Ateweberhan, M., Gough, C., Fennelly L. and Frejaville, Y.

The Nearshore Rocky Reefs of Western Ghana, West Africa:

Baseline ecological research surveys

blue ventures
discovery through research

Omnibus Business Centre,
39-41 North Road,
London
N7 9DP
research@blueventures.org

Tel: +44 (0)20 7697 8598
Fax: +44 (0)800 066 4032

USAID FROM THE AMERICAN PEOPLE
Coastal Resources Center University of Rhode Island
Hɛn Mpoano

This publication is available electronically on the Blue Ventures website at http://blueventures.org and the Coastal Resources Center's website at http://www.crc.uri.edu

For more information contact: Coastal Resources Center, University of Rhode Island, Narragansett Bay Campus, South Ferry Road, Narragansett, Rhode Island 02882, USA. Brian Crawford, Director International Programs at Email: brian@crc.uri.edu; Tel: 401-874-6224; Fax: 401-874-6920

Acknowledgements: This study was commissioned by the Coastal Resources Center (CRC), University of Rhode Island through support from the United States Agency for International Development (USAID). We would like to express our gratitude to CRC for supporting the study and our thanks also go to CRC and World Fish Center staff in Ghana for their collaboration, in particular Mark Fenn for his instrumental advice throughout the project. Our special appreciation is extended to the fishers in Western Ghana who participated in our work, and welcomed us into their community. Finally, our warm regards go to Mike and Silvia and their staff at Kedas Lodge, Miemia, for sharing their local knowledge and friendly hospitality.

Citation: Ateweberhan, M., Gough, C., Fennelly, L., and Frejaville, Y. (2012). Nearshore Rocky Reefs of Western Ghana, West Africa: Baseline ecological research surveys. Blue Ventures Conservation, London, United Kingdom. 104 pp.

Disclaimer: This publication is made possible by the generous support of the American people through USAID/Ghana. The contents are the responsibility of the authors as part of the Integrated Coastal and Fisheries Governance Project and do not necessarily reflect the views of not reflect the views of USAID/Ghana or the United States Government. Associate Cooperative Agreement No. 641-A-00-09-00036-00 for "Integrated Coastal and Fisheries Governance (ICFG) Program for the Western Region of Ghana," under the Leader with Associates Award No. EPP-A-00-04-00014-00.

Cover photo: Ghanaian fisherman sorting the morning catch

Cover photo credit: Gough, C. 2012

1. Table of Contents

EXECUTIVE SUMMARY

Ghana's coastal region supports productive fisheries that provide a major supply of protein and significant economic support to the nation. Over the decades poor fisheries governance and management - in large part due to the open access nature of the fisheries, overfishing and the use of destructive fishing methods - have led to marked declines in fisheries landings.

With the majority of studies focusing on the more productive and commercially more important pelagic and deep demersal environments, ecological information on the near shore rocky reef habitats (NSRH) of Ghana and West Africa in general is very limited. The present study fills this knowledge gap, by investigating the general status of the NSRH and fisheries of western Ghana, providing baseline information on the fish, invertebrate and benthic communities.

Results point towards extreme overfishing in these habitats and provide empirical evidence in support of the call for effective fisheries management.

Fish community is characterised by low biomass and dominated by small-sized lower trophic groups

Fish abundance data shows that sites were categorised by three main groups: 1) those dominated by surgeonfish (Acanthuridae), 2) those dominated by damselfish (Pomacentridae) and jacks (Carangidae) and 3) those dominated by wrasse (Labridae).

Overall fish abundance was explained predominantly by the large number of small bodied pomacentrids and labrids occurring mostly at shallow depths.

Species richness and diversity indices suggest intermediate to high levels of disturbance, with the physical removal of fish preventing species from achieving high levels of abundance.

The average biomass observed in this study was low (399 kg ha-1) consistent with the dominance of small sized, low trophic level fish indicating high levels of exploitation.

The highest biomass observed in this study (1000 kg ha^{-1}) may be indicative of the productivity potential of the area; however 69% of this biomass comprised low trophic groups, suggesting that the potential biomass could be considerably higher if fishing pressure was reduced.

Fisheries in these NSRH are dominated by one-man unmotorised canoes deploying either hook and line, or set nets at the transition between the rocky and soft bottom areas. Hook and line fishing is known for being very selective targeting mostly carnivorous, and particularly piscivorous fish. Large predatory fishes were virtually absent and most predators observed during the study were small sized groupers. As large bodied and more aggressive grouper species are removed by fishing, competitive release may allow populations of the small sized grouper Niger hind, *Cephalopholis nigri,* to dominate.

The dominance of NSRH by low trophic level, small bodied fish and near absence of large sized carnivorous fish suggests that fishing pressure plays a prominent role in structuring the community.

Invertebrate community is dominated by few species indicating links to overfishing

The slate pencil urchin *Eucidaris tribuloides var. Africana* is the most abundant and most widely distributed motile invertebrate species observed.

It's extremely high abundance is most likely a result of trophic cascades related to overfishing of predatory fish.

Very low densities of commercially important macro-invertebrate groups, such as lobsters, shrimps and octopus were observed. In conjunction with the reduced predation by fish related to overfishing, overharvesting of these important predatory invertebrate species could have resulted in the release and dominance of their prey.

Dominance by sea urchins often results in ecological disturbances through excessive bioerosion (herbivorous urchins) or predation (carnivorous urchins) suggesting that dominance by *E. tribuloides* in Ghana's NSRH could have caused significant shifts in the benthic composition.

In addition, dominance of one or few species may render an ecosystem less resilient to natural or human induced environmental disturbances, with the removal of dominant species resulting in the release and dominance of their prey species.

Benthic community reflects interactive effects of physical environmental parameters and human impacts

Crustose coralline algae are the most dominant feature in the benthic community of Ghana's NSRH, followed by turf, blue-green and fleshy algae. This pattern probably results from interactive effects between the physical environment and biotic changes associated with overfishing and dominance (see above).

