Kehpara Open monitoring stations, 2012.

Table 15 Finfish species observed in highest densities in outer-reef habitats of the Kehpara MPA and Kehpara Open monitoring sites, 2012. See Appendix 7 and 8 for a full list of densities of individual fish species observed at each monitoring site.

Site	Species	Family	Density (fish/m^2±SE)
Kehpara MPA	*Chromis margaritifer*	Pomacentridae	0.283±0.059
	Chromis xanthura	Pomacentridae	0.101±0.025
	Ctenochaetus striatus	Acanthuridae	0.098±0.041
	Acanthurus nigrofuscus	Acanthuridae	0.044±0.036
	Chrysiptera traceyi	Pomacentridae	0.029±0.011
Kehpara Open	*Chromis margaritifer*	Pomacentridae	0.268±0.077
	Chromis xanthura	Pomacentridae	0.104±0.037
	Ctenochaetus striatus	Acanthuridae	0.065±0.025
	Acanthurus nigrofuscus	Acanthuridae	0.057±0.031
	Zebrasoma scopas	Acanthuridae	0.043±0.011

Table 16 Finfish species with the highest biomass in outer-reef habitats of the Kehpara MPA and Kehpara Open monitoring sites, 2012. See Appendix 7 and 8 for a full list of biomass of individual fish species observed at each monitoring site.

Site	Species	Family	Biomass (g/m^2±SE)
Kehpara MPA	*Plectorhinchus albovittatus*	Haemulidae	31.665±31.665
	Lutjanus gibbus	Lutjanidae	16.123±16.123
	Ctenochaetus striatus	Acanthuridae	12.088±7.794
	Scarus altipinnis	Scaridae	2.249±2.249
	Chlorurus sordidus	Scaridae	1.982±0.805
Kehpara Open	*Ctenochaetus striatus*	Acanthuridae	4.801±2.504
	Zebrasoma scopas	Acanthuridae	3.198±1.666
	Acanthurus nigrofuscus	Acanthuridae	1.827±1.305
	Acanthurus nigricans	Acanthuridae	1.577±0.677
	Chlorurus sordidus	Scaridae	0.946±0.693

6. Invertebrate Surveys

Methods and Materials

Data collection

Invertebrates

Three survey methods were used to assess the abundance, size and condition of invertebrate resources and their habitat across reef zones. Manta tows were used to provide a broad-scale assessment of invertebrate resources associated with reef areas. In this assessment, a 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 26). Hand tally counters were also mounted on the manta board to assist with enumerating the common species on site. The snorkeler's observation belt was two metres wide and tows were conducted in depths typically ranging from one to ten metres. Each tow replicate was 300 m in length and was calibrated using the odometer function within the trip computer option of a Garmin 76Map GPS. Six 300 m manta tow replicates were conducted within each station, with the start and end GPS positions of each tow recorded to an accuracy of within ten metres.

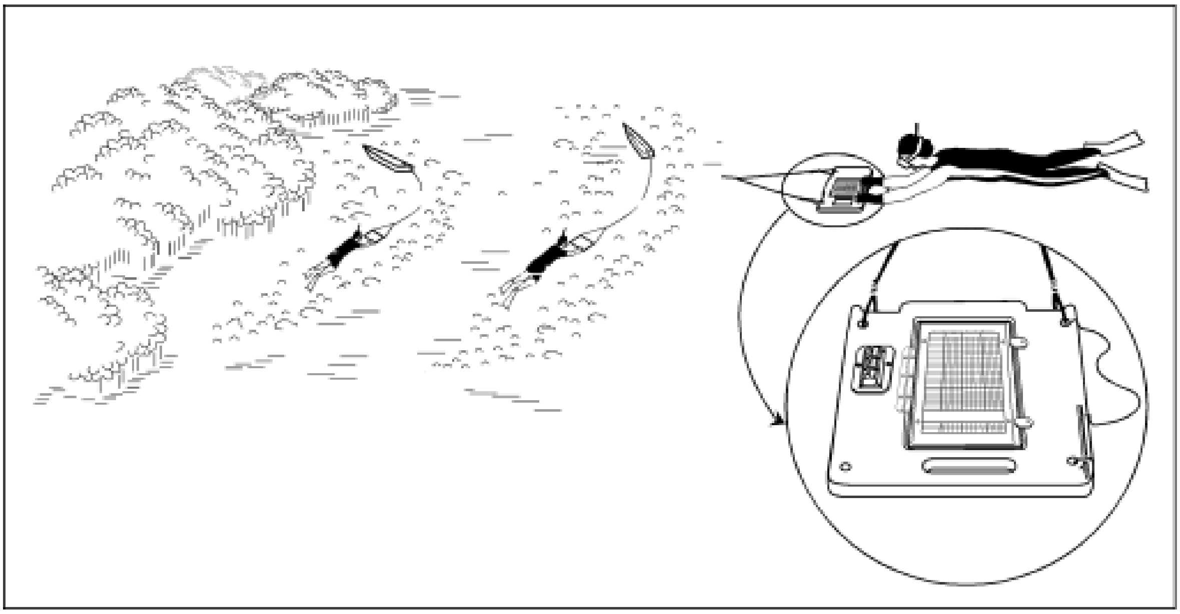

Figure 26 Broad-scale method: manta tow survey

To assess the abundance, size and condition of invertebrate resources and their habitat at finer-spatial scales, reef-benthos transects (RBT) and soft-benthos transects (SBT) were conducted. These techniques were conducted by two snorkelers equipped with measuring instruments attached to their record boards (slates) for recording the abundance and size of invertebrate species. For some species, such as sea urchins (e.g. *Echinometra sp.*), only abundance was recorded due to difficulty in measuring the size of these organisms. Each transect was 40 meters long with a one meter wide observation belt, conducted in depths ranging from one to three meters. The two snorkelers conducted three transects each, totalling six 40 m transects for each station (Figure 27; Figure 28). The GPS position of each station was recorded in the centre of the station.

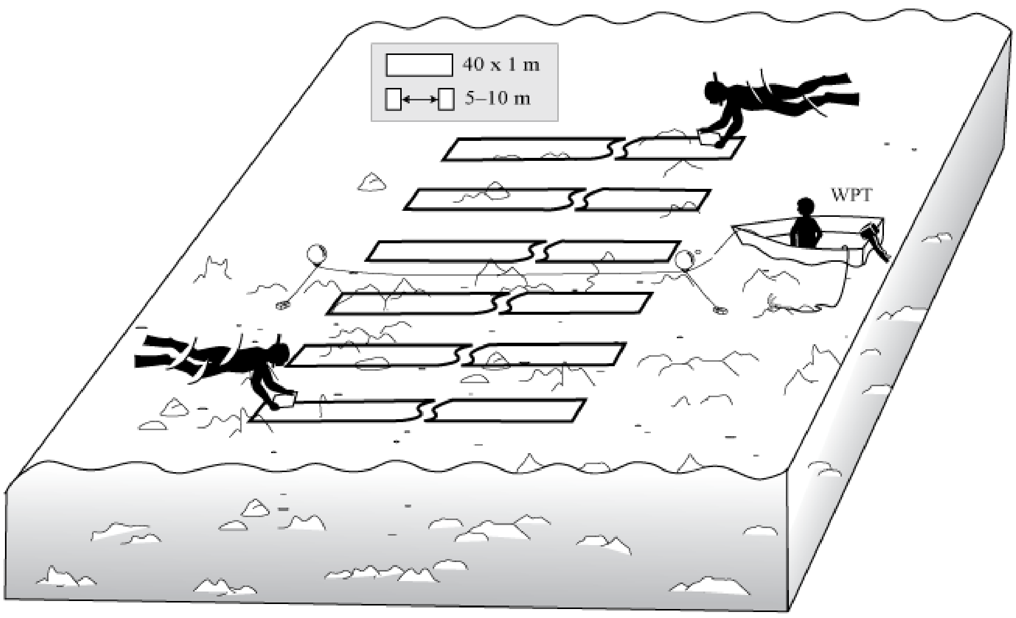

Figure 27 Fine-scale method: reef-benthos transects

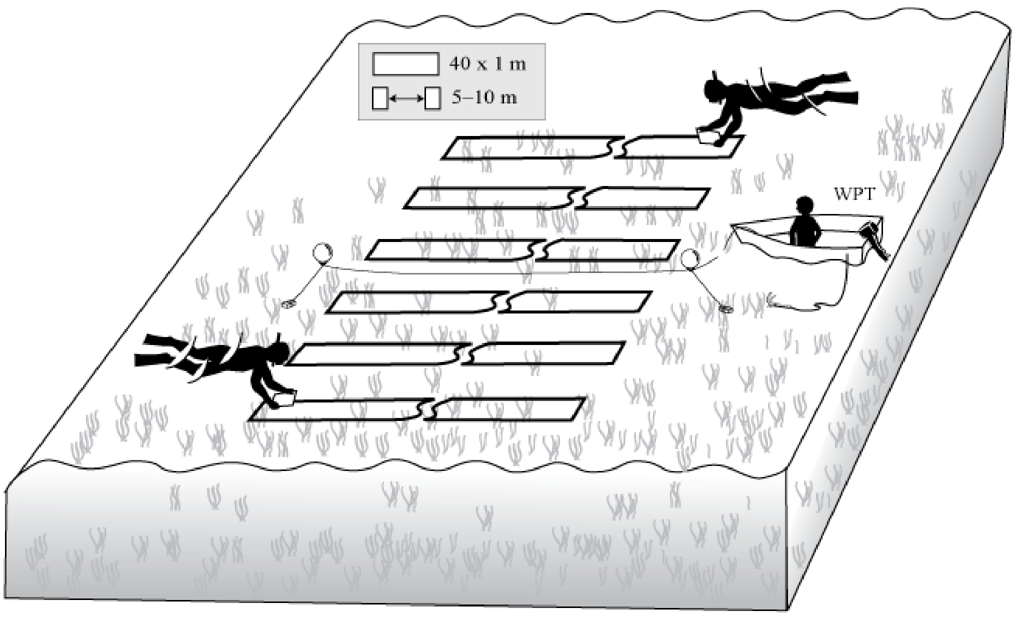

Figure 28 Fine-scale method: soft-benthos transects

Habitats supporting invertebrates

The manta tow, reef-benthos and soft-benthos transects used the same survey form (Appendix 9) which also includes a section for recording substrate cover. Following each invertebrate assessment transect, habitat data was recorded in seven broad categories:

1. Relief and complexity
   - Relief – describes average height variation for hard and soft benthos (scale 1-5, with 1 = low relief and 5 = high relief);
   - Complexity – describes average surface variation for substrates (relative to places for animals to find shelter; scale 1–5, with 1= low complexity and 5 = high complexity);
2. Ocean influence – describes the distance and influence of area to open sea (scale 1–5, with 1 = low ocean influence and 5 = high ocean influence);
3. Depth – average depth of the surveyed area (in meters);
4. Substrate categories (totalling to 100%):
   - Soft sediments including (1) *mud*, (2) *mud and sand*, (3) *sand* and (4) *coarse sand*;
   - (5) *rubble* - small fragments of coral between 0.5 and 15cm;
   - (6) *boulders* - detached big pieces of coral stone more than 30cm;
   - (7) c*onsolidated rubble* - cemented pieces of coral and limestone debris,
   - (8) *pavement* - solid fixed flat limestone;
   - (9) *coral live* any live hard coral; and
   - (10) *coral dead* any dead carbonated edifices that are still in place and retain a general coral shape;
5. Other substrate types (recorded in occurrences not totalling to 100%)
   - (11) s*oft coral*;
   - (12) *sponges*; and,
   - (13) *fungids*;
   - (14) *crustose coralline algae*;
   - (15) *coralline algae* (e.g. *Halimeda*);
   - (16) *other algae* - includes all fleshy macroalgae not having calcium carbonate deposits; and
   - (17) *seagrass* (e.g. *Halophila*);
6. Epiphytes and silt
   - Epiphytes – describes the coverage of filamentous algae such as turf algae on hard substrate(scale 1–5, with 1 = no cover and 5 = high cover);
   - Silt – easily suspended fine particles (scale 1–5, as 1 = no silt and 5 = high silt);
7. Bleaching - the percentage of bleached live coral.

Data analysis

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

1) richness – the number of genera and species counted in each survey method;

2) diversity – total number of observed species per habitat and site divided by the number of stations;
3) mean density per station (individuals/ha);
4) mean size (mm).

As with the finfish analyses, relationships between environmental parameters and invertebrate resources have not been fully explored in this baseline report. To explore differences in invertebrate densities and their habitats among sites, density data for each individual invertebrate species, and habitat categorical data, of each transect was square-root transformed to reduce heterogeneity of variances and analysed by one-way ANOVA at $P = 0.05$, using Statistica 7.1, with site (MPA vs. Open) as a fixed factor in the analyses.

Results

Manta tow

Survey coverage

A total of seven manta tow stations were established, with two full manta tow transects (6 x 300 m replicates) conducted within the Kehpara MPA, and four full manta tow transects conducted within the Kehpara Open site. An additional manta tow station was divided between the MPA and Open sites, with 3 x 300 m replicates of this station conducted in each site (Figure 29; Table 17). Due to poor conditions at the time of survey, no manta tow surveys were conducted in the outer-reef and passage habitats surveyed by Tardy et al. (2009), precluding comparisons of these datasets. GPS positions of all manta tow replicates are tabulated in Appendix 10.

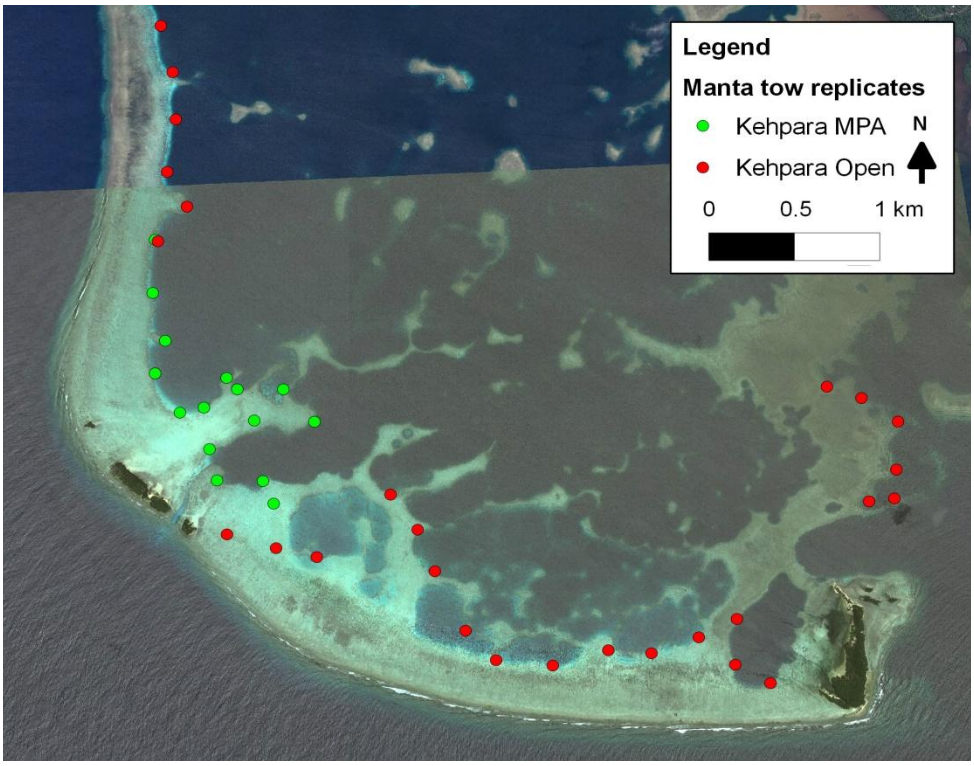

Figure 29 Locations of manta tow replicates established in the Kehpara region, 2012.