Fisheries landings comprise a high proportion of juvenile fish

Large sized fish observed in local catches are mainly herbivorous parrotfish and surgeonfish while large-sized predatory fish (grouper and snapper) were seldom observed. The visual surveys and catch observations support fishers' perceptions of decreasing total catches, increasing effort, declining yield (catch per unit effort - CPUE) and decreasing fish sizes and trophic levels.

The small mesh sizes of the set nets commonly used in western Ghana catch fish under optimal/mature size. Many fishers continue to use nets below the approved mesh size, and in some instances these are accompanied by other illegal fishing practices, such as use of monofilament nets, dynamite and poison fishing.

Summary and conclusions

The near shore rocky reefs of Ghana are characterised by communities typical of marine areas experiencing high levels of overfishing and associated cascading trophic effects. The near complete removal of top predatory fish by overfishing has resulted in the release of prey species and a shift to a lower diversity ecosystem, with fish, invertebrate and benthic communities now dominated by a few abundant species.

This marine and coastal ecosystem and the services that it provides would benefit greatly from the introduction of integrated coastal management.

Many of the species targeted by local fisheries in the NSRH are reef associated resident populations and local management could be a highly effective approach in species protection, as well as in facilitating habitat restoration and the recovery of depleted stocks.

Given the low diversity and functional redundancy of NSRH habitats, as well as their poor benthic complexity and high species-level dominance at every level of the ecosystem, if present levels of fishing intensity continue these ecosystems will have little capacity to resist or recover from future acute disturbances.

Management recommendations

Effective management of these areas is likely to be critical to restoring key functional groups and safeguarding ecosystem resilience.

An ecosystem-based management approach involving a combination of a network of small marine protected areas (MPAs) with multiple use zoning is suggested as the best model. The network of marine protected areas (MPA) should include core 'no-take-zones' at their centre, surrounded by temporary closures and gear restriction zones. Core no-take-zones will allow full recovery of populations, increasing the size and biomass of fish stocks. In the long term this will also benefit adjacent common use areas through supply of adult fish and larvae for recruitment (spill-over effect).

Fisheries management through gear and catch restrictions will limit overfishing and habitat destruction, thereby promoting recovery of fish biomass, restoration of habitat, enhancement of ecosystem resilience and sustainability of fisheries.

An integrated ecosystem approach should be followed as far as possible by considering spatial links and interconnections of NSRH with other adjacent environments so that maximum management benefits can be achieved.

The rapid coastal population growth and urbanisation of western Ghana, notably through the expansion of industries such as agriculture, oil and mineral mining, means that natural resource conservation and management will require high levels of integration and the involvement of multiple and diverse stakeholder groups. Co-management of MPAs with primary stakeholders such as local village councils, chief fishermen and chief fisherwomen, fish-traders, and fishmongers should be followed to help ensure that management plans are met with high levels of compliance by local communities and other stakeholders.

In addition to conservation of coastal biodiversity and vital resources, responsible fisheries management will provide an opportunity for Ghana to safeguard it traditional coastal culture and fishing heritage, and achieve meeting its international obligations of conservation and sustainable development and play a regional role of responsible participatory coastal stewardship.

1. Introduction

Ghana's coastal environment and fisheries resources

The Guinea Current Large Marine Ecosystem (GCLME) contains some of the most productive coastal and offshore waters in the world (Binet and Marchal 1993; Binet 1997; Chukwuone *et al.* 2009). These high levels of productivity are due to the seasonal upwellings that occur off the coast of Ghana and Cote d'Ivoire twice annually, typically with a larger/stronger upwelling from July to September and a second weaker pulse from December to January (Koranteng 1995).

The upwelling system supports productive fisheries with two main components: a seasonal pelagic fishery and a deep sea (demersal) fishery as well as shallow rocky and soft bottom habitats and wetlands (lagoons, estuaries and delta systems) that support minor finfish and shellfish fisheries (Mensah 1979; Entsua-Mensah and Dankwa 1997; Entsua-Mensah *et al.* 2000; Dankwa and Gordon 2002). The pelagic fishery has received the greatest research and management focus due to the high productivity and economic benefits it provides. It is exploited by diverse fleets, from un-motorized canoes to industrial ships. Small, schooling species (sardines, anchovies, and mackerel) make up the majority of the catch. Evidence from fisheries landings shows that the catch of small pelagics is currently at its lowest since the 1970s (Finegold *et al*. 2010). Natural variability of the stocks and overexploitation, including illegal means such as light fishing, are believed to be the main reasons for this declining trend (Finegold *et al*. 2010).

Figure 1.1. Growing numbers of fishers and increasing use of destructive fishing practises lead to overexploitation.

The high productivity levels linked to the upwelling system have also been shown to extend into the deeper part of the continental shelf (Perry and Sumaila 2007) and supports rich stocks of demersal (bottom-dwelling) fish. Many shallow near shore rocky and soft bottom, lagoon and mangrove habitats also stretch along the coast of Ghana. However, unlike the pelagic fishery, the smaller but yet possibly more vulnerable shallow demersal and lagoon system fisheries have been overlooked in management and policy. Demersal fish are often closely associated with the bottom habitat and their often sedentary nature makes them highly susceptible to overfishing and habitat damage. Heavy exploitation of demersal stocks were noted in the 1970s (Gulland *et al.* 1973), with more recent fisheries research surveys reporting marked declines in the abundance of demersal fish biomass between 0 and 30 m depth, and with predatory fish in particular facing greater impact (Koranteng and Pauly 2004). Recent analysis of demersal fish landings in Ghana also provide evidence for sequential overfishing with decadal shifts in the composition of fish landings (Finegold *et al*. 2010).

Food Security and Economy

Ghana's marine fisheries comprise over 70% of the national catch, accounting for an estimated 374,229 mt per year (FAO 2003; Tetteh 2010). Fish constitutes an important food source, commodity and industry in Ghana. Hugely reliant on fish and fisheries products for nutrition, estimates suggest that almost 60% of animal proteins consumed by Ghanaians are derived from fish and 75% of total annual production is consumed locally (Sarpong *et al*. 2005). The annual per capita consumption is estimated at approximately 29.6 kg, which is considerably higher than in neighbouring nations: Togo (7.0 kg), Benin (16.4 kg), Ivory Coast (12.3 kg) and Nigeria (9.0 kg), and almost double the world average of 17.8 kg (FAO 2011).

The fisheries sector plays a vital role in Ghana's national economy, providing 4.5% to Gross Domestic Product (GDP). Approximately one third of landings are marketed for export to other African countries as well as destinations in the European Union, Japan, and North America, while imports are reportedly much higher, often twice this amount and estimated at US$121.4 million in 2009 (Finegold *et al.* 2010).

Fisheries and its sub-sectors (both marine and freshwater) are estimated to provide direct employment for approximately 1.5 million people (FAO 2003; Finegold *et al*. 2010).

Population growth, fisheries exploitation and environmental threats

Ghana has a long history as an artisanal fishing nation stretching back to the 16th and 17th centuries (Overa 2001) and the Fante (or Fanti) people of western Ghana have an established reputation for being the best fishermen in West Africa. They are thought to be responsible for introducing effective fishing techniques to other parts of Ghana, as well as other countries in the GCLME (Haakonsen and Diaw 1991).

Ghana's population reached 24 million in 2011, and the country has a population growth rate of 1.9% per annum (GSS 2007-2012). The coastal population, similar to those in other developing nations, is growing faster than the national average (at around 3%) (Creel 2003; EPA/UNOPS 2004) and the population of the western region is expected to double by 2020 (GSS 2007-2012). High levels of consumption, and rapid population growth means that the national demand for fisheries resources is at its highest in history, around 676,052 mt pa (FAO 2011). With annual landings estimated just over 300,000 mt pa (2009 data) and with up to 30% of landings destined for export, more than half of the fish consumed in Ghana is now being imported from other countries (FAO 2011).

Ghana's marine fisheries are described as fully exploited, overexploited or collapsed (UNEP/LME 2010) and a number of traits observed in the fisheries sector correspond to symptoms of Malthusian Overfishing (Pauly *et al*. 1989) Many fishers use small mesh size nets against the Fisheries Departments' approved legal limits (Koranteng 2002), leading to observations of both recruitment and growth overfishing; 2) Fishers use prohibited light fishing techniques, capturing fish outside of the major fishing season, when these stocks are normally in a resting phase. It is believed that this disturbs the natural biological cycle of the fish, and could have serious repercussions on spawning stock biomass (Bannerman and Quartey 2005); 3) Light fishing techniques are used in conjunction with other destructive and non-selective methods such as the use of small mesh size nets, which is also believed to have further negative consequences on the sustainability of the fishery; 4) There is illegal dynamite and poison fishing (e.g. carbide and mosquito coils) being carried out by small groups of fishers with substantial negative impacts on stocks and habitats as well as posing significant hazard to the fishers themselves (Box 1.1); 5) Overfishing and habitat destruction are accompanied by other chronic anthropogenic impacts, such as sedimentation from fluvial discharge, as well as organic enrichment and pollution of coastal waters.

Figure 1.2. Ghana's fisheries employ 1.5 million people in associated industries including a large number of women

In the western region, many communities lack appropriate waste disposal systems and wastes are discharged directly in the nearest body of water (lagoon, lake or sea). The coastal areas have recently experienced blooms of a green seaweed *Enteromorpha clathrata* locally known as "green-green" and a brown seaweed *Sargassum sp*. The former has been linked to build up of organic nutrients whose source is believed to be the Abidjan area in Cote D'Ivoire (Coastal Resource Centre 2010). The main cause of the latter is less understood but nutrient overload from terrestrial runoff and oil pollution could be some of the main causes (McDiarmid 2012). Both algal bloom events have affected local fisheries directly by causing damage to fishing nets.

Box 1.1. Reflections of a fisher from Miemia on dynamite fishing

Dynamite fishing is carried out across the western region but occurs most frequently between Dixcove (East) and Cape three points (West).

Dynamite is purchased locally, and originates from one of the many mineral/gold mining operations in the area. The dynamite comes in the form of plastic, high explosive (TNT) sticks approximately 30 cm long and 10 cm wide. These sticks are then split into 2/3 sections and secured to a floatable object (e.g. wooden sticks). A makeshift waterproof fuse is inserted and then, when a large shoal of fish is observed below the water surface the fuse is lit, the package thrown into the water and the charge detonates.

Due to the large number of fish lost due to sinking and the risks associated with using dynamite, skilled professional fishermen generally engage in this practise only when it is more profitable than normal techniques. However, during the upwelling seasons, when schools of large bodied pelagic fish such as carangids (jack/trevally) and scombrids (mackerel and tuna) migrate close to shore and water surface it is easy for anyone to harvest good catches from the small percentage of fish that float to the surface, and as such non fishermen also go to sea to engage in this practise

Dynamite fishing also forms a component of illegal light fishing. As the shoals of small clupeids (sardine and herring) are attracted to the surface by the lights, explosives are thrown in to stun them and then nets are used to recover them to a vessel.

Lagoons often serve as sources of drinking water for many communities, as well as a source of fish, and contamination of these water bodies poses significant health risks for people and livestock. Many lagoons are open to the sea, and these contaminants may eventually end up in the sea affecting the natural functioning of marine systems. In addition, high levels of organic pollutants, including plastics in the marine environment have been reported (Coastal Resource Centre 2010). Plastic fibres, and toxic chemicals leached from plastics, build up in food webs (Mato *et al.* 2001; Thompson *et al.* 2009), and marine birds, mammals and reptiles can become entangled in floating plastics and ghost nets that persist long after they have been discarded in the marine environment (Cundell 1974; Azzarello and Van Vleet 1987; Gregory and Andrady 2003). Plastic consumption in these organisms can cause suffocation and starvation.