Table 17 Summary of manta tow stations established within the Kehpara MPA and Kehpara Open monitoring sites, 2012.

Site	Number of stations	Number of replicates	Area surveyed (m^2)
Kehpara MPA	2.5	15	9,000
Kehpara Open	4.5	27	16,200

Habitats supporting invertebrates

The substrate of Kehpara MPA stations was dominated by dead coral, while Kehpara Open stations were characterised by high cover sand, rubble and dead coral (Figure 30). Habitats where manta tows were conducted within the Kehpara MPA were slightly more complex

(2.23 vs. 1.77 complexity index) and had a greater mean cover of dead coral (49.4% vs. 23.5%) than those within the Open site (P = 0.029 and P = 0.001, respectively) (Figure 30). In contrast Kehpara Open stations had a greater mean cover of rubble (9.4% vs. 16.5%) and coralline algae (P = 0.022 and P = 0.006, respectively). A full list of percent cover of each habitat variable recorded during the manta tow surveys is presented as Appendix 11.

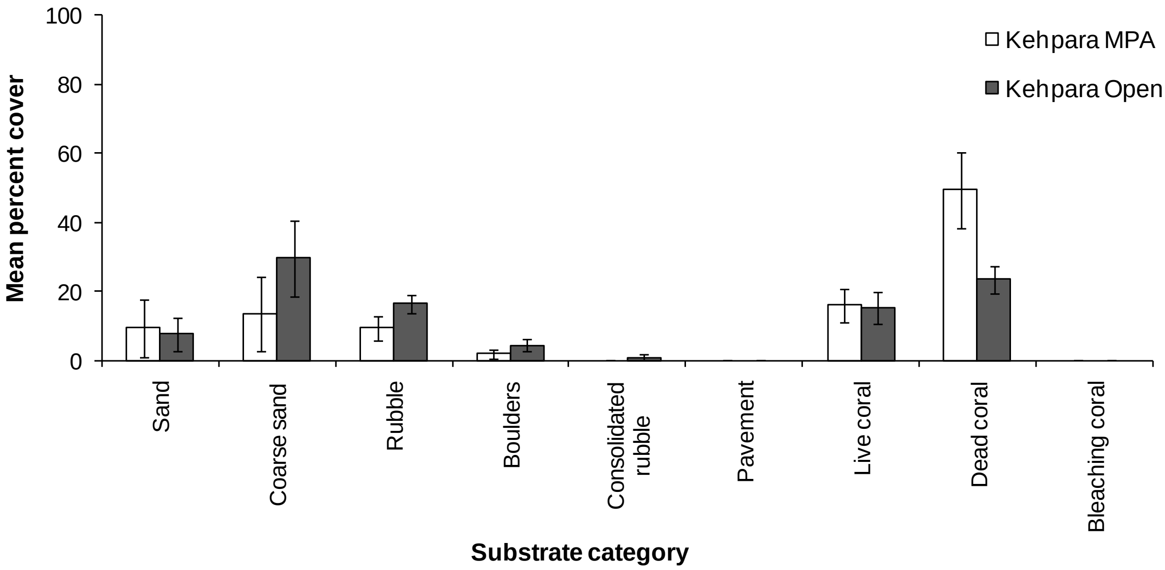

Figure 30 Mean percent cover (± SE) of each major substrate category of manta tow survey stations at the Kehpara MPA and Kehpara Open monitoring sites, 2012.

Invertebrates

A total of 17 invertebrate species were recorded during the manta tow surveys at both the Kehpara MPA and Open stations (Table 18). Species diversity was slightly higher within the Kehpara MPA stations compared to Open stations (Table 18). Individual species observed in the highest mean densities during the manta tow surveys within both the Kehpara MPA and Open sites included the sea cucumbers *Holothuria atra*, *H. edulis* and *Bohadschia argus* (Figure 31). The mean densities of the medium-value greenfish *Stichopus chloronotus* and the elongate giant clam *Tridacna maxima* were significantly higher at the MPA site than the Open site (P = 0.014 and P = 0.037 respectively) (Figure 31). The density of individual species observed during the manta tow surveys at each site is presented as Appendix 12.

Table 18 Number of genera and species, and diversity of invertebrates observed during manta tow surveys at the Kehpara MPA and Kehpara Open monitoring sites, 2012.

Parameter	Site	
	Kehpara MPA	**Kehpara Open**
Number of genera	11	10
Number of species	17	17
Diversity	6.8	3.8

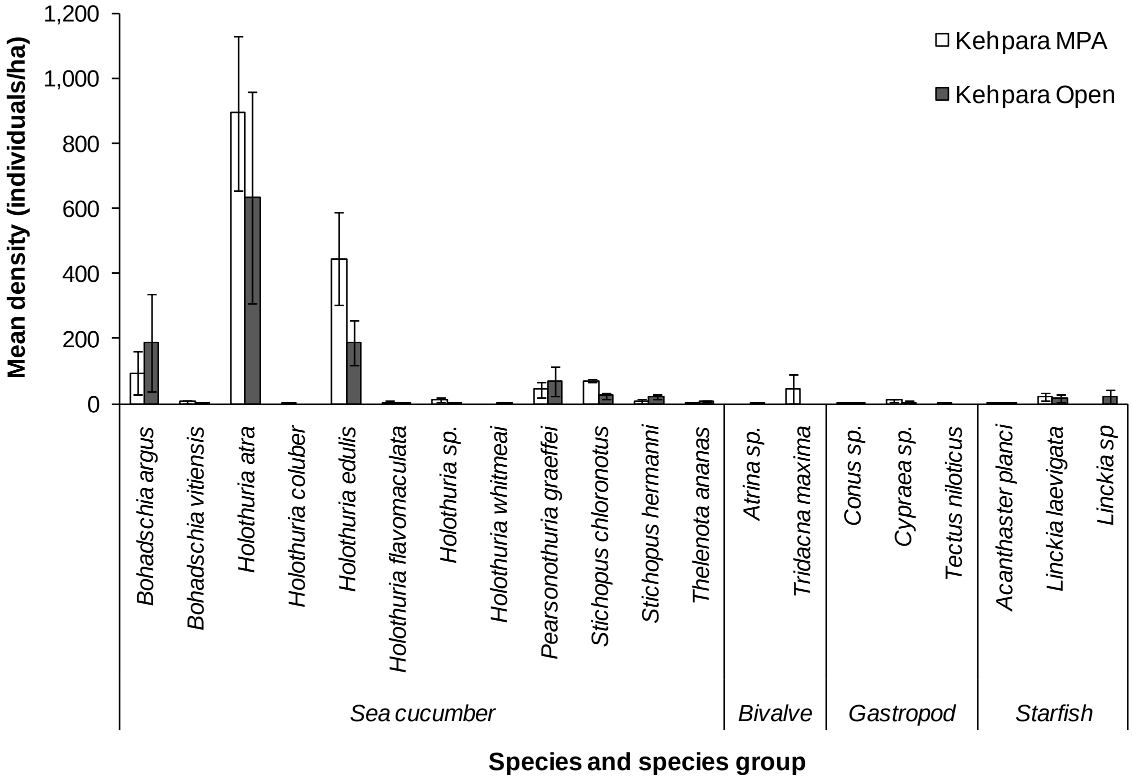

Figure 31 Overall mean densities of invertebrate species (± SE) observed during manta tow surveys at the Kehpara MPA and Kehpara Open monitoring sites, 2012.

The crown-of-thorns starfish, *Acanthaster planci*, was observed at three of the 15 manta tow replicates within the Kehpara MPA and four of the 27 replicates within the Open site (Figure 32). Densities were relatively low (< 20 individuals/ha) at any manta tow replicate site, and showed no significant difference among the MPA and Open sites (Figure 32).

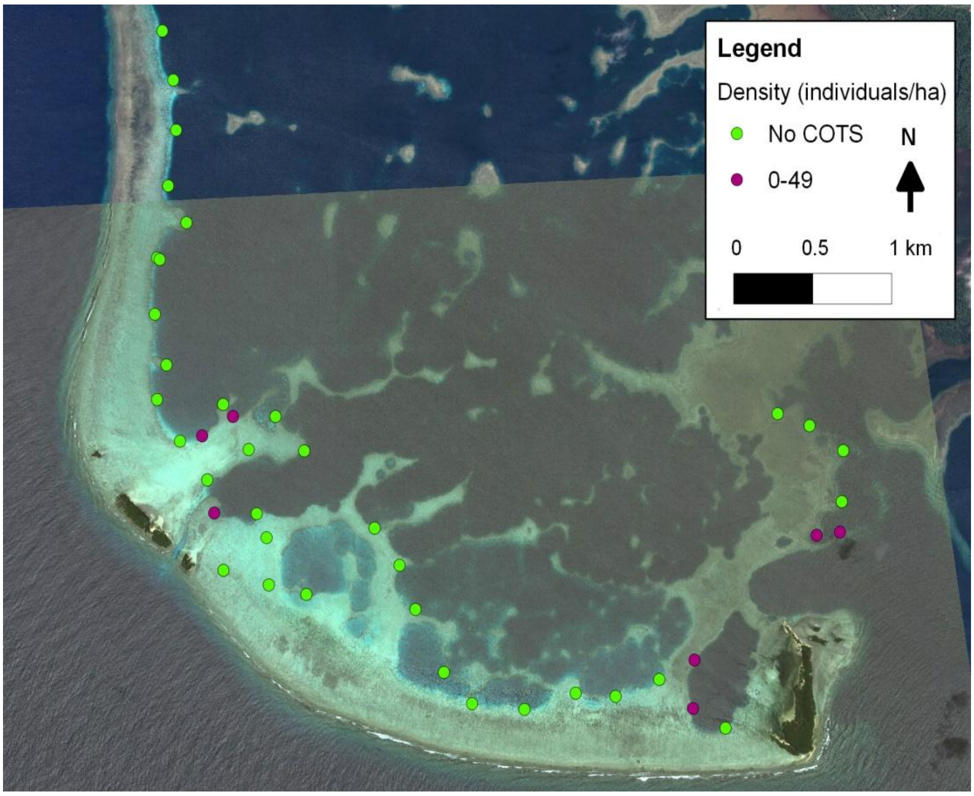

Figure 32 Crown-of-thorns starfish (COTS; *Acanthaster planci*) densities (individuals /ha) at each manta tow replicate, 2012.

Reef-benthos transects

Coverage

A total of 16 RBT stations were established within the Kehpara region, with eight established within each of the MPA and Open sites (Figure 33; Table 9). GPS positions of reef-benthos stations are tabulated in Appendix 13.

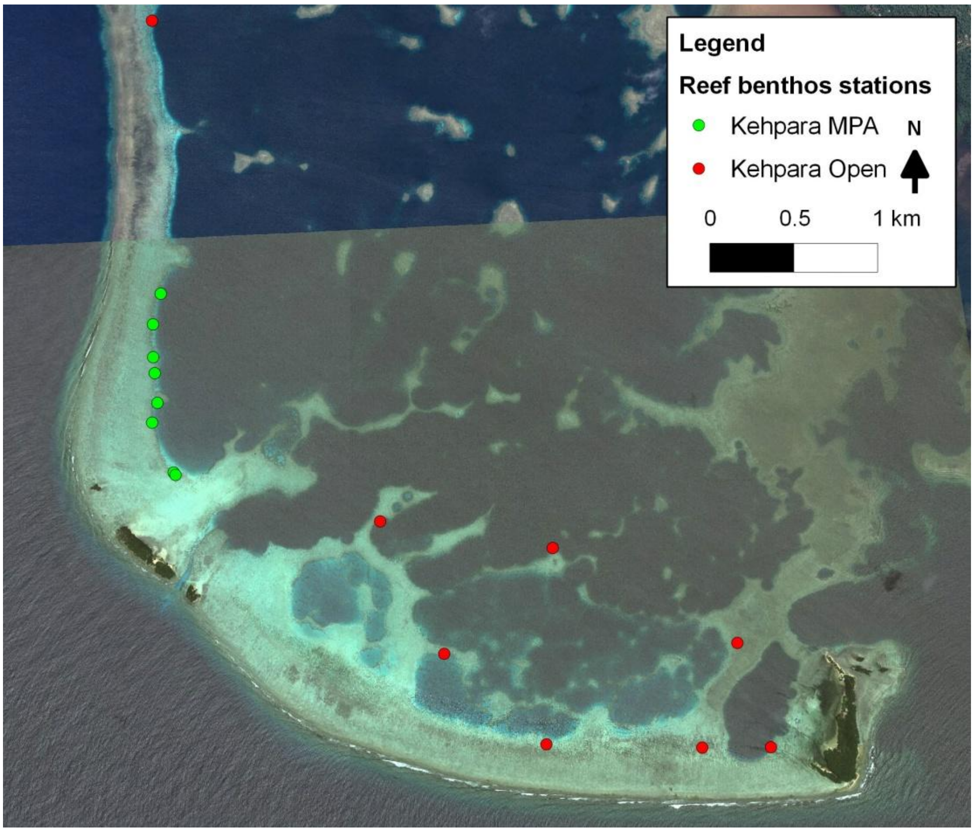

Figure 33 **Locations of reef-benthos transect stations established in the Kehpara region, 2012. Six replicate 40 m transects were conducted at each station.**

Table 19 **Summary of reef-benthos transect stations established within the Kehpara MPA and Kehpara Open monitoring sites, 2012.**

Site	Number of stations	Number of replicates	Area surveyed (m)
Kehpara MPA	8	48	1,920
Kehpara Open	8	48	1,920

Habitats supporting invertebrates

The substrate at RBT stations of both the Kehpara MPA and Kehpara Open sites was largely similar, and dominated by live coral and sand (Figure 34). RBT stations within the Kehpara MPA were slightly deeper (1.15 m vs. 0.97 m) and more complex (2.23 vs. 1.77 complexity index) than those within the Open site (P < 0.001 and P = 0.015, respectively). While no difference was observed in the percent cover of the major substrate categories (Figure 34), the mean cover of coralline algae, crustose coralline algae, other algae, soft coral, sponge and fungids was significantly higher within the Kehpara MPA than the Open site ($P < 0.05$). In contrast the percent cover of seagrass was higher within the Open site ($P = 0.002$). A full list of percent cover of each habitat variable recorded during the RBT surveys is presented as Appendix 11.

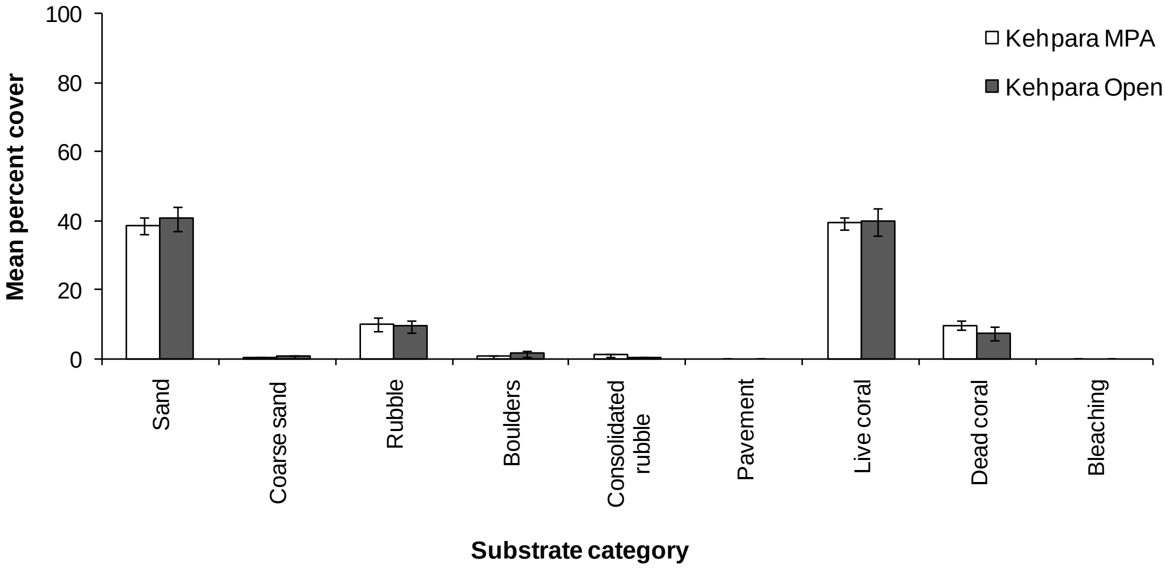

Figure 34 Mean percent cover (± SE) of each major substrate category at reef-benthos transect stations at the Kehpara MPA and Kehpara Open monitoring sites, 2012.

Invertebrates

A total of 53 invertebrate species were recorded during the reef-benthos surveys (Appendix 14). Species diversity was considerably higher within the Kehpara MPA sites, where 47 species were recorded, compared to 25 species within the Open site (Appendix 14). The individual species observed in the highest mean densities during the RBT surveys within the MPA site included the gastropods *Dendropoma maximum* (22,098.96±6,825.72 individuals/ha), and *Tectus pyramis* (197.92±174.44 individual/ha), the sea cucumbers *Holothuria atra* (3,276.04±601.18 individuals/ha) and *H. edulis* (729.17±107.97 individuals/ha) and the starfish *Linckia laevigata* (1,182.29±125.97 individuals/ha) (Appendix 14). The individual species observed in the highest mean densities during the RBT surveys within the Kehpara Open site included the sea cucumbers *H. atra* (4,270.83±1,506.95 individuals/ha) and *H. edulis* (583.33±260.45 individuals/ha) (Appendix 14). The mean density of the sea cucumbers *Bohadschia vitiensis*, *Holothuria edulis* and *Stichopus chloronotus*, the gastropods *Coralliophora violacea*[2], *Dendropoma maximum* and *Conomurex luhuanus*[3], and the starfish *A. planci*, *Linckia laevigata* and *Linckia* sp. were significantly higher within the Kehpara MPA than the Open site ($P <$

[2] This species was formerly known as *Coralliophora neritoidea*
[3] This species was formerly known as *Strombus luhuanus*

0.05). The density of individual species observed during the RBT surveys at each site is presented as Appendix 14.

Table 20 Number of genera and species, and diversity of invertebrates observed during reef-benthos transects at the Kehpara MPA and Open monitoring sites, 2012.

Parameter	Site	
	Kehpara MPA	Kehpara Open
Number of genera	27	17
Number of species	47	25
Diversity	5.9	3.1

Few differences in mean size were evident for species common to both the Kehpara MPA and Open monitoring sites. The mean size of the sea cucumber *Stichopus chloronotus* and the gastropods *Cypraea tigris* and *Dendropoma maximum* appeared larger within the MPA site, while the mean size of *Tridacna maxima* appeared slightly larger with the Open site (Table 21).

Table 21 Mean size (± SE) of measured invertebrates during reef-benthos transects at the Kehpara MPA and Open monitoring sites, 2012. Only those species with $\geq$ 5 measured individuals are presented.

Group	Species	Mean size (mm)	
		Kehpara MPA	Kehpara Open
Sea cucumber	*Bohadschia argus*	238.9±9.1	261.6±10.4
	Bohadschia vitiensis	234.2±18.7	-
	Holothuria atra	149.9±2.0	150.9±2.0
	Holothuria edulis	140.5±5.3	142.7±3.5
	Stichopus chloronotus	207.7±11.0	141.0±12.4
Bivalve	*Hippopus hippopus*	137.8±74.7	140.0±30.0
	Pinctada margaritifera	146.7±16.1	150.0
	Tridacna maxima	123.1±6.2	220.8±30.1
Gastropod	*Coralliophila violacea*	20.4±0.8	-
	Conomurex luhuanus	40.0±8.5	-
	Conus marmoreus	117.8±35.2	60.0
	Cypraea tigris	72.6±7.2	46.0±6.0
	Dendropoma maximum	193.5±79.4	86.5±3.5
	Lambis crocata	56.7±14.5	-
	Lambis lambis	136.7±10.5	96.0±10.8
	Tectus pyramis	36.0±16.3	-
	Thais aculeata	85.2±21.0	-
	Turbo argyrostomus	98.3±10.9	-

The crown-of-thorns starfish, *A. planci*, was observed at seven of the eight RBT stations (88% of replicates) within the Kehpara MPA and three of the eight within the Open site (38% of replicates) (Figure 32). Densities were significantly higher within the Kehpara MPA (P = 0.022), and were variable among stations, with densities in the MPA ranging from 0 to 208.33 individuals/ha (Figure 35).

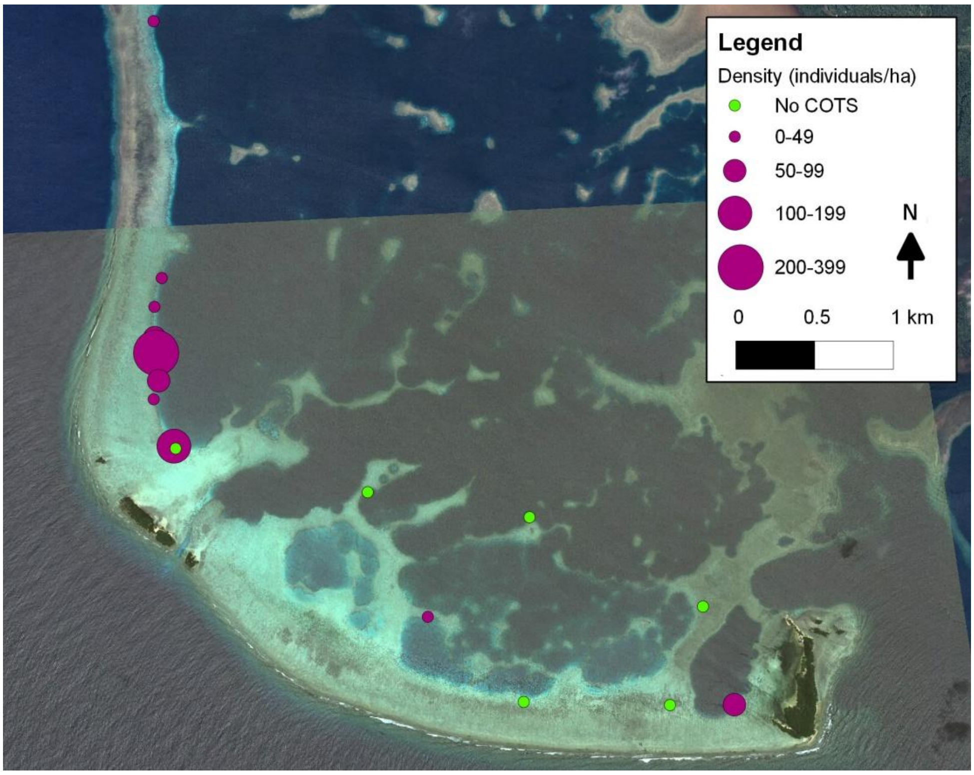

Figure 35 Crown-of-thorns starfish (COTS; *Acanthaster planci*) densities (individuals /ha) at each reef-benthos transect station, 2012.

Soft-benthos transects

Coverage

A total of five SBT stations were established during the baseline surveys, with one station established within the Pwudoi MPA and four established in the Open area (Figure 36; Table 22). GPS positions of all soft-benthos stations are tabulated in Appendix 15.

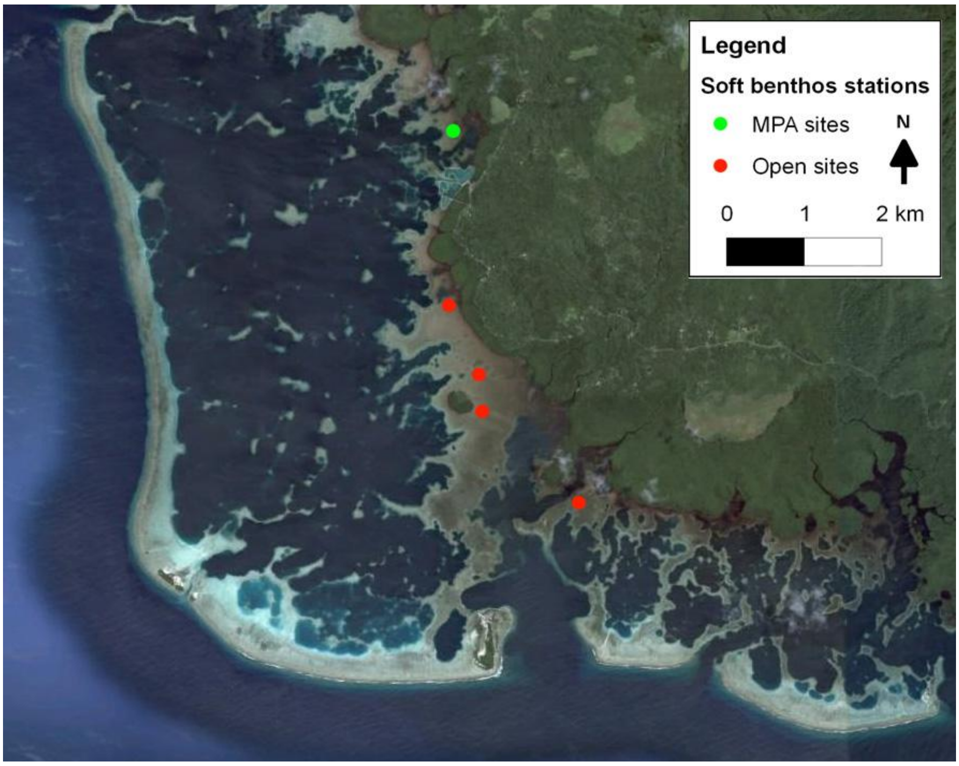

Figure 36 Locations of soft-benthos invertebrate assessment stations established in Pohnpei, 2012. Six replicate 40 m transects were conducted at each soft-benthos station.

Table 22 Summary of soft-benthos transect stations established within the Kehpara MPA and Kehpara Open monitoring sites, 2012.

Site	Number of stations	Number of replicates	Area surveyed (m)
Pwudoi MPA	1	6	240
Open sites	4	24	960

Habitats supporting invertebrates

The substrate at SBT stations at both the MPA and Open sites was dominated by sand (100% and 85.63% cover, respectively). Seagrass was common at both sites, with mean coverage of 40% and 54.1±15.0% at the MPA and Open sites, respectively. No significant difference was observed in any habitat variable among the sites. A full list of percent cover of each habitat variable recorded at the SBT stations is presented as Appendix 16.

Invertebrates

Four species were observed during the soft-benthos transects in the Pwudoi MPA station (the sea cucumbers *Holothuria atra*, *Stichopus vastus*, *Synapta maculata* and the gastropod *Lambis lambis*), while 14 species were observed in the areas open to fishing (Figure 37; Table 23). Species diversity was similar among sites (Table 23), suggesting the limited number of species observed in the MPA was due to the low sampling effort in this region. No difference in mean density was evident for any species among the MPA and Open sites, likely resulting from the small number of replicates in each site. A full list of densities of individual species observed during the soft-benthos transects at each site is presented as Appendix 17.

Table 23 Number of genera and species, and diversity of invertebrates observed during soft-benthos transects at the Pwudoi MPA and Open monitoring sites, 2012.

Parameter	Site	
	Pwudoi MPA	Open site
Number of genera	4	10
Number of species	4	14
Diversity	4	3.5

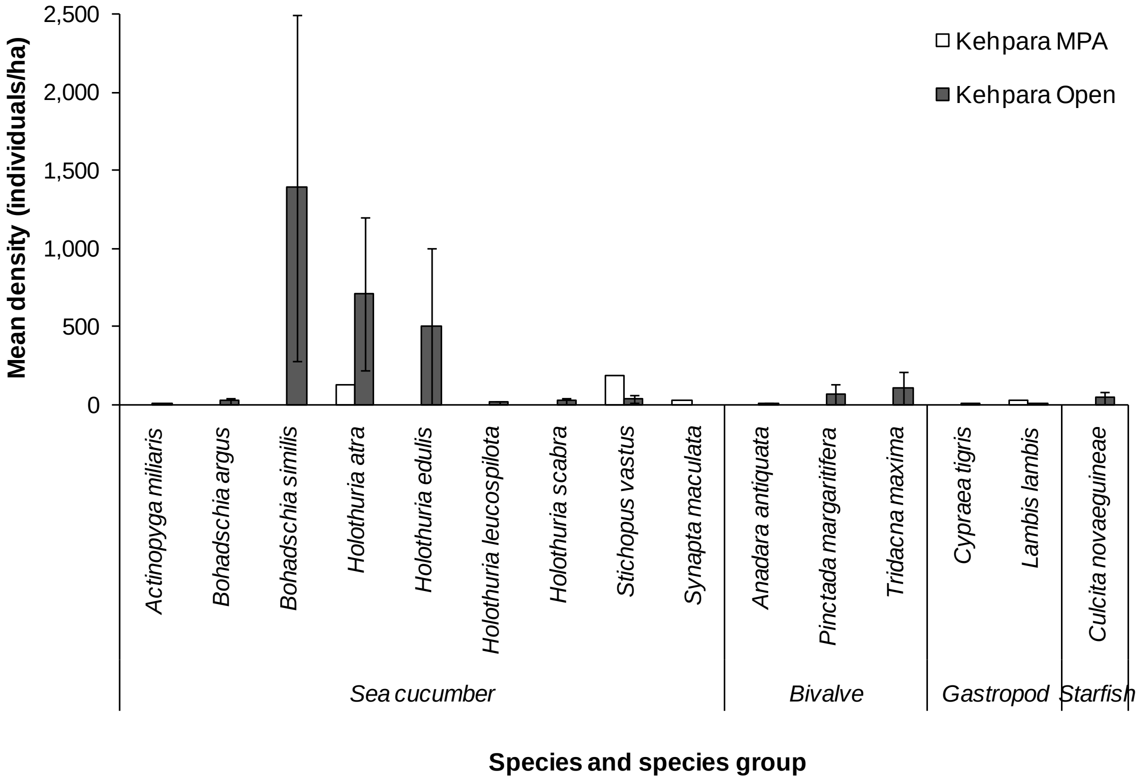

Figure 37 Overall mean density of invertebrate species (± SE) observed during soft-benthos transects within and adjacent to the Pwudoi MPA, Pohnpei, 2012.