Climate Change impacts

Climate change, through ocean acidification and warming is significantly influencing physical and biological marine processes both at global and regional scales (Harley *et al*. 2006; Pörtner 2008; Rosenzweig *et a*l. 2008), and poses major and unforeseen challenges for ecosystems and societies. Climate variables may influence fisheries through physio-chemical effects on physiology and population dynamics, and shifts in the abundance and distribution of exploited species and assemblages (Perry *et al*. 2005; Last *et al*. 2011). In addition to changes in trophic interactions, the increasing intensity and frequency of extreme weather events such as storms and floods could affect fishing operations and infrastructure (Choi and Fisher 2003; Allison *et al.* 2009). Many marine stocks are already suffering from the consequences of overfishing and other environmental stresses, how climate change will interact with these other threats is less predictable. The combined effects of a strong dependence on fisheries for national economy and food security, high sensitivity of these fisheries to climatic variations (Binet 1997; Minta 2003) and the limited social capacity of communities to adapt imply that Ghana, along with many other nations is placed amongst the most vulnerable to climate change (Allison *et al*. 2009). There are already some indications that the decline in the pelagic fisheries is linked to climate change effects on productivity, growth of target species and catchability (Minta 2003).

The current project and study objectives

Despite terrestrial and some small wetland areas protected by the state, there are currently no Marine Protected Areas (MPA) in Ghana, and the fishery remains "open access". Marine protected areas have proved successful in restoring some level of sustainability to fisheries worldwide through the reduction of fishing pressure and preserving the larger fecund fish within their boundaries (Claudet *et al*. 2006; Edgar and Stuart-Smith 2009; Stobar *et al*. 2009). The build-up in the biomass of fecund fish helps in repopulating surrounding fished areas with adult fish and larvae known as the spill-over effect. Previous research conducted in the region has concentrated on monitoring of the extraction of biomass mainly through landings data and trawl surveys (Koranteng and Pauly 2004). Although effective in pelagic and demersal populations in soft bottom habitats, these methods are less effective for rocky habitats with complex terrains. Landings data have also been shown to have inherent problems associated with changes to fisheries technology causing an underestimation of effective fishing effort (Finegold *et al*. 2010).

The current project is an integral component of the Coastal Resources Center's (CRC, University of Rhode Island) Integrated Coastal and Fisheries Governance (ICFG) initiative for the western Ghana region. The initiative, also called *Hen Mpoano,* aims to establish Ghana's first marine protected area. By obtaining baseline ecological, fisheries and relevant socioeconomic data, the current research will complement other efforts by CRC and its counterparts.

The primary objective of this project is to quantitatively assess the current status of the marine and coastal ecosystems of the region, putting into place the protocols and methods needed to ensure the long term monitoring of key ecological, fisheries and socioeconomic variables to enable adaptive management and zoning of Ghana's first MPA. It also seeks to provide pre-requisite ecological and biological data required for identifying priority areas for protection within the proposed MPA, as well as providing technical guidance in the establishment of long-term fisheries and socioeconomic monitoring programmes to support MPA zoning and adaptive management.

The main focal area of the research is the near shore rocky habitats (NSRH) between Axim and Busua/Butre (Figure 2.1.), which is at the centre of the *Hen Mpoano* initiative. Fisheries research in Ghana has largely focused on the highly productive pelagic and deep soft and rocky bottom demersal environments. Inland waters and coastal wetlands are also relatively well studied. The NSRH however remains little investigated and the current research intends to fill the information gap that exists for this important environment that probably forms a crucial link between the deep, pelagic and intertidal and coastal wetland areas.

The standard underwater visual census (UVC) surveys involved assessment of three key ecosystem properties: a) fish community structure and biomass, b) macro-invertebrate community structure and c) benthic community structure.

Fish community structure and biomass

Fish assemblages represent different functional guilds and influence community structure of other fish, invertebrate and benthos and significantly affect resilience of a system to human induced and natural disturbances. Reef associated fishes are vulnerable to natural disturbances and anthropogenic activities, particularly those that impact the physical structure of the habitats in which they reside. Many fish species are commercially important, particularly in resource-poor coastal regions, in addition to being a food resource for local communities. With changes in fish community structure acting as indicators of ecosystem health, it is vital to assess fish diversity and abundance as well as determining stock biomass of commercially important species, so that appropriate management strategies can be implemented and their effects monitored over time.

Invertebrate abundance and community structure

Some invertebrate species, such as sea urchins and sea stars are often recognised as ‘keystone’ species due to the ecological roles they play as grazers, bio-eroders and/or predators, while others, such as octopus and lobster, are commercially important and play critical ecological roles as predators. Abundance of urchins and other invertebrates and their ecological influences are controlled both by bottom up, such as the availability of food and habitat, and top-down processes such as predation. Surveying invertebrate communities is therefore of great importance in assessing the rate of herbivory, bio-erosion and predation, as well as providing a useful indicator of fishing intensity and general ecosystem health.

Benthic cover and community structure

Marine ecosystems are largely dependent on the primary productivity of different macro algal species assemblages and functional groups that form key components of the benthic community. Other benthic species form main substrate foundation for attachment and growth of other benthos and habitat and shelter for different vertebrate and invertebrate groups. Thus, benthic community surveys are paramount to habitat assessments not only because they provide information on diversity and structure of the habitats themselves but also as a key indicators of the general health and productivity of the ecosystem. Anthropogenic factors such as fishing pressure and pollution, for example, can greatly affect competitive processes and result in ecological dominance. Depending on the susceptibility of the dominant taxa and their effect on other ecological processes the ability of a benthic system to tolerate, resist and recover from natural and human induced disturbances can vary.

2. Methods

Research Area

The focal point for the current study was in the centre of the Coastal Resource Center's (CRC) *Hɛn Mpoano* intervention zone in the Western Region of Ghana. The research area covers the coastline that stretches from the Ankobra River on the western side of the Nzema East District (4°53'49.47"N; 2°16'18.68"W), to the community of Butre in the Ahanta West District (4°49'26.09"N; 1°55'2.87"W), and is inclusive of the management/conservation priority site of Cape Three Points (Coastal Resources Center 2011 Assessment of critical habitats).