7. Capacity Building

One of the key objectives of the project is to train local Fisheries Officers in undertaking monitoring programs and resource assessments. The training includes planning logistics, safety protocols, site selection criteria, species identification, survey methods and other preparations required for conducting resource assessments. This is to build local capacity before conducting the baseline assessment and to provide staff with the skills so regular re-assessments of the pilot sites can be carried out in the future.

A week of training was conducted before the actual baseline assessments of both finfish and invertebrate resources. A total of eight officers were trained: three from OFA, two from CSP, two from DLNR-MCU, and one from FSM R&D (Table 24). The training initially consisted of classroom sessions where assessment methods and survey forms were explained in detail and slideshows of species photos were presented for identification. This was followed by field activities where the trainees practiced a method, as well as species identification. Only when the results of the trainees were consistent with senior project staff were the trainees able to participate in the baseline assessment.

Table 24 List of trainees who participated in the baseline assessment

Name	Title	Organisation
Itaia Fred	Hatchery Specialist	OFA
Pelson Moses	Aquaculture Specialist	OFA
Clay Hedson	Fishery Specialist	OFA
Selino Maxin	Marine Program Assistant / Data Manager	CSP
Kirino Olpet	Marine Technician	CSP
Scotty Malakai	Fishery Specialist	DLNR-MCU
Derek Pelep	Fisheries Assistant	DLNR-MCU
Dave Mathias	Marine Conservation Management Specialist	FSM R&D

8. Recommendations for Future Monitoring

The following recommendations are proposed for future monitoring events:

Benthic habitat and finfish assessments

- Many of the back-reef monitoring stations established during the baseline survey were established in shallow (< 1 m deep) water. Accordingly, these habitats will likely only support transient finfish communities due to tidal effects. For future surveys it is recommended that deeper water back-reef transects be established, where possible.

- 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 used in conjunction with the D-UVC surveys.

Invertebrate surveys

- For this baseline study, manta tow surveys were conducted on back-and lagoon-reef habitats only. As various reef habitats, and the organisms they support, differ greatly in their vulnerability to climate change, it is recommended that manta tow monitoring stations be established on the outer reef of both Kehpara MPA and Kehpara Open sites. Inclusion of outer-reef habitats will also allow for comparison against the surveys of Tardy et al (2009), providing an additional time series with which to assess temporal patterns in invertebrate resources and their habitats.

- During the baseline assessment, only one SBT station was established within a protected area (Pwudoi Mangrove Reserve), while four SBT stations were established in areas open to fishing. During re-survey events, it is recommended that additional SBT stations be established within the Pwudoi MPA.

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Appendix 1 GPS positions of benthic habitat assessments

Station ID	Habitat	Transect name	Latitude (N)	Longitude (E)
Kehpara MPA 1	Back	Rb16	6.8075833	158.1165833
	Back	Rb17	6.8069000	158.1166500
	Back	Rb18	6.8059833	158.1166833
	Lagoon	Rl1	6.8014167	158.1243000
	Lagoon	Rl2	6.8011540	158.1236510
	Lagoon	Rl3	6.8003833	158.1228833
	Outer	Rs13	6.8065167	158.1132833
	Outer	Rs14	6.8056167	158.1130833
	Outer	Rs15	6.8047330	158.1127833
Kehpara MPA 2	Back	Rb34	6.8010000	158.1156833
	Back	Rb35	6.8004167	158.1160667
	Back	Rb36	6.7996667	158.1162500
	Lagoon	Rl19	6.7950000	158.1235500
	Lagoon	Rl20	6.7947667	158.1240833
	Lagoon	Rl21	6.7946667	158.1249000
	Outer	Rs22	6.8002667	158.1117667
	Outer	Rs23	6.7997500	158.1119167
	Outer	Rs24	6.7985500	158.1121333
Kehpara Open 1	Back	Rb10	6.7869500	158.1282333
	Back	Rb11	6.7867500	158.1289500
	Back	Rb12	6.7859167	158.1301833
	Lagoon	Rl31	6.7969000	158.1354833
	Lagoon	Rl32	6.7964667	158.1350000
	Lagoon	Rl33	6.7961170	158.1342330
	Outer	Rs7	6.7827667	158.1277333
	Outer	Rs8	6.7827667	158.1277333
	Outer	Rs9	6.7824500	158.1289170
Kehpara Open 2	Back	Rb28	6.7843500	158.1446833
	Back	Rb29	6.7843500	158.1451833
	Back	Rb30	6.7841833	158.1458333
	Lagoon	Rl25	6.7946670	158.1387670
	Lagoon	Rl26	6.7942333	158.1380833
	Lagoon	Rl27	6.7938833	158.1374667
	Outer	Rs4	6.7798667	158.1446000
	Outer	Rs5	6.7798333	158.1455167
	Outer	Rs6	6.7799000	158.1462667

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

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

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

ST	SCIENTIFIC NAME	NBER	LGT	D1	D2	COMMENTS

Appendix 3 Form used to assess habitats supporting finfish

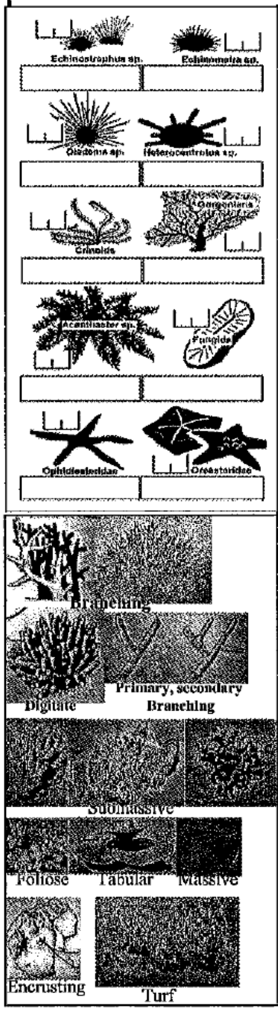
Campaign |______________| **Site** |______________________| **Diver** |__|__| **Transect** |__|__|__|

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

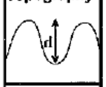
Start time: |__|__| :|__|__| End time: |__|__| :|__|__| Secchi disc visibility |__|__| m	Left ☐	Right ☐	
Primary reef: Coastal ☐ Lagoon ☐ Back ☐ Outer ☐	**Secondary Reef:** Coastal ☐ Lagoon ☐ Back ☐ Outer ☐		
current / oceanic influence / terrigenous influence — none ☐☐☐ medium ☐☐☐ strong ☐☐☐	draw profile including estimate of slope in degree: Flat ☐ Floor ☐ Gentle slope ☐ Steep slope ☐	Remarks:	

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

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



Topography



Complexity

1 : none

2 :low

3 : medium

4 : strong

5:Exceptional

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 GPS positions of finfish D-UVC transects

Station ID	Habitat	Transect name	Longitude (E)	Latitude (N)
Kehpara MPA 1	Back	Rb16	6.8075833	158.1165833
	Back	Rb17	6.8069000	158.1166500
	Back	Rb18	6.8059833	158.1166833
	Lagoon	Rl1	6.8014167	158.1243000
	Lagoon	Rl2	6.8011540	158.1236510
	Lagoon	Rl3	6.8003833	158.1228833
	Outer	Rs13	6.8065167	158.1132833
	Outer	Rs14	6.8056167	158.1130833
	Outer	Rs15	6.8047330	158.1127833
Kehpara MPA 2	Back	Rb34	6.8010000	158.1156833
	Back	Rb35	6.8004167	158.1160667
	Back	Rb36	6.7996667	158.1162500
	Lagoon	Rl19	6.7950000	158.1235500
	Lagoon	Rl20	6.7947667	158.1240833
	Lagoon	Rl21	6.7946667	158.1249000
	Outer	Rs22	6.8002667	158.1117667
	Outer	Rs23	6.7997500	158.1119167
	Outer	Rs24	6.7985500	158.1121333
Kehpara Open 1	Back	Rb10	6.7869500	158.1282333
	Back	Rb11	6.7867500	158.1289500
	Back	Rb12	6.7859167	158.1301833
	Lagoon	Rl31	6.7969000	158.1354833
	Lagoon	Rl32	6.7964667	158.1350000
	Lagoon	Rl33	6.7961170	158.1342330
	Outer	Rs7	6.7827667	158.1277333
	Outer	Rs8	6.7827667	158.1277333
	Outer	Rs9	6.7824500	158.1289170
Kehpara Open 2	Back	Rb28	6.7843500	158.1446833
	Back	Rb29	6.7843500	158.1451833
	Back	Rb30	6.7841833	158.1458333
	Lagoon	Rl25	6.7946670	158.1387670
	Lagoon	Rl26	6.7942333	158.1380833
	Lagoon	Rl27	6.7938833	158.1374667
	Outer	Rs4	6.7798667	158.1446000
	Outer	Rs5	6.7798333	158.1455167
	Outer	Rs6	6.7799000	158.1462667

Appendix 5 Mean density and biomass of all finfish families recorded at the Kehpara MPA site by habitat

Habitat	Family	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back	Acanthuridae	0.208	0.034	14.620	6.351
Back	Balistidae	0.004	0.002	0.215	0.193
Back	Chaetodontidae	0.021	0.007	0.756	0.329
Back	Labridae	0.043	0.009	0.797	0.160
Back	Lethrinidae	0.004	0.002	0.481	0.344
Back	Lutjanidae	0.001	0.001	0.274	0.274
Back	Microdesmidae	0.001	0.001	0.000	0.000
Back	Mullidae	0.016	0.005	0.560	0.147
Back	Nemipteridae	0.006	0.004	0.387	0.341
Back	Ostraciidae	0.000	0.000	0.006	0.006
Back	Pomacanthidae	0.002	0.001	0.005	0.002
Back	Pomacentridae	0.086	0.033	0.322	0.165
Back	Scaridae	0.035	0.013	3.089	1.009
Back	Serranidae	0.003	0.001	0.075	0.048
Back	Siganidae	0.001	0.001	0.149	0.149
Back	Zanclidae	0.001	0.001	0.112	0.112
Lagoon	Acanthuridae	0.062	0.016	3.843	1.187
Lagoon	Apogonidae	0.003	0.003	0.013	0.013
Lagoon	Caesionidae	0.010	0.005	0.985	0.460
Lagoon	Chaetodontidae	0.023	0.005	1.537	0.974
Lagoon	Gobiidae	0.001	0.001	0.001	0.001
Lagoon	Holocentridae	0.002	0.001	0.228	0.200
Lagoon	Labridae	0.035	0.010	1.714	0.922
Lagoon	Lethrinidae	0.003	0.001	0.318	0.186
Lagoon	Lutjanidae	0.003	0.003	0.161	0.161
Lagoon	Microdesmidae	0.002	0.002	0.000	0.000
Lagoon	Mullidae	0.010	0.005	1.722	1.025
Lagoon	Nemipteridae	0.002	0.002	0.256	0.245
Lagoon	Pomacanthidae	0.003	0.002	0.475	0.411
Lagoon	Pomacentridae	0.226	0.054	0.716	0.196
Lagoon	Scaridae	0.024	0.013	2.390	1.724
Lagoon	Serranidae	0.001	0.001	0.280	0.280
Lagoon	Siganidae	0.007	0.004	0.373	0.209
Lagoon	Tetraodontidae	0.000	0.000	0.004	0.004
Lagoon	Zanclidae	0.003	0.001	0.165	0.106
Outer	Acanthuridae	0.232	0.040	21.792	10.831
Outer	Apogonidae	0.001	0.001	0.018	0.018
Outer	Balistidae	0.005	0.003	0.838	0.554
Outer	Caesionidae	0.027	0.023	4.402	3.133

Habitat	Family	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Carangidae	0.002	0.001	0.767	0.507
Outer	Chaetodontidae	0.031	0.006	2.021	0.856
Outer	Cirrhitidae	0.002	0.002	0.005	0.005
Outer	Haemulidae	0.007	0.007	31.665	31.665
Outer	Holocentridae	0.002	0.002	0.993	0.993
Outer	Labridae	0.043	0.007	1.521	0.748
Outer	Lethrinidae	0.002	0.001	1.412	0.897
Outer	Lutjanidae	0.026	0.024	17.081	16.801
Outer	Microdesmidae	0.007	0.002	0.000	0.000
Outer	Mullidae	0.028	0.012	2.872	0.827
Outer	Pomacanthidae	0.003	0.002	0.164	0.095
Outer	Pomacentridae	0.461	0.055	0.902	0.217
Outer	Scaridae	0.032	0.017	6.107	3.501
Outer	Serranidae	0.007	0.003	0.233	0.110
Outer	Siganidae	0.009	0.002	1.355	0.408
Outer	Zanclidae	0.003	0.001	0.347	0.206

Appendix 6 Mean density and biomass of all finfish families recorded at the Kehpara Open site by habitat

Habitat	Family	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back	Acanthuridae	0.019	0.008	0.209	0.091
Back	Balistidae	0.002	0.001	0.121	0.065
Back	Chaetodontidae	0.014	0.003	0.232	0.081
Back	Labridae	0.056	0.020	0.433	0.144
Back	Mullidae	0.001	0.000	0.008	0.006
Back	Nemipteridae	0.007	0.003	0.208	0.139
Back	Pomacentridae	0.645	0.104	3.093	1.013
Back	Scaridae	0.007	0.003	0.214	0.144
Back	Serranidae	0.003	0.002	0.093	0.040
Back	Siganidae	0.017	0.012	0.223	0.159
Lagoon	Acanthuridae	0.054	0.011	3.270	0.997
Lagoon	Apogonidae	0.003	0.003	0.008	0.008
Lagoon	Aulostomidae	0.000	0.000	0.003	0.003
Lagoon	Chaetodontidae	0.027	0.006	1.344	0.335
Lagoon	Gobiidae	0.000	0.000	0.009	0.009
Lagoon	Labridae	0.036	0.008	1.505	0.431
Lagoon	Lethrinidae	0.000	0.000	0.045	0.045
Lagoon	Lutjanidae	0.000	0.000	0.162	0.162
Lagoon	Mullidae	0.005	0.003	0.458	0.273
Lagoon	Pomacanthidae	0.002	0.002	0.462	0.431
Lagoon	Pomacentridae	0.518	0.074	2.913	1.243
Lagoon	Scaridae	0.033	0.012	2.418	0.599
Lagoon	Serranidae	0.001	0.001	0.032	0.021
Lagoon	Siganidae	0.017	0.003	0.759	0.177
Lagoon	Zanclidae	0.007	0.002	0.597	0.210
Outer	Acanthuridae	0.194	0.022	12.516	4.026
Outer	Apogonidae	0.001	0.001	0.012	0.009
Outer	Balistidae	0.005	0.002	1.359	1.116
Outer	Caesionidae	0.018	0.014	7.025	6.234
Outer	Chaetodontidae	0.018	0.001	0.869	0.425
Outer	Cirrhitidae	0.001	0.001	0.003	0.003
Outer	Holocentridae	0.000	0.000	0.015	0.015
Outer	Labridae	0.057	0.018	1.493	0.641
Outer	Lethrinidae	0.002	0.002	0.238	0.238
Outer	Microdesmidae	0.008	0.005	0.000	0.000
Outer	Mullidae	0.004	0.002	0.336	0.268
Outer	Nemipteridae	0.004	0.004	0.079	0.072
Outer	Pomacanthidae	0.003	0.001	0.128	0.107
Outer	Pomacentridae	0.434	0.075	0.972	0.351