Figure 2.1. Satellite image showing locations of the 14 survey sites (See Table 2.1 for full names and habitat features of sites).

The research area was divided arbitrarily into five 10-15 km sections of coastline (quadrants), and using information gathered from focus group interviews, habitat maps of the area and local dive guide knowledge, 3-4 survey sites were selected in each quadrant based on habitat type (Headland, Bay, Patch and Island where they occurred). Due to adverse weather and oceanographic conditions, the number of proposed survey sites and transects was reduced from the initially planned 6 replicate transects each in 22 sites. Between 3 to 6 replicate transects were surveyed, with one site having 2 replicates and another site having 8.

Environmental data

Site characteristics

In order to assess the effects of environmental characteristics sites were classified by:

Habitat Type: headland, bay, patch and island.

Exposure Level: sheltered, semi-exposed and exposed based on the openness of the site to open sea.

Wave Action: low, medium and high wave energy environments based on the amount of wave action observed at each site.

Fishing Pressure: Fishing pressure was represented by the number of fishers in the nearest fishing villages, obtained from the focus group interviews, and the distance of a survey site from the village. Assuming that distance is inversely related to fishing pressure, a single composite index of fishing pressure was used by dividing the number of fishers in a village by the distance between a survey site and a fishing village. In addition, information on the number of fishing boats near the survey area observed during field trips was included. A semi-quantitative scale of low, medium and high fishing pressure was used.

The degree or level of intensity of a particular environmental parameter (e.g. low, medium, high) was determined following discussion among researchers until a consensus was achieved (Table 2.1.).

The location of each site was geo-referenced using GPS (GARMIN GPS72H), downloaded into MapSource and imported into Google Earth**.** At the start of each survey the following information was noted: Date (ddmmyyyy), Time (hh:mm) and Tide (High, Low, Falling, Rising). The following parameters were collected for each individual transect: Depth (m), *in situ* water temperature (˚C). *In situ* visibility (m) and sea condition were measured at the end of each transect (scale of 1-5) and slope (angle degrees), % Rock, sediment size and depth (scale of 1-3) were estimated.

Rugosity is a measure of the habitat, and is a commonly used as indicator of the amount of space available for colonisation by benthic organisms, and shelter and foraging area for mobile organisms. It was measured on each transect by laying the transect line following the contour of the reef, pushing the tape down into holes, cracks and crevices. On reaching the end of the tape measure (50 m) the substrate is marked, the line is pulled taut and the difference (m) between the slack line and the taut line is taken as a measure of rugosity.

Table 2.1. Site names, codes and assigned levels for environmental variables.

Site Name	Site Code	No. Fish Belts	No. Benthic belts	No. Invertebrate belts	No. Biomass belts	Habitat Type	Exposure level	Wave action level	Fishing pressure level
Abokwe Leeward	ABO_L	3	3	3	3	Island	Sheltered	Low	High
Abokwe Seaward	ABO_S	3	3	3	3	Island	Exposed	Med	High
Akitakyi Bay Big	AKE_B	6	6	6	6	Bay	Sheltered	Low	Low
Akitakyi Bay Small Left	AKE_SL	2	2	3	3	Bay	Semi exposed	High	Low
Akitakyi Bay Small Right	AKE_SR	3	3	0	3	Bay	Semi exposed	High	Low
Atwiwa	ATW	3	3	2	3	Patch	Sheltered	Low	Low
Cape Three Points	C3P	3	3	0	1	Headland	Exposed	Med	High
Miemia	MIE	3	3	3	3	Bay	Semi exposed	High	Med
Miemia Inner Patch	MIEMIA INNER	5	5	6	6	Patch	Semi exposed	High	Low
Miemia Outer Patch	MIEMIA OUTER	3	3	3	3	Patch	Semi exposed	Med	Med
Mutrakni Point	MUT	6	6	6	6	Headland	Exposed	Med	Med
Paradise Beach	PAR	6	6	6	6	Bay	Semi exposed	Low	Med
Princess Town Fort	PTF	3	3	3	3	Headland	Semi exposed	Med	Med
West Point	WPT	6	8	8	8	Headland	Exposed	Med	High

Biological data

Biological data was collected in replicate 50 m transects, laid perpendicular to the shore. The tape measure was secured at the starting location using a short piece of metal re-bar driven into the sediment or wedged into the rock. The tape measure was then laid by the fish surveyor. Fish surveyors always preceded other surveyors in order to avoid fish being scared by other divers, which would add bias to the data.

Fish species diversity, abundance and biomass

Underwater Visual Census (UVC) is a widely used surveying technique for the assessment of reef fish communities. This study employs two UVC methods:

The first technique was used for surveying fish abundance and diversity. The surveyor would swim along the 50 m transect counting and recording fish (identified to species) 2.5 m either side of the line, covering an area of 250 m^2. In order to reduce error, fish were observed in a moving box of 5 m in front of the diver by taking care to avoid double counting of fish moving in and out. In the second technique, fish biomass surveys were conducted by estimating individual length of fish according to the following size categories: 3-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80 and >80 cm. Unlike in the diversity transects fish were identified only to the family level.

Invertebrate Belts

Invertebrate counts were conducted along the same 50 m length biomass transects. A 2 m x 50 m corridor (100 m^2 area) was observed, and all motile marine macro epifauna recorded. All individuals were subsequently identified to the highest possible taxonomic level.

Benthic surveys

Cover of the major substrate and benthic groups was assessed along the 50 m transects that were used in fish diversity surveys (see above). Ten 0.5 x 0.5 m quadrats (Figure 2.2.) were placed haphazardly along each side of a transect line and cover estimated. The following major benthic animal groups were considered: hard coral, soft coral, sea anemone, sponge, zoanthid, gorgonian, antipatharia, tunicate and barnacle. Benthic macro algae were classified into the following five functional groups: blue-green algal mat, fleshy algae, turf algae, articulate coralline and crustose coralline algae. Substrates devoid of benthic organisms were recorded as bare rock, sand or mud.

Fisher interviews

In order to establish understanding of the fishing communities of the western region a number of semi structured workshops/focus groups were undertaken in eight villages along the coast. Contact was made primarily with the chief fisherman from each village and a small gathering of between 6 and 12 fishers, each representing different types of boat and fishing techniques were assembled for the discussion[1].

---

[1] Results from fisher interviews are presented as Supplementary Information

The questions asked were intended to allow researchers to understand where and how they fished and included the collection of information on the different types of fishing boats, fishing gear, where and how these fishing gears were employed and which species they primarily targeted in different fishing areas and during different seasons. Due to the informal nature of the meetings additional information on fishers' perceptions of the status of the fisheries, pattern of change in recent years, and targeting protected or endangered species was often offered by fishermen.

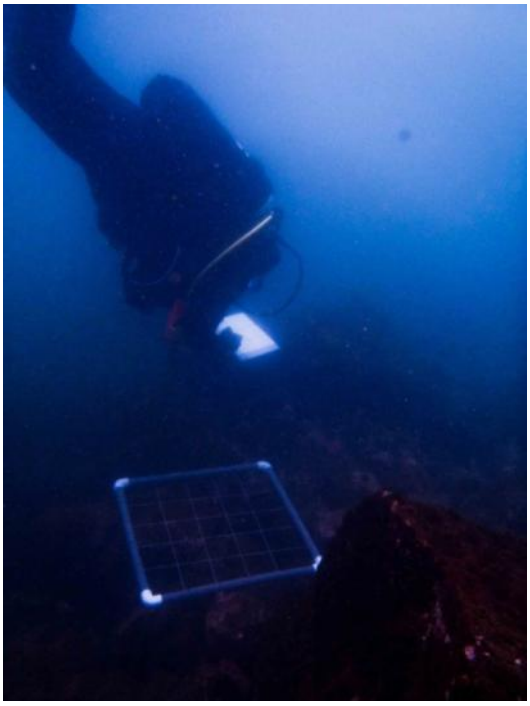


Figure 2.2. Divers undertake benthic surveys using quadrats.

Fishing surveys

Following focus group interviews, observations of local catches and review of national fisheries statistics, it became apparent that a large proportion of the shallow demersal fisheries catch originates from habitats with muddy sediments adjacent to the rocky reef, sites that were surveyed using the methods detailed above. These underwater visual survey methods are ineffective in muddy or turbid areas, which often have low visibility. However, because of the importance of these habitats to local fisheries, broad assessments were undertaken so as to gain knowledge on the species and establish overlap in target species between these and the NSRH[2].

In Figure 2.3, the same two nets (see Figure 2.4.) were deployed each day between 10:30 and 12:30, and retrieved the next morning between 9:00 and 10:30. In order to reduce bias, fishing was carried out by the same fishers in all three days. Soak time was calculated as the period of time from start of deployment to end time of retrieval of the net.

---

[2] Results from fishing surveys are also presented as Supplementary Information

Figure 2.3. Location of fishing sites (red lines indicate location and direction of fishing nets).

During retrieval of the nets, fish were removed and placed flat on a wooden board with a tape measure. Each individual fish was photographed and then returned to the fishermen. On returning to shore, photographs were downloaded onto the computer and two researchers identified independently each fish to the highest taxonomic level possible and using the tape measure present in the photograph recorded its length. Once identification was agreed, the mean length was calculated from the two observations. Length-weight conversions were collected from http://www.fishbase.org and the estimated weight of each fish calculated[3].

Total yield (kg) was calculated from estimated fish weights and catch per unit effort (CPUE) calculated as total catch/total soak-time (kg hr^{-1}).

---

[3] Where length: weight conversions were not available, information on the closest species available was used.

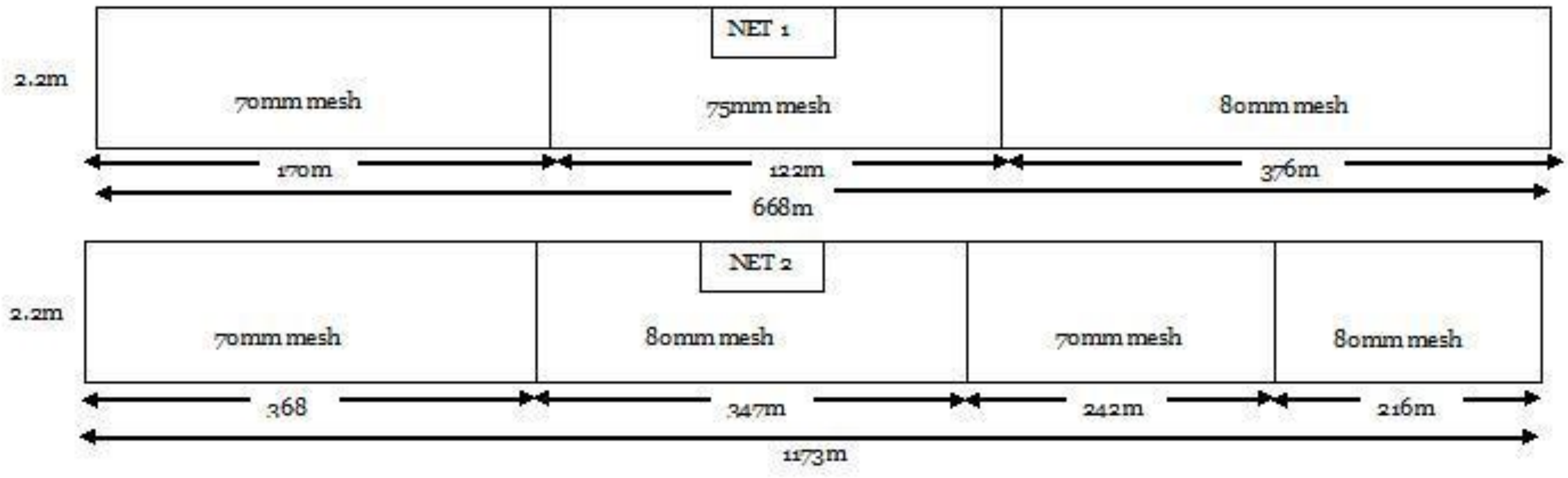


Figure 2.4. Dimensions of fishing nets employed during fishing surveys.