Habitat	Family	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Scaridae	0.028	0.015	1.777	0.803
Outer	Serranidae	0.001	0.001	0.240	0.155
Outer	Siganidae	0.013	0.005	0.843	0.305
Outer	Zanclidae	0.003	0.002	0.370	0.242

Appendix 7 Mean density and biomass of all fish species recorded at the Kehpara MPA site by habitat

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back	Acanthuridae	*Acanthurus gahhm*	0.006	0.004	0.827	0.693
Back	Acanthuridae	*Acanthurus nigricans*	0.006	0.003	0.170	0.094
Back	Acanthuridae	*Acanthurus nigricauda*	0.001	0.001	0.045	0.045
Back	Acanthuridae	*Acanthurus nigrofuscus*	0.028	0.015	2.224	1.621
Back	Acanthuridae	*Acanthurus nigroris*	0.053	0.039	0.723	0.466
Back	Acanthuridae	*Acanthurus triostegus*	0.013	0.006	0.572	0.295
Back	Acanthuridae	*Ctenochaetus striatus*	0.099	0.042	9.600	6.767
Back	Acanthuridae	*Zebrasoma scopas*	0.002	0.002	0.030	0.030
Back	Acanthuridae	*Zebrasoma veliferum*	0.001	0.001	0.429	0.429
Back	Balistidae	*Balistapus undulatus*	0.001	0.001	0.014	0.010
Back	Balistidae	*Melichthys vidua*	0.001	0.001	0.078	0.078
Back	Balistidae	*Rhinecanthus aculeatus*	0.002	0.001	0.123	0.112
Back	Chaetodontidae	*Chaetodon auriga*	0.004	0.003	0.124	0.070
Back	Chaetodontidae	*Chaetodon citrinellus*	0.004	0.002	0.041	0.025
Back	Chaetodontidae	*Chaetodon ephippium*	0.003	0.001	0.202	0.108
Back	Chaetodontidae	*Chaetodon lineolatus*	0.001	0.001	0.056	0.056
Back	Chaetodontidae	*Chaetodon lunulatus*	0.004	0.002	0.164	0.118
Back	Chaetodontidae	*Chaetodon melannotus*	0.001	0.001	0.035	0.035
Back	Chaetodontidae	*Chaetodon rafflesii*	0.002	0.001	0.029	0.020
Back	Chaetodontidae	*Chaetodon trifascialis*	0.000	0.000	0.001	0.001
Back	Chaetodontidae	*Chaetodon ulietensis*	0.001	0.001	0.065	0.049
Back	Chaetodontidae	*Chaetodon vagabundus*	0.001	0.001	0.039	0.018
Back	Labridae	*Cheilinus chlorourus*	0.000	0.000	0.001	0.001
Back	Labridae	*Cheilinus undulatus*	0.000	0.000	0.162	0.162
Back	Labridae	*Gomphosus varius*	0.001	0.000	0.019	0.012
Back	Labridae	*Halichoeres chrysus*	0.000	0.000	0.005	0.005
Back	Labridae	*Halichoeres hortulanus*	0.008	0.003	0.127	0.044
Back	Labridae	*Halichoeres marginatus*	0.000	0.000	0.003	0.003
Back	Labridae	*Halichoeres trimaculatus*	0.007	0.003	0.070	0.045
Back	Labridae	*Labroides dimidiatus*	0.008	0.002	0.014	0.004
Back	Labridae	*Oxycheilinus celebicus*	0.001	0.001	0.097	0.097
Back	Labridae	*Thalassoma hardwicke*	0.017	0.006	0.285	0.083
Back	Labridae	*Thalassoma quinquevittatum*	0.000	0.000	0.015	0.015
Back	Lethrinidae	*Lethrinus harak*	0.001	0.001	0.382	0.361
Back	Lethrinidae	*Lethrinus semicinctus*	0.003	0.002	0.099	0.055
Back	Lutjanidae	*Lutjanus semicinctus*	0.001	0.001	0.274	0.274
Back	Microdesmidae	*Nemateleotris magnifica*	0.001	0.001	0.000	0.000
Back	Mullidae	*Mulloidichthys flavolineatus*	0.001	0.001	0.045	0.045
Back	Mullidae	*Parupeneus barberinus*	0.005	0.002	0.233	0.140

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back	Mullidae	*Parupeneus bifasciatus*	0.007	0.004	0.169	0.083
Back	Mullidae	*Parupeneus cyclostomus*	0.001	0.001	0.095	0.095
Back	Mullidae	*Parupeneus multifasciatus*	0.001	0.000	0.018	0.011
Back	Nemipteridae	*Scolopsis bilineata*	0.002	0.002	0.346	0.346
Back	Nemipteridae	*Scolopsis lineatus*	0.004	0.004	0.041	0.041
Back	Ostraciidae	*Ostracion meleagris*	0.000	0.000	0.006	0.006
Back	Pomacanthidae	*Centropyge vrolikii*	0.002	0.001	0.005	0.002
Back	Pomacentridae	*Chromis margaritifer*	0.002	0.002	0.001	0.001
Back	Pomacentridae	*Chromis viridis*	0.002	0.002	0.006	0.006
Back	Pomacentridae	*Chrysiptera biocellata*	0.007	0.005	0.020	0.015
Back	Pomacentridae	*Chrysiptera brownriggii*	0.002	0.002	0.004	0.004
Back	Pomacentridae	*Chrysiptera traceyi*	0.003	0.002	0.006	0.006
Back	Pomacentridae	*Chrysiptera unimaculata*	0.005	0.005	0.014	0.013
Back	Pomacentridae	*Dascyllus aruanus*	0.016	0.007	0.035	0.016
Back	Pomacentridae	*Dascyllus melanurus*	0.001	0.001	0.001	0.001
Back	Pomacentridae	*Dascyllus trimaculatus*	0.003	0.003	0.006	0.006
Back	Pomacentridae	*Plectroglyphidodon lacrymatus*	0.002	0.002	0.006	0.006
Back	Pomacentridae	*Plectroglyphidodon leucozonus*	0.004	0.002	0.006	0.004
Back	Pomacentridae	*Pomacentrus moluccensis*	0.002	0.002	0.003	0.003
Back	Pomacentridae	*Pomacentrus simsiang*	0.000	0.000	0.000	0.000
Back	Pomacentridae	*Stegastes fasciolatus*	0.000	0.000	0.001	0.001
Back	Pomacentridae	*Stegastes nigricans*	0.038	0.023	0.212	0.132
Back	Scaridae	*Chlorurus sordidus*	0.027	0.011	2.150	0.598
Back	Scaridae	*Hipposcarus longiceps*	0.006	0.003	0.279	0.143
Back	Scaridae	*Scarus dimidiatus*	0.001	0.001	0.531	0.531
Back	Scaridae	*Scarus ghobban*	0.001	0.001	0.129	0.106
Back	Serranidae	*Epinephelus merra*	0.003	0.001	0.075	0.048
Back	Siganidae	*Siganus lineatus*	0.001	0.001	0.149	0.149
Back	Zanclidae	*Zanclus cornutus*	0.001	0.001	0.112	0.112
Lagoon	Acanthuridae	*Acanthurus blochii*	0.012	0.012	0.488	0.488
Lagoon	Acanthuridae	*Acanthurus gahhm*	0.000	0.000	0.001	0.001
Lagoon	Acanthuridae	*Acanthurus grammoptilus*	0.000	0.000	0.082	0.082
Lagoon	Acanthuridae	*Acanthurus nigricauda*	0.003	0.002	0.316	0.299
Lagoon	Acanthuridae	*Acanthurus nigrofuscus*	0.012	0.008	0.469	0.394
Lagoon	Acanthuridae	*Acanthurus pyroferus*	0.000	0.000	0.015	0.015
Lagoon	Acanthuridae	*Ctenochaetus striatus*	0.027	0.012	2.338	1.422
Lagoon	Acanthuridae	*Naso lituratus*	0.001	0.001	0.057	0.057
Lagoon	Acanthuridae	*Zebrasoma scopas*	0.005	0.002	0.059	0.021
Lagoon	Acanthuridae	*Zebrasoma veliferum*	0.001	0.001	0.017	0.012
Lagoon	Apogonidae	*Cheilodipterus quinquelineatus*	0.003	0.003	0.013	0.013
Lagoon	Caesionidae	*Caesio caerulaurea*	0.001	0.001	0.426	0.426

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Lagoon	Caesionidae	*Pterocaesio marri*	0.009	0.006	0.560	0.354
Lagoon	Chaetodontidae	*Chaetodon auriga*	0.007	0.003	0.467	0.349
Lagoon	Chaetodontidae	*Chaetodon bennetti*	0.001	0.000	0.036	0.026
Lagoon	Chaetodontidae	*Chaetodon ephippium*	0.002	0.001	0.141	0.107
Lagoon	Chaetodontidae	*Chaetodon lunulatus*	0.004	0.002	0.067	0.032
Lagoon	Chaetodontidae	*Chaetodon melannotus*	0.001	0.001	0.005	0.005
Lagoon	Chaetodontidae	*Chaetodon rafflesii*	0.001	0.001	0.015	0.015
Lagoon	Chaetodontidae	*Chaetodon ulietensis*	0.003	0.001	0.095	0.048
Lagoon	Chaetodontidae	*Chaetodon vagabundus*	0.001	0.001	0.207	0.207
Lagoon	Chaetodontidae	*Forcipiger flavissimus*	0.001	0.001	0.062	0.062
Lagoon	Chaetodontidae	*Heniochus chrysostomus*	0.001	0.001	0.091	0.091
Lagoon	Chaetodontidae	*Heniochus monoceros*	0.001	0.001	0.158	0.131
Lagoon	Chaetodontidae	*Heniochus singularius*	0.001	0.000	0.050	0.042
Lagoon	Chaetodontidae	*Heniochus varius*	0.001	0.001	0.143	0.143
Lagoon	Gobiidae	*Amblygobius rainfordi*	0.001	0.001	0.001	0.001
Lagoon	Holocentridae	*Myripristis murdjan*	0.000	0.000	0.200	0.200
Lagoon	Holocentridae	*Neoniphon sammara*	0.001	0.001	0.027	0.024
Lagoon	Labridae	*Anampses twistii*	0.001	0.001	0.002	0.002
Lagoon	Labridae	*Cheilinus chlorourus*	0.000	0.000	0.000	0.000
Lagoon	Labridae	*Cheilinus fasciatus*	0.011	0.002	1.276	0.676
Lagoon	Labridae	*Cheilinus undulatus*	0.001	0.001	0.099	0.099
Lagoon	Labridae	*Coris aygula*	0.001	0.001	0.002	0.002
Lagoon	Labridae	*Coris gaimard*	0.002	0.001	0.003	0.002
Lagoon	Labridae	*Epibulus insidiator*	0.002	0.001	0.184	0.118
Lagoon	Labridae	*Gomphosus varius*	0.001	0.001	0.007	0.007
Lagoon	Labridae	*Halichoeres hortulanus*	0.002	0.001	0.074	0.053
Lagoon	Labridae	*Labroides bicolor*	0.002	0.001	0.001	0.001
Lagoon	Labridae	*Labroides dimidiatus*	0.009	0.003	0.021	0.009
Lagoon	Labridae	*Oxycheilinus celebicus*	0.000	0.000	0.001	0.001
Lagoon	Labridae	*Thalassoma hardwicke*	0.004	0.001	0.043	0.016
Lagoon	Labridae	*Thalassoma lutescens*	0.000	0.000	0.002	0.002
Lagoon	Lethrinidae	*Lethrinus erythropterus*	0.001	0.001	0.100	0.070
Lagoon	Lethrinidae	*Monotaxis grandoculis*	0.001	0.001	0.218	0.193
Lagoon	Lutjanidae	*Lutjanus fulvus*	0.003	0.003	0.161	0.161
Lagoon	Microdesmidae	*Ptereleotris evides*	0.002	0.002	0.000	0.000
Lagoon	Mullidae	*Mulloidichthys flavolineatus*	0.003	0.003	0.167	0.167
Lagoon	Mullidae	*Parupeneus barberinus*	0.005	0.002	0.439	0.216
Lagoon	Mullidae	*Parupeneus bifasciatus*	0.001	0.001	0.731	0.684
Lagoon	Mullidae	*Parupeneus multifasciatus*	0.002	0.001	0.385	0.278
Lagoon	Nemipteridae	*Scolopsis bilineata*	0.000	0.000	0.009	0.009
Lagoon	Nemipteridae	*Scolopsis lineatus*	0.002	0.002	0.247	0.247