Data Analysis

A combination of univariate and multivariate techniques were applied in analysing the data. Comparisons in abundance, diversity, biomass and cover for selected (important taxa) by site, habitat type, exposure and wave strength were made. Aspects of community structure were investigated with multivariate analyses. Relationships between target biotic variables and environmental and biotic factors expected to influence their distribution were also analysed with both univariate and multivariate techniques.

The occurrence and abundance of different fish and invertebrate species was used to calculate species richness (SpR) and Simpson's species diversity index (SDI). Species richness was calculated as the total number of species observed on each site, while Simpson's Diversity Index was calculated using the following formula:

$$\mathbf{(1-\lambda) = 1 - (\Sigma pi^2)}$$

Where pi = the proportion of the total count arising from the i^{th} species (Magurran 1988). This index reduces the relative importance of abundant categories, expressing diversity not only as a measure of species richness but also how evenly individuals are distributed among the different species. An increasing SDI value corresponds with increasing diversity, while dominance of a few or a single species lowers the SDI value.

The trophic level for each fish species was recorded using published trophic level data (Froese *et al*. 2000) where a trophic level of ≤ 2 is equivalent to a herbivore, 2.1 to 3.7 is an omnivore (trophs below 2.1 - 2.9 preferentially feeding on vegetal matter and those above 2.9 – 3.7 preferring animal foodstuffs), and 3.7 to 4.5 is a carnivorous animal feeding entirely on other lower troph animals (3.7 - 4.0 preferring decapods and invertebrates and those above 4.0 preferring fish).

Fish weight was determined using published length-weight conversions (Froese *et al.* 2000), and the mid-point of each size class was used to convert size-frequency data into biomass data. Final biomass was calculated in kg ha^{-1} in order to allow comparisons with other studies.

Taxa-site associations were analysed using covariance based Principal Component Analysis (PCA) on fish community composition and biomass, invertebrate abundance and cover of major benthic groups. PCA was also used in identifying important taxa contributing to the observed variations in distributions. Differences in abundance, biomass, cover of taxa and functional groups identified as important by PCA were tested using univariate analysis against a number of a-priori defined factors: site, habitat type (bay, patch, headland or island), exposure (sheltered, semi exposed, exposed), wave energy (low, medium or high) and fishing pressure (low, medium, high). Homogeneity and normality of data were tested using Levene's test of Homogeneity and Kolmogorov-Smirnov's test respectively. Most data was not homogeneous, nor normally distributed; therefore the non-parametric Wilcoxon's ANOVA was used, with further paired Mann-Whitney U-tests conducted to discern the direction of differences.

Step-wise multiple regression analysis was conducted to test relationships between targeted biotic parameters and both biological and abiotic factors influencing distributions. Biomass of large sized carnivorous fish (proxy to predation), cover of the important benthic groups identified by PCA (BGA-mat, CCA, fleshy Algae, turf algae and sand) and habitat variables (depth, % rock, rugosity, complexity and wave action) and fishing pressure were included in the model. Relationships between abundance and biomass of important fish families and habitat, environmental and benthic variables were tested.

For invertebrates, in addition to the habitat variables indicated above, biomass of fish families feeding exclusively on invertebrates or those feeding on both invertebrate and fish (Balistidae, Dasyatidae, Ephippidae, Haemulidae, Labridae, Lethrinidae, Lutjanidae, Serranidae) was included. In addition to habitat variables (see above), biomass of major herbivorous fish (Acanthuridae, Scaridae, Pomacentridae) and sea urchin abundance were considered as the main biotic factors affecting benthic distribution. The model with the lowest Aikaki Information Criterion (AIC) and the highest fit (R^2) within AIC of ± 2 was selected (Burnham and Anderson 2002).

3. Results

Fish total Abundance

Over the entire survey period, 14 sites were surveyed and a total of 55 fish transects completed. A total of 7808 fish was observed on these transects, with 46 species representing 25 fish families recorded (Appendix 1).

Overall mean fish abundance was (141.96 ± 16.58 individuals transect^{-1}) and significantly varied across sites (Kruskal-Wallis χ^2 = 22.29; p = 0.009), ranging from the lowest average abundance at Akitakyi Small (54.66 ± 2.73) to the highest at Abokwe Seaward (350.00 ± 163.86), and Akitakyi Big (224.50 ± 63.34) to Paradise Beach and Abokwe Leeward also exhibited low abundance (72.20 ± 11.78 and 72.33 ± 30.82 respectively) (Figure 3.1).

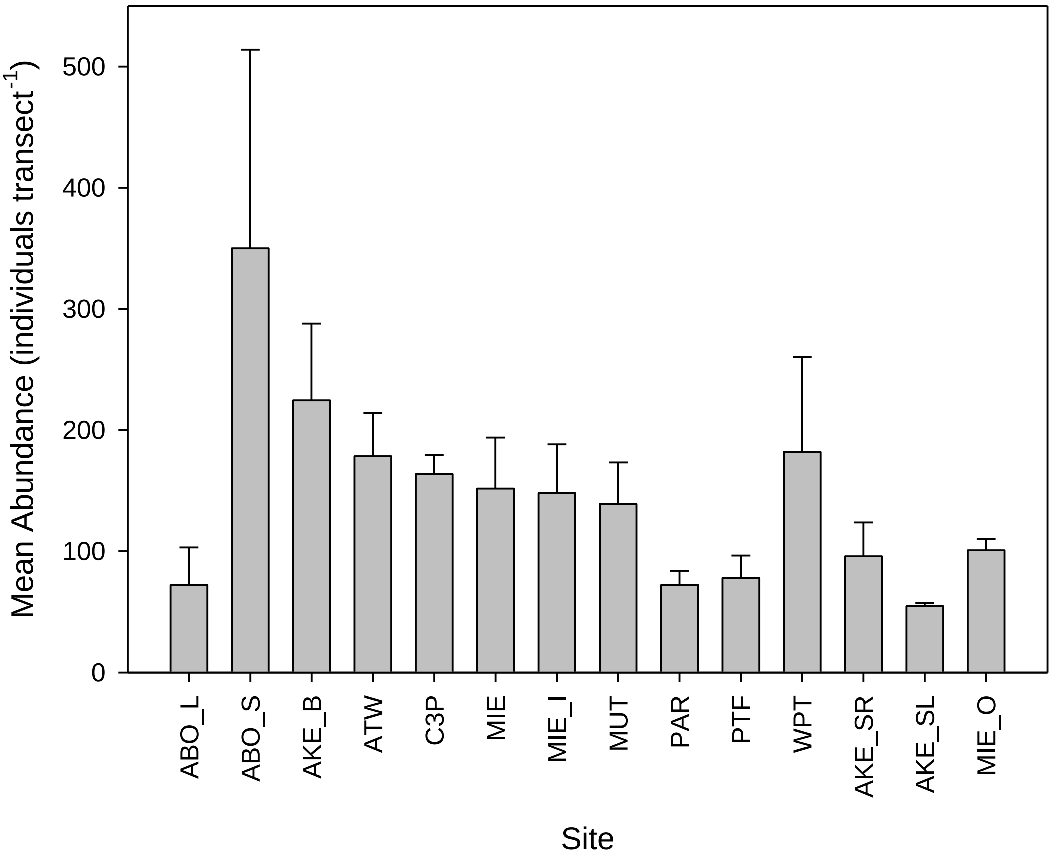


Figure 3.1. Mean total abundance of fish at each survey site.

Mean total abundance was significantly different between exposure scenarios (χ^2 =7.98; p = 0.02) with higher abundance in sheltered sites than in semi-exposed, or exposed sites (Appendix 4; Figure 3.2.). Mean abundance did not differ between habitat types (χ^2 = 3.68; p = 0.30), wave action (χ^2 = 3.69; p = 0.16) or fishing pressure (χ^2 = 3.94; p = 0.14) categories.

Multiple regression analysis showed significant effects of depth and % rock (R^2 = 0.13; ANOVA F = 2.96; p = 0.03). Total fish abundance was negatively related to depth (t = -2.01; p = 0.05) while % rock had a positive effect. Rugosity and sand were retained by the model although neither had a significant effect.

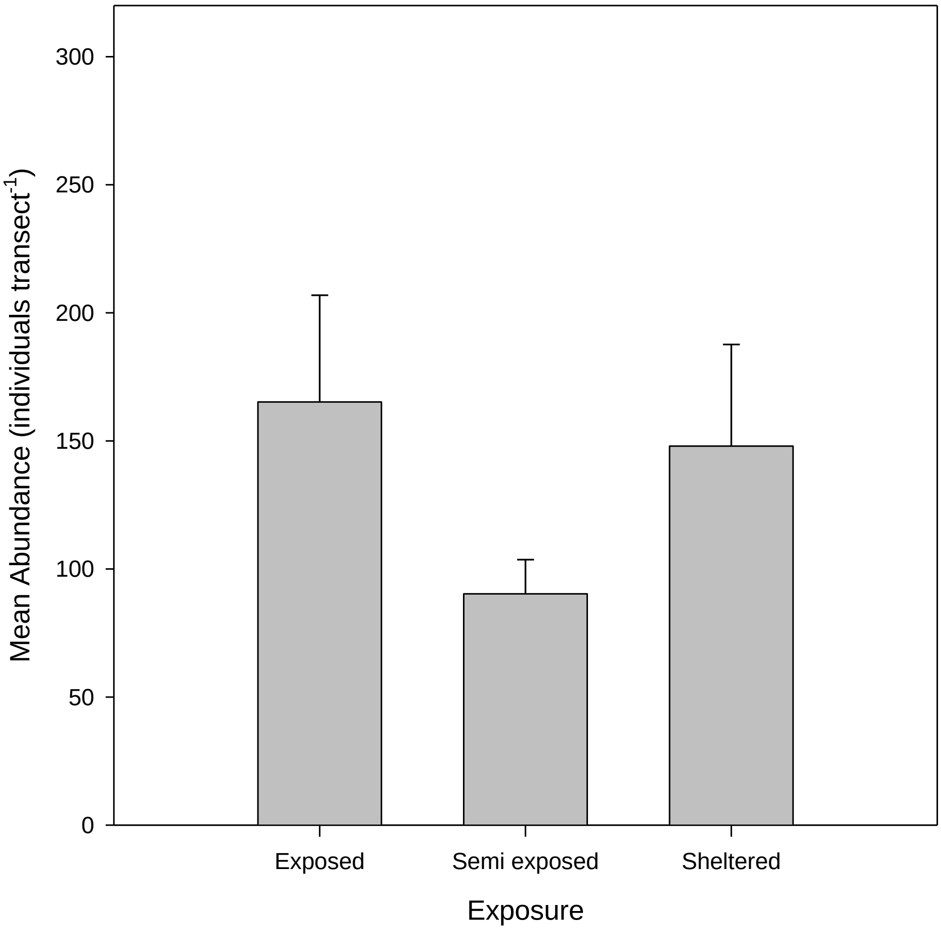


Figure 3.2. Difference in mean fish abundance by exposure (Kruskal Wallis χ2 = 7.98; p = 0.02).

Fish family abundance

Principal Component Analysis (PCA) showed that differences in fish community composition were explained mainly by the abundance of Pomacentridae (damselfish), Carangidae (jacks and trevally), Labridae