Habitat	Family	Species	Density (fish/m²)	SE density	Biomass (g/m²)	SE biomass
Lagoon	Pomacanthidae	*Centropyge vrolikii*	0.000	0.000	0.003	0.003
Lagoon	Pomacanthidae	*Pygoplites diacanthus*	0.003	0.002	0.472	0.412
Lagoon	Pomacentridae	*Abudefduf vaigiensis*	0.005	0.005	0.009	0.009
Lagoon	Pomacentridae	*Amblyglyphidodon curacao*	0.132	0.018	0.533	0.201
Lagoon	Pomacentridae	*Chromis ternatensis*	0.005	0.005	0.019	0.019
Lagoon	Pomacentridae	*Chromis vanderbilti*	0.001	0.001	0.000	0.000
Lagoon	Pomacentridae	*Chromis viridis*	0.029	0.021	0.030	0.019
Lagoon	Pomacentridae	*Chromis xanthura*	0.005	0.005	0.006	0.006
Lagoon	Pomacentridae	*Chrysiptera traceyi*	0.007	0.005	0.005	0.003
Lagoon	Pomacentridae	*Chrysiptera unimaculata*	0.002	0.002	0.002	0.002
Lagoon	Pomacentridae	*Dascyllus aruanus*	0.026	0.020	0.042	0.034
Lagoon	Pomacentridae	*Pomacentrus auriventris*	0.001	0.001	0.001	0.001
Lagoon	Pomacentridae	*Pomacentrus coelestis*	0.002	0.002	0.002	0.002
Lagoon	Pomacentridae	*Pomacentrus pavo*	0.004	0.004	0.007	0.007
Lagoon	Pomacentridae	*Pomacentrus simsiang*	0.001	0.001	0.001	0.001
Lagoon	Pomacentridae	*Pomacentrus vaiuli*	0.003	0.002	0.003	0.002
Lagoon	Pomacentridae	*Stegastes nigricans*	0.002	0.002	0.057	0.057
Lagoon	Scaridae	*Chlorurus sordidus*	0.021	0.012	1.755	1.372
Lagoon	Scaridae	*Hipposcarus longiceps*	0.001	0.001	0.027	0.027
Lagoon	Scaridae	*Scarus dimidiatus*	0.002	0.001	0.453	0.389
Lagoon	Scaridae	*Scarus ghobban*	0.001	0.000	0.155	0.148
Lagoon	Serranidae	*Cephalopholis argus*	0.001	0.001	0.278	0.278
Lagoon	Serranidae	*Epinephelus merra*	0.000	0.000	0.002	0.002
Lagoon	Siganidae	*Siganus doliatus*	0.001	0.001	0.016	0.016
Lagoon	Siganidae	*Siganus puellus*	0.005	0.003	0.335	0.197
Lagoon	Siganidae	*Siganus vulpinus*	0.001	0.001	0.023	0.023
Lagoon	Tetraodontidae	*Canthigaster valentini*	0.000	0.000	0.004	0.004
Lagoon	Zanclidae	*Zanclus cornutus*	0.003	0.001	0.165	0.106
Outer	Acanthuridae	*Acanthurus achilles*	0.008	0.008	1.912	1.912
Outer	Acanthuridae	*Acanthurus gahhm*	0.002	0.002	0.045	0.045
Outer	Acanthuridae	*Acanthurus lineatus*	0.001	0.001	0.039	0.039
Outer	Acanthuridae	*Acanthurus nigricans*	0.021	0.004	1.653	0.734
Outer	Acanthuridae	*Acanthurus nigrofuscus*	0.044	0.036	1.254	0.893
Outer	Acanthuridae	*Acanthurus nigroris*	0.010	0.010	0.149	0.149
Outer	Acanthuridae	*Acanthurus pyroferus*	0.000	0.000	0.001	0.001
Outer	Acanthuridae	*Ctenochaetus binotatus*	0.002	0.002	0.157	0.157
Outer	Acanthuridae	*Ctenochaetus striatus*	0.098	0.041	12.088	7.794
Outer	Acanthuridae	*Naso lituratus*	0.009	0.003	1.946	1.077
Outer	Acanthuridae	*Zebrasoma flavescens*	0.000	0.000	0.001	0.001
Outer	Acanthuridae	*Zebrasoma scopas*	0.026	0.006	1.417	0.652
Outer	Acanthuridae	*Zebrasoma veliferum*	0.009	0.007	1.130	0.789

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Apogonidae	*Cheilodipterus quinquelineatus*	0.001	0.001	0.018	0.018
Outer	Balistidae	*Balistapus undulatus*	0.001	0.000	0.043	0.029
Outer	Balistidae	*Melichthys vidua*	0.004	0.003	0.795	0.532
Outer	Caesionidae	*Caesio caerulaurea*	0.003	0.003	1.273	1.273
Outer	Caesionidae	*Caesio teres*	0.023	0.023	3.129	3.129
Outer	Carangidae	*Caranx melampygus*	0.002	0.001	0.767	0.507
Outer	Chaetodontidae	*Chaetodon auriga*	0.007	0.003	0.889	0.515
Outer	Chaetodontidae	*Chaetodon citrinellus*	0.001	0.001	0.034	0.034
Outer	Chaetodontidae	*Chaetodon ephippium*	0.002	0.001	0.047	0.029
Outer	Chaetodontidae	*Chaetodon kleinii*	0.000	0.000	0.020	0.020
Outer	Chaetodontidae	*Chaetodon lineolatus*	0.001	0.001	0.029	0.029
Outer	Chaetodontidae	*Chaetodon lunulatus*	0.005	0.004	0.197	0.155
Outer	Chaetodontidae	*Chaetodon melannotus*	0.001	0.001	0.008	0.008
Outer	Chaetodontidae	*Chaetodon pelewensis*	0.001	0.001	0.010	0.010
Outer	Chaetodontidae	*Chaetodon rafflesii*	0.003	0.002	0.017	0.011
Outer	Chaetodontidae	*Chaetodon reticulatus*	0.001	0.001	0.086	0.072
Outer	Chaetodontidae	*Chaetodon ulietensis*	0.003	0.002	0.082	0.053
Outer	Chaetodontidae	*Chaetodon vagabundus*	0.001	0.001	0.182	0.182
Outer	Chaetodontidae	*Forcipiger flavissimus*	0.002	0.001	0.016	0.010
Outer	Chaetodontidae	*Heniochus chrysostomus*	0.001	0.001	0.081	0.052
Outer	Chaetodontidae	*Heniochus monoceros*	0.002	0.001	0.280	0.227
Outer	Chaetodontidae	*Heniochus singularius*	0.000	0.000	0.043	0.043
Outer	Cirrhitidae	*Paracirrhites forsteri*	0.002	0.002	0.005	0.005
Outer	Haemulidae	*Plectorhinchus albovittatus*	0.007	0.007	31.665	31.665
Outer	Holocentridae	*Myripristis adusta*	0.002	0.002	0.993	0.993
Outer	Labridae	*Anampses meleagrides*	0.001	0.001	0.009	0.009
Outer	Labridae	*Anampses twistii*	0.000	0.000	0.001	0.001
Outer	Labridae	*Bodianus axillaris*	0.000	0.000	0.003	0.003
Outer	Labridae	*Cheilinus fasciatus*	0.001	0.001	0.043	0.043
Outer	Labridae	*Cheilinus trilobatus*	0.001	0.001	0.004	0.004
Outer	Labridae	*Coris aygula*	0.001	0.001	0.001	0.001
Outer	Labridae	*Coris gaimard*	0.001	0.000	0.005	0.004
Outer	Labridae	*Epibulus insidiator*	0.002	0.001	0.576	0.350
Outer	Labridae	*Gomphosus varius*	0.003	0.001	0.017	0.006
Outer	Labridae	*Halichoeres chrysus*	0.001	0.001	0.016	0.014
Outer	Labridae	*Halichoeres hortulanus*	0.007	0.002	0.307	0.115
Outer	Labridae	*Hemigymnus fasciatus*	0.001	0.001	0.365	0.365
Outer	Labridae	*Hemigymnus melapterus*	0.000	0.000	0.018	0.018
Outer	Labridae	*Labroides bicolor*	0.002	0.001	0.015	0.012
Outer	Labridae	*Labroides dimidiatus*	0.018	0.002	0.032	0.011
Outer	Labridae	*Stethojulis bandanensis*	0.000	0.000	0.001	0.001

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Labridae	*Thalassoma hardwicke*	0.001	0.001	0.017	0.017
Outer	Labridae	*Thalassoma lunare*	0.000	0.000	0.034	0.034
Outer	Labridae	*Thalassoma lutescens*	0.003	0.002	0.031	0.026
Outer	Labridae	*Thalassoma quinquevittatum*	0.000	0.000	0.027	0.027
Outer	Lethrinidae	*Lethrinus semicinctus*	0.000	0.000	0.114	0.114
Outer	Lethrinidae	*Monotaxis grandoculis*	0.002	0.001	1.298	0.838
Outer	Lutjanidae	*Aphareus furca*	0.001	0.001	0.095	0.095
Outer	Lutjanidae	*Lutjanus fulviflammus*	0.001	0.001	0.507	0.507
Outer	Lutjanidae	*Lutjanus gibbus*	0.023	0.023	16.123	16.123
Outer	Lutjanidae	*Macolor niger*	0.001	0.001	0.355	0.220
Outer	Microdesmidae	*Nemateleotris magnifica*	0.007	0.002	0.000	0.000
Outer	Mullidae	*Parupeneus barberinus*	0.011	0.011	0.092	0.067
Outer	Mullidae	*Parupeneus bifasciatus*	0.010	0.003	1.862	0.831
Outer	Mullidae	*Parupeneus cyclostomus*	0.001	0.001	0.057	0.056
Outer	Mullidae	*Parupeneus multifasciatus*	0.005	0.001	0.861	0.503
Outer	Pomacanthidae	*Centropyge vrolikii*	0.002	0.001	0.004	0.003
Outer	Pomacanthidae	*Pygoplites diacanthus*	0.002	0.001	0.160	0.096
Outer	Pomacentridae	*Amphiprion chrysopterus*	0.002	0.001	0.016	0.009
Outer	Pomacentridae	*Amphiprion clarkii*	0.002	0.001	0.027	0.026
Outer	Pomacentridae	*Amphiprion perideraion*	0.002	0.001	0.004	0.002
Outer	Pomacentridae	*Chromis margaritifer*	0.283	0.059	0.307	0.060
Outer	Pomacentridae	*Chromis ternatensis*	0.003	0.003	0.002	0.002
Outer	Pomacentridae	*Chromis vanderbilti*	0.001	0.001	0.001	0.001
Outer	Pomacentridae	*Chromis viridis*	0.003	0.003	0.001	0.001
Outer	Pomacentridae	*Chromis xanthura*	0.101	0.025	0.461	0.198
Outer	Pomacentridae	*Chrysiptera traceyi*	0.029	0.011	0.027	0.013
Outer	Pomacentridae	*Chrysiptera unimaculata*	0.002	0.001	0.002	0.002
Outer	Pomacentridae	*Lepidozygus tapeinosoma*	0.011	0.011	0.002	0.002
Outer	Pomacentridae	*Plectroglyphidodon lacrymatus*	0.002	0.002	0.007	0.007
Outer	Pomacentridae	*Plectroglyphidodon leucozonus*	0.000	0.000	0.015	0.015
Outer	Pomacentridae	*Pomacentrus auriventris*	0.005	0.004	0.007	0.004
Outer	Pomacentridae	*Pomacentrus coelestis*	0.003	0.002	0.002	0.001
Outer	Pomacentridae	*Pomacentrus vaiuli*	0.012	0.012	0.021	0.021
Outer	Scaridae	*Chlorurus microrhinos*	0.003	0.003	1.051	1.051
Outer	Scaridae	*Chlorurus sordidus*	0.019	0.008	1.982	0.805
Outer	Scaridae	*Hipposcarus longiceps*	0.001	0.000	0.193	0.179
Outer	Scaridae	*Scarus altipinnis*	0.006	0.006	2.249	2.249
Outer	Scaridae	*Scarus dimidiatus*	0.000	0.000	0.012	0.012
Outer	Scaridae	*Scarus ghobban*	0.001	0.001	0.258	0.186
Outer	Scaridae	*Scarus globiceps*	0.001	0.001	0.188	0.188
Outer	Scaridae	*Scarus rivulatus*	0.001	0.001	0.174	0.174

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Serranidae	*Cephalopholis argus*	0.001	0.000	0.061	0.041
Outer	Serranidae	*Cephalopholis urodeta*	0.002	0.001	0.160	0.094
Outer	Serranidae	*Epinephelus tukula*	0.001	0.001	0.011	0.007
Outer	Serranidae	*Pseudanthias pascalus*	0.003	0.003	0.001	0.001
Outer	Siganidae	*Siganus vulpinus*	0.009	0.002	1.355	0.408
Outer	Zanclidae	*Zanclus cornutus*	0.003	0.001	0.347	0.206

Appendix 8 Mean density and biomass of all fish recorded at the Kehpara Open site by habitat

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back	Acanthuridae	*Acanthurus nigricans*	0.002	0.002	0.001	0.001
Back	Acanthuridae	*Acanthurus triostegus*	0.017	0.008	0.206	0.091
Back	Acanthuridae	*Zebrasoma veliferum*	0.000	0.000	0.001	0.001
Back	Balistidae	*Rhinecanthus aculeatus*	0.002	0.001	0.121	0.065
Back	Chaetodontidae	*Chaetodon auriga*	0.006	0.002	0.073	0.032
Back	Chaetodontidae	*Chaetodon citrinellus*	0.000	0.000	0.000	0.000
Back	Chaetodontidae	*Chaetodon ephippium*	0.003	0.001	0.131	0.068
Back	Chaetodontidae	*Chaetodon lunulatus*	0.000	0.000	0.001	0.001
Back	Chaetodontidae	*Chaetodon rafflesii*	0.001	0.000	0.002	0.001
Back	Chaetodontidae	*Chaetodon semeion*	0.001	0.001	0.005	0.005
Back	Chaetodontidae	*Chaetodon trifascialis*	0.002	0.001	0.018	0.012
Back	Chaetodontidae	*Chaetodon ulietensis*	0.000	0.000	0.001	0.001
Back	Labridae	*Gomphosus varius*	0.001	0.001	0.014	0.014
Back	Labridae	*Halichoeres chrysus*	0.002	0.001	0.011	0.011
Back	Labridae	*Halichoeres hortulanus*	0.001	0.001	0.010	0.010
Back	Labridae	*Halichoeres trimaculatus*	0.035	0.015	0.201	0.071
Back	Labridae	*Hemigymnus melapterus*	0.002	0.002	0.047	0.047
Back	Labridae	*Labroides dimidiatus*	0.003	0.002	0.001	0.001
Back	Labridae	*Oxycheilinus celebicus*	0.000	0.000	0.002	0.002
Back	Labridae	*Thalassoma hardwicke*	0.013	0.010	0.143	0.115
Back	Labridae	*Thalassoma lutescens*	0.000	0.000	0.002	0.002
Back	Labridae	*Thalassoma trilobatum*	0.000	0.000	0.001	0.001
Back	Mullidae	*Parupeneus indicus*	0.000	0.000	0.001	0.001
Back	Mullidae	*Parupeneus multifasciatus*	0.000	0.000	0.006	0.006
Back	Nemipteridae	*Scolopsis bilineata*	0.005	0.002	0.176	0.140
Back	Nemipteridae	*Scolopsis lineatus*	0.003	0.002	0.032	0.023
Back	Pomacentridae	*Chromis margaritifer*	0.001	0.001	0.000	0.000
Back	Pomacentridae	*Chromis viridis*	0.042	0.018	0.031	0.013
Back	Pomacentridae	*Chromis xanthura*	0.004	0.004	0.039	0.039
Back	Pomacentridae	*Chrysiptera biocellata*	0.027	0.027	0.085	0.085
Back	Pomacentridae	*Chrysiptera traceyi*	0.016	0.009	0.029	0.016
Back	Pomacentridae	*Chrysiptera unimaculata*	0.036	0.028	0.237	0.216
Back	Pomacentridae	*Dascyllus aruanus*	0.325	0.043	1.163	0.493
Back	Pomacentridae	*Dascyllus melanurus*	0.064	0.036	0.461	0.387
Back	Pomacentridae	*Dascyllus trimaculatus*	0.011	0.008	0.397	0.321
Back	Pomacentridae	*Plectroglyphidodon dickii*	0.001	0.001	0.004	0.004
Back	Pomacentridae	*Plectroglyphidodon lacrymatus*	0.007	0.007	0.008	0.008
Back	Pomacentridae	*Plectroglyphidodon leucozonus*	0.004	0.002	0.033	0.025
Back	Pomacentridae	*Pomacentrus moluccensis*	0.012	0.011	0.019	0.018

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Back	Pomacentridae	*Pomacentrus nagasakiensis*	0.016	0.016	0.030	0.030
Back	Pomacentridae	*Pomacentrus vaiuli*	0.000	0.000	0.002	0.002
Back	Pomacentridae	*Stegastes nigricans*	0.079	0.037	0.552	0.324
Back	Scaridae	*Chlorurus sordidus*	0.003	0.001	0.051	0.034
Back	Scaridae	*Hipposcarus longiceps*	0.002	0.002	0.011	0.011
Back	Scaridae	*Scarus oviceps*	0.002	0.002	0.152	0.152
Back	Serranidae	*Epinephelus merra*	0.003	0.002	0.093	0.040
Back	Siganidae	*Siganus spinus*	0.017	0.012	0.223	0.159
Lagoon	Acanthuridae	*Acanthurus achilles*	0.001	0.001	0.092	0.092
Lagoon	Acanthuridae	*Acanthurus nigricans*	0.001	0.000	0.080	0.070
Lagoon	Acanthuridae	*Acanthurus nigrofuscus*	0.009	0.008	0.539	0.369
Lagoon	Acanthuridae	*Acanthurus nigroris*	0.004	0.004	0.040	0.040
Lagoon	Acanthuridae	*Ctenochaetus striatus*	0.024	0.012	1.408	0.576
Lagoon	Acanthuridae	*Naso lituratus*	0.002	0.001	0.372	0.171
Lagoon	Acanthuridae	*Naso unicornis*	0.001	0.001	0.292	0.292
Lagoon	Acanthuridae	*Zebrasoma scopas*	0.011	0.003	0.399	0.130
Lagoon	Acanthuridae	*Zebrasoma veliferum*	0.002	0.001	0.047	0.014
Lagoon	Apogonidae	*Apogon fragilis*	0.002	0.002	0.002	0.002
Lagoon	Apogonidae	*Cheilodipterus quinquelineatus*	0.001	0.001	0.006	0.006
Lagoon	Aulostomidae	*Aulostomus chinensis*	0.000	0.000	0.003	0.003
Lagoon	Chaetodontidae	*Chaetodon auriga*	0.002	0.001	0.131	0.091
Lagoon	Chaetodontidae	*Chaetodon ephippium*	0.006	0.002	0.431	0.176
Lagoon	Chaetodontidae	*Chaetodon lunulatus*	0.009	0.002	0.378	0.098
Lagoon	Chaetodontidae	*Chaetodon melannotus*	0.000	0.000	0.017	0.017
Lagoon	Chaetodontidae	*Chaetodon rafflesii*	0.002	0.001	0.034	0.022
Lagoon	Chaetodontidae	*Chaetodon trifascialis*	0.001	0.001	0.058	0.044
Lagoon	Chaetodontidae	*Chaetodon ulietensis*	0.003	0.001	0.092	0.037
Lagoon	Chaetodontidae	*Chaetodon vagabundus*	0.000	0.000	0.068	0.068
Lagoon	Chaetodontidae	*Coradion altivelis*	0.000	0.000	0.005	0.005
Lagoon	Chaetodontidae	*Forcipiger flavissimus*	0.001	0.001	0.051	0.051
Lagoon	Chaetodontidae	*Heniochus chrysostomus*	0.000	0.000	0.023	0.023
Lagoon	Chaetodontidae	*Heniochus monoceros*	0.001	0.001	0.050	0.037
Lagoon	Chaetodontidae	*Heniochus varius*	0.000	0.000	0.005	0.005
Lagoon	Gobiidae	*Cryptocentrus fasciatus*	0.000	0.000	0.009	0.009
Lagoon	Labridae	*Anampses meleagrides*	0.001	0.001	0.085	0.085
Lagoon	Labridae	*Anampses twistii*	0.000	0.000	0.010	0.010
Lagoon	Labridae	*Cheilinus chlorourus*	0.001	0.001	0.016	0.016
Lagoon	Labridae	*Cheilinus fasciatus*	0.005	0.003	0.445	0.232
Lagoon	Labridae	*Cheilinus undulatus*	0.000	0.000	0.070	0.070
Lagoon	Labridae	*Coris aygula*	0.001	0.001	0.016	0.008
Lagoon	Labridae	*Epibulus insidiator*	0.002	0.001	0.426	0.289

Habitat	Family	Species	Density ($fish/m^2$)	SE density	Biomass (g/m^2)	SE biomass
Lagoon	Labridae	*Gomphosus varius*	0.001	0.001	0.041	0.029
Lagoon	Labridae	*Halichoeres hortulanus*	0.001	0.000	0.026	0.018
Lagoon	Labridae	*Halichoeres richmondi*	0.000	0.000	0.001	0.001
Lagoon	Labridae	*Halichoeres trimaculatus*	0.001	0.001	0.030	0.030
Lagoon	Labridae	*Labroides dimidiatus*	0.007	0.001	0.019	0.002
Lagoon	Labridae	*Oxycheilinus celebicus*	0.007	0.003	0.132	0.048
Lagoon	Labridae	*Thalassoma hardwicke*	0.007	0.006	0.129	0.068
Lagoon	Labridae	*Thalassoma lunare*	0.001	0.000	0.030	0.019
Lagoon	Labridae	*Thalassoma lutescens*	0.000	0.000	0.029	0.029
Lagoon	Lethrinidae	*Lethrinus semicinctus*	0.000	0.000	0.045	0.045
Lagoon	Lutjanidae	*Macolor niger*	0.000	0.000	0.162	0.162
Lagoon	Mullidae	*Parupeneus barberinus*	0.004	0.003	0.346	0.282
Lagoon	Mullidae	*Parupeneus multifasciatus*	0.001	0.001	0.112	0.089
Lagoon	Pomacanthidae	*Centropyge bicolor*	0.000	0.000	0.001	0.001
Lagoon	Pomacanthidae	*Pygoplites diacanthus*	0.002	0.002	0.461	0.431
Lagoon	Pomacentridae	*Abudefduf vaigiensis*	0.045	0.029	0.100	0.063
Lagoon	Pomacentridae	*Amblyglyphidodon curacao*	0.355	0.073	1.855	0.843
Lagoon	Pomacentridae	*Amblyglyphidodon leucogaster*	0.024	0.016	0.349	0.306
Lagoon	Pomacentridae	*Chromis margaritifer*	0.002	0.002	0.003	0.003
Lagoon	Pomacentridae	*Chromis viridis*	0.063	0.026	0.299	0.183
Lagoon	Pomacentridae	*Dascyllus aruanus*	0.001	0.001	0.003	0.003
Lagoon	Pomacentridae	*Dascyllus trimaculatus*	0.002	0.002	0.081	0.081
Lagoon	Pomacentridae	*Pomacentrus coelestis*	0.003	0.003	0.003	0.002
Lagoon	Pomacentridae	*Pomacentrus pavo*	0.022	0.022	0.217	0.217
Lagoon	Pomacentridae	*Stegastes nigricans*	0.001	0.001	0.003	0.003
Lagoon	Scaridae	*Chlorurus frontalis*	0.000	0.000	0.054	0.054
Lagoon	Scaridae	*Chlorurus microrhinos*	0.001	0.001	0.166	0.114
Lagoon	Scaridae	*Chlorurus sordidus*	0.024	0.013	1.374	0.637
Lagoon	Scaridae	*Hipposcarus longiceps*	0.001	0.001	0.030	0.030
Lagoon	Scaridae	*Scarus dimidiatus*	0.002	0.001	0.262	0.189
Lagoon	Scaridae	*Scarus forsteni*	0.001	0.001	0.080	0.080
Lagoon	Scaridae	*Scarus ghobban*	0.001	0.001	0.210	0.136
Lagoon	Scaridae	*Scarus globiceps*	0.001	0.001	0.049	0.033
Lagoon	Scaridae	*Scarus spinus*	0.002	0.001	0.191	0.146
Lagoon	Serranidae	*Cephalopholis argus*	0.000	0.000	0.005	0.005
Lagoon	Serranidae	*Epinephelus merra*	0.001	0.001	0.027	0.019
Lagoon	Siganidae	*Siganus doliatus*	0.006	0.003	0.170	0.087
Lagoon	Siganidae	*Siganus puellus*	0.007	0.002	0.425	0.143
Lagoon	Siganidae	*Siganus spinus*	0.001	0.001	0.075	0.075
Lagoon	Siganidae	*Siganus vulpinus*	0.003	0.001	0.089	0.040
Lagoon	Zanclidae	*Zanclus cornutus*	0.007	0.002	0.597	0.210

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Acanthuridae	*Acanthurus achilles*	0.003	0.003	0.233	0.233
Outer	Acanthuridae	*Acanthurus grammoptilus*	0.001	0.001	0.207	0.207
Outer	Acanthuridae	*Acanthurus nigricans*	0.020	0.004	1.577	0.677
Outer	Acanthuridae	*Acanthurus nigrofuscus*	0.057	0.031	1.827	1.305
Outer	Acanthuridae	*Ctenochaetus striatus*	0.065	0.025	4.801	2.504
Outer	Acanthuridae	*Ctenochaetus strigosus*	0.001	0.001	0.004	0.004
Outer	Acanthuridae	*Naso lituratus*	0.004	0.002	0.648	0.436
Outer	Acanthuridae	*Zebrasoma scopas*	0.043	0.011	3.198	1.666
Outer	Acanthuridae	*Zebrasoma veliferum*	0.000	0.000	0.022	0.022
Outer	Apogonidae	*Cheilodipterus quinquelineatus*	0.001	0.001	0.012	0.009
Outer	Balistidae	*Balistapus undulatus*	0.002	0.001	0.427	0.384
Outer	Balistidae	*Melichthys vidua*	0.003	0.002	0.932	0.736
Outer	Caesionidae	*Caesio caerulaurea*	0.003	0.003	0.690	0.690
Outer	Caesionidae	*Caesio lunaris*	0.004	0.004	0.016	0.016
Outer	Caesionidae	*Caesio teres*	0.011	0.011	6.319	6.319
Outer	Chaetodontidae	*Chaetodon auriga*	0.000	0.000	0.065	0.065
Outer	Chaetodontidae	*Chaetodon bennetti*	0.000	0.000	0.017	0.017
Outer	Chaetodontidae	*Chaetodon citrinellus*	0.003	0.001	0.024	0.011
Outer	Chaetodontidae	*Chaetodon ephippium*	0.004	0.002	0.397	0.228
Outer	Chaetodontidae	*Chaetodon lunula*	0.001	0.001	0.138	0.138
Outer	Chaetodontidae	*Chaetodon lunulatus*	0.003	0.001	0.106	0.055
Outer	Chaetodontidae	*Chaetodon melannotus*	0.001	0.001	0.002	0.002
Outer	Chaetodontidae	*Chaetodon rafflesii*	0.001	0.001	0.010	0.010
Outer	Chaetodontidae	*Chaetodon reticulatus*	0.000	0.000	0.037	0.037
Outer	Chaetodontidae	*Chaetodon speculum*	0.002	0.002	0.042	0.035
Outer	Chaetodontidae	*Forcipiger flavissimus*	0.000	0.000	0.013	0.013
Outer	Chaetodontidae	*Heniochus monoceros*	0.002	0.002	0.019	0.019
Outer	Cirrhitidae	*Paracirrhites forsteri*	0.001	0.001	0.003	0.003
Outer	Holocentridae	*Neoniphon sammara*	0.000	0.000	0.015	0.015
Outer	Labridae	*Cheilinus chlorourus*	0.001	0.001	0.075	0.075
Outer	Labridae	*Coris aygula*	0.001	0.001	0.001	0.000
Outer	Labridae	*Coris gaimard*	0.000	0.000	0.000	0.000
Outer	Labridae	*Epibulus insidiator*	0.003	0.001	0.878	0.560
Outer	Labridae	*Gomphosus varius*	0.003	0.001	0.019	0.014
Outer	Labridae	*Halichoeres chrysus*	0.001	0.001	0.002	0.002
Outer	Labridae	*Halichoeres hortulanus*	0.009	0.002	0.423	0.170
Outer	Labridae	*Labroides bicolor*	0.003	0.002	0.001	0.001
Outer	Labridae	*Labroides dimidiatus*	0.031	0.017	0.027	0.011
Outer	Labridae	*Macropharyngodon meleagris*	0.000	0.000	0.001	0.001
Outer	Labridae	*Oxycheilinus celebicus*	0.001	0.001	0.008	0.008
Outer	Labridae	*Oxycheilinus unifasciatus*	0.000	0.000	0.001	0.001

Habitat	Family	Species	Density (fish/m^2)	SE density	Biomass (g/m^2)	SE biomass
Outer	Labridae	*Thalassoma lutescens*	0.001	0.001	0.004	0.003
Outer	Labridae	*Thalassoma purpureum*	0.001	0.001	0.036	0.036
Outer	Labridae	*Thalassoma quinquevittatum*	0.002	0.002	0.016	0.011
Outer	Lethrinidae	*Monotaxis grandoculis*	0.002	0.002	0.238	0.238
Outer	Microdesmidae	*Nemateleotris helfrichi*	0.000	0.000	0.000	0.000
Outer	Microdesmidae	*Nemateleotris magnifica*	0.003	0.002	0.000	0.000
Outer	Microdesmidae	*Ptereleotris evides*	0.004	0.003	0.000	0.000
Outer	Mullidae	*Parupeneus barberinus*	0.001	0.000	0.009	0.006
Outer	Mullidae	*Parupeneus bifasciatus*	0.001	0.001	0.201	0.201
Outer	Mullidae	*Parupeneus multifasciatus*	0.003	0.001	0.126	0.065
Outer	Nemipteridae	*Scolopsis affinis*	0.004	0.004	0.073	0.073
Outer	Nemipteridae	*Scolopsis lineatus*	0.000	0.000	0.006	0.006
Outer	Pomacanthidae	*Centropyge flavissimus*	0.000	0.000	0.000	0.000
Outer	Pomacanthidae	*Centropyge heraldi*	0.001	0.001	0.001	0.001
Outer	Pomacanthidae	*Centropyge vrolikii*	0.001	0.001	0.006	0.005
Outer	Pomacanthidae	*Pygoplites diacanthus*	0.001	0.001	0.121	0.108
Outer	Pomacentridae	*Amphiprion chrysopterus*	0.003	0.002	0.004	0.003
Outer	Pomacentridae	*Amphiprion clarkii*	0.001	0.001	0.039	0.039
Outer	Pomacentridae	*Amphiprion melanopus*	0.002	0.002	0.012	0.012
Outer	Pomacentridae	*Amphiprion perideraion*	0.001	0.001	0.001	0.001
Outer	Pomacentridae	*Chromis margaritifer*	0.268	0.077	0.243	0.066
Outer	Pomacentridae	*Chromis xanthura*	0.104	0.037	0.528	0.286
Outer	Pomacentridae	*Dascyllus trimaculatus*	0.004	0.003	0.006	0.005
Outer	Pomacentridae	*Plectroglyphidodon lacrymatus*	0.018	0.014	0.063	0.059
Outer	Pomacentridae	*Pomacentrus coelestis*	0.017	0.017	0.061	0.061
Outer	Pomacentridae	*Pomacentrus pavo*	0.013	0.013	0.009	0.009
Outer	Pomacentridae	*Pomacentrus vaiuli*	0.002	0.001	0.006	0.004
Outer	Scaridae	*Chlorurus sordidus*	0.024	0.015	0.946	0.693
Outer	Scaridae	*Scarus altipinnis*	0.001	0.001	0.161	0.161
Outer	Scaridae	*Scarus dimidiatus*	0.000	0.000	0.181	0.181
Outer	Scaridae	*Scarus ghobban*	0.001	0.001	0.199	0.199
Outer	Scaridae	*Scarus globiceps*	0.001	0.001	0.290	0.262
Outer	Serranidae	*Cephalopholis urodeta*	0.001	0.001	0.240	0.155
Outer	Siganidae	*Siganus argenteus*	0.001	0.001	0.010	0.010
Outer	Siganidae	*Siganus doliatus*	0.001	0.001	0.109	0.069
Outer	Siganidae	*Siganus randalli*	0.001	0.001	0.060	0.060
Outer	Siganidae	*Siganus vulpinus*	0.010	0.003	0.664	0.290
Outer	Zanclidae	*Zanclus cornutus*	0.003	0.002	0.370	0.242

Appendix 9 Invertebrate survey form

DATE		RECORDER		Pg No	

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

Appendix 10 GPS positions of manta tow surveys conducted at the Kehpara MPA and Kehpara Open monitoring sites, 2012

Site	Station ID	Replicate	Start Latitide (N)	Start Longitude (E)
Kehpara MPA	Manta 3	1	6.808317	158.117567
Kehpara MPA	Manta 3	2	6.805333	158.11745
Kehpara MPA	Manta 3	3	6.80265	158.118117
Kehpara MPA	Manta 3	4	6.800817	158.117583
Kehpara MPA	Manta 3	5	6.798617	158.1189
Kehpara MPA	Manta 3	6	6.7989	158.120167
Kehpara MPA	Manta 4	1	6.800567	158.121367
Kehpara MPA	Manta 4	2	6.799933	158.121933
Kehpara MPA	Manta 4	3	6.799933	158.124367
Kehpara MPA	Manta 4	4	6.798117	158.126017
Kehpara MPA	Manta 4	5	6.798183	158.122833
Kehpara MPA	Manta 4	6	6.796567	158.120467
Kehpara MPA	Manta 5	1	6.794817	158.120867
Kehpara MPA	Manta 5	2	6.794783	158.1233
Kehpara MPA	Manta 5	3	6.793517	158.123867
Kehpara Open	Manta 1	1	6.800133	158.153117
Kehpara Open	Manta 1	2	6.7995	158.15495
Kehpara Open	Manta 1	3	6.798183	158.156883
Kehpara Open	Manta 1	4	6.795483	158.1568
Kehpara Open	Manta 1	5	6.7937	158.155367
Kehpara Open	Manta 1	6	6.793867	158.1567
Kehpara Open	Manta 2	1	6.808233	158.117717
Kehpara Open	Manta 2	2	6.810183	158.11925
Kehpara Open	Manta 2	3	6.812133	158.1182
Kehpara Open	Manta 2	4	6.815083	158.11865
Kehpara Open	Manta 2	5	6.817733	158.118483
Kehpara Open	Manta 2	6	6.820333	158.11785
Kehpara Open	Manta 5	1	6.791783	158.1214
Kehpara Open	Manta 5	2	6.791017	158.124
Kehpara Open	Manta 5	3	6.790517	158.12615
Kehpara Open	Manta 6	1	6.783483	158.150167
Kehpara Open	Manta 6	2	6.784517	158.1483
Kehpara Open	Manta 6	3	6.787083	158.148383
Kehpara Open	Manta 6	4	6.78605	158.146367
Kehpara Open	Manta 6	5	6.78515	158.143867
Kehpara Open	Manta 6	6	6.785317	158.141583
Kehpara Open	Manta 7	1	6.78445	158.13865
Kehpara Open	Manta 7	2	6.78475	158.13565
Kehpara Open	Manta 7	3	6.7864	158.134033
Kehpara Open	Manta 7	4	6.789733	158.1324

Site	Station ID	Replicate	Start Latitide (N)	Start Longitude (E)
Kehpara Open	Manta 7	5	6.792067	158.131483
Kehpara Open	Manta 7	6	6.794033	158.13005

Appendix 11 Mean category score or percent cover (± SE) of each habitat category at the manta tow and reef-benthos transect (RBT) stations of the Kehpara MPA and Open monitoring sites, 2012

Habitat category	Manta tow		RBT	
	Kehpara MPA	Kehpara Open	Kehpara MPA	Kehpara Open
Relief	3.28±0.15	2.80±0.23	1.63±0.16	1.46±0.19
Complexity	3.78±0.11	3.20±0.18	2.23±0.22	1.77±0.24
Oceanic influence	3.11±0.11	3.40±0.19	1.27±0.16	1.31±0.19
Mud	0.00±0.00	1.67±1.29	0.00±0.00	0.00±0.00
Sand	9.44±8.23	7.83±4.84	38.67±2.34	40.73±3.51
Coarse sand	13.61±10.83	29.67±11.06	0.21±0.21	0.73±0.48
Rubble	9.44±3.38	16.53±2.74	10.10±18.2	9.52±1.74
Boulders	1.94±1.21	4.47±1.71	0.63±0.63	1.56±0.78
Consolidated rubble	0.00±0.00	1.00±1.00	1.23±0.43	0.42±0.31
Pavement	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Live coral	16.11±4.75	15.33±4.71	39.35±1.83	39.75±3.81
Dead coral	49.44±10.83	23.50±3.80	9.81±1.17	7.29±1.99
Bleaching coral	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Crustose coralline algae	3.61±3.61	10.83±7.79	20.63±5.25	8.06±3.17
Coralline algae	0.00±0.00	5.33±3.43	10.85±2.41	3.52±0.92
Other algae	0.00±0.00	0.00±0.00	39.54±6.58	19.50±7.63
Seagrass	0.00±0.00	0.00±0.00	0.00±0.00	9.90±6.48
Soft coral	1.72±1.72	2.10±1.61	10.29±1.36	5.31±1.40
Sponge	0.28±0.28	0.27±0.23	10.60±1.07	3.98±0.87
Fungids	0.00±0.00	0.03±0.03	5.19±1.69	2.42±1.00

Appendix 12 Mean density (± SE) of individual invertebrate species recorded during manta tow surveys at the Kehpara MPA and Kehpara Open monitoring sites, 2012

Group	Species	Density (individuals/ha)	
		Kehpara MPA	Kehpara Open
Sea cucumber	*Bohadschia argus*	94.44±67.36	187.22±149.94
	Bohadschia vitiensis	5.56±3.21	0.56±0.56
	Holothuria atra	893.52±236.01	634.44±327.82
	Holothuria coluber	2.78±2.78	-
	Holothuria edulis	445.37±142.20	187.78±68.55
	Holothuria flavomaculata	4.63±3.34	1.11±0.68
	Holothuria sp.	13.89±6.99	2.22±2.22
	Holothuria whitmeai	-	0.56±0.56
	Pearsonothuria graeffei	43.52±25.37	69.44±45.51
	Stichopus chloronotus	70.37±5.16	23.89±9.88
	Stichopus hermanni	6.48±6.48	21.67±9.23
	Thelenota ananas	2.78±2.78	5.56±1.76
Bivalve	*Atrina* sp.	-	0.56±0.56
	Tridacna maxima	45.37±43.99	
Gastropod	*Conus* sp.	0.93±0.93	0.56±0.56
	Cypraea sp.	11.11±5.56	4.44±4.44
	Tectus niloticus	2.78±2.78	
Starfish	*Acanthaster planci*	3.70±0.93	2.22±1.36
	Linckia laevigata	23.15±11.82	16.67±11.11
	Linckia sp.	-	21.67±21.67

Appendix 13 GPS positions of reef-benthos transects conducted at the Kehpara MPA and Kehpara Open monitoring sites, 2012

Site	Station ID	Latitude (N)	Longitude (E)
Kehpara MPA	RBT 1	6.808367	158.117617
Kehpara MPA	RBT 2	6.806717	158.1172
Kehpara MPA	RBT 3	6.80495	158.117217
Kehpara MPA	RBT 4	6.804083	158.1173
Kehpara MPA	RBT 5	6.802483	158.11745
Kehpara MPA	RBT 6	6.801417	158.117167
Kehpara MPA	RBT 7	6.798733	158.118333
Kehpara MPA	RBT 8	6.79860	158.118433
Kehpara Open	RBT 9	6.823083	158.117117
Kehpara Open	RBT 10	6.783983	158.15055
Kehpara Open	RBT 11	6.784117	158.13845
Kehpara Open	RBT 12	6.788983	158.132933
Kehpara Open	RBT 13	6.796117	158.129467
Kehpara Open	RBT 14	6.79470	158.138767
Kehpara Open	RBT 15	6.78960	158.148733
Kehpara Open	RBT 16	6.78395	158.14685

Appendix 14 Mean density (± SE) of individual invertebrate species recorded during reef-benthos transect assessments at the Kehpara MPA and Kehpara Open monitoring sites, 2012

Group	Species	Density (individuals/ha)	
		Kehpara MPA	Kehpara Open
Sea cucumber	*Actinopyga mauritiana*	5.21±5.21	5.21±5.21
	Bohadschia argus	250.00±63.97	223.96±97.70
	Bohadschia graeffei	10.42±10.42	-
	Bohadschia vitiensis	52.08±26.99	-
	Holothuria atra	3276.04±601.18	4270.83±1506.95
	Holothuria coluber	-	15.63±15.63
	Holothuria edulis	729.17±107.97	583.33±260.45
	Holothuria flavomaculata	-	255.21±237.59
	Holothuria fuscogilva	-	5.21±5.21
	Holothuria fuscopunctata	5.21±5.21	5.21±5.21
	Holothuria leucospilota	5.21±5.21	26.04±26.04
	Holothuria whitmeai	-	10.42±10.42
	Pearsonothuria graeffei	-	5.21±5.21
	Stichopus chloronotus	182.29±100.20	52.08±21.52
	Thelenota ananas	5.21±5.21	5.21±5.21
Bivalve	*Hippopus hippopus*	20.83±15.75	10.42±6.82
	Pinctada margaritifera	31.25±13.06	15.63±15.63
	Tridacna maxima	281.25±16.94	218.75±149.77
	Tridacna squamosa	10.42±10.42	-
Gastropod	*Cerithium nodulosum*	10.42±6.82	-
	Charonia tritonis	15.63±15.63	-
	Conomurex luhuanus	41.67±17.61	-
	Conus litteratus	5.21±5.21	-
	Conus marmoreus	20.83±11.14	5.21±5.21
	Conus sp.	5.21±5.21	-
	Conus vexillum	20.83±15.75	5.21±5.21
	Coralliophila violacea[4]	72.92±53.26	-
	Cypraea sp.	5.21±5.21	-
	Cypraea tigris	98.96±47.20	26.04+20.74
	Dendropoma maximum	22098.96±6825.72	10.42±10.42
	Dendropoma sp.	2416.67±2416.67	-
	Lambis crocata	15.63±15.63	-
	Lambis lambis	52.08±26.99	26.04±20.74
	Lambis truncata	15.63±7.62	-
	Mitra mitra	5.21±5.21	-
	Monetaria moneta[5]	5.21±5.21	-

[4] This species was formerly known as *Coralliophila violacea*

Group	**Species**	**Density (individuals/ha)**	
		Kehpara MPA	**Kehpara Open**
	Pleuroploca trapezium	10.42±10.42	-
	Strombus chrysostomus	5.21±5.21	-
	Strombus gibberulus gibbosus	10.42±10.42	-
	Tectus pyramis	197.92±174.44	-
	Thais aculeata	26.04±17.50	-
	Thais kieneri	5.21±5.21	-
	Thais tuberosa	5.21±5.21	-
	Trochus maculata	5.21±5.21	-
	Turbo argyrostomus	15.63±15.63	-
	Vasum turbinellus[6]	5.21±5.21	-
Starfish	*Acanthaster planci*	78.13±22.87	20.83±11.14
	Culcita novaeguineae	52.08±25.82	31.25±20.46
	Culcita sp.	10.42±10.42	-
	Linckia laevigata	1182.29±125.97	656.25
	Linckia sp.	135.42±73.34	-
Urchin	*Diadema* sp.	5.21±5.21	-
	Toxopneustes sp.	-	5.21±5.21

[5] This species was formerly known as *Cypraea moneta*
[6] This species was formerly known as *Vasum turbinellum*

Appendix 15 GPS positions of soft-benthos transects conducted at the Pwudoi MPA and Open monitoring sites, 2012

Site	Station ID	Latitude (N)	Longitude (E)
Pwudoi MPA	SBT 5	6.84835	158.1534
Open site	SBT 1	6.8135	158.15385
Open site	SBT 2	6.8025	158.1663
Open site	SBT 3	6.8177	158.15525
Open site	SBT 4	6.827633	158.15165

Appendix 16 Mean category score or percent cover (± SE) of each habitat category at the soft-benthos transect (SBT) stations at the Pwudoi MPA and Open monitoring sites, 2012

Habitat category	Pwudoi MPA	Open site
Relief	1.00	1.00±0.00
Complexity	2.00	1.38±0.13
Oceanic influence	1.00	1.00±0.00
Mud	0.00	12.50±9.46
Sand	100.00	85.63±8.80
Coarse sand	0.00	1.25±1.25
Rubble	0.00	0.63±0.63
Boulders	0.00	0.00±0.00
Consolidated rubble	0.00	0.00±0.00
Pavement	0.00	0.00±0.00
Live coral	0.00	0.00±0.00
Dead coral	0.00	0.00±0.00
Bleaching coral	0.00	0.00±0.00
Crustose coralline algae	0.00	0.63±0.63
Coralline algae	0.00	12.08±9.36
Other algae	0.00	0.42±0.42
Seagrass	40.00	54.08±14.97
Soft coral	0.00	1.04±0.63
Sponge	10.00	0.50±0.40
Fungids	0.00	0.00±0.00
Epiphytes	0.00	0.63±0.00
Particulates	0.00	1.00±0.58

Appendix 17 Mean density (± SE) of individual invertebrate species recorded during soft-benthos transect assessments at the Pwudoi MPA and Open monitoring sites, 2012

Group	Species	Density (individuals/ha)	
		Pwudoi MPA	Open
Sea cucumber	*Actinopyga miliaris*	-	0.52±0.52
	Bohadschia argus	-	20.83±20.83
	Bohadschia similis	-	1386.46±1108.78
	Holothuria atra	125.00	706.25±491.97
	Holothuria edulis	-	500.00±500.00
	Holothuria leucospilota	-	10.42±10.42
	Holothuria scabra	-	21.35±20.67
	Stichopus vastus	187.50	31.77±24.58
	Synapta maculata	20.83	-
Bivalve	*Anadara antiquata*	-	4.69±4.69
	Pinctada margaritifera	-	62.50±62.50
	Tridacna maxima	-	104.17±104.17
Gastropod	*Cypraea tigris*	-	2.08±2.08
	Lambis lambis	20.83	1.04±1.04
Starfish	*Culcita novaeguineae*	-	41.67±41.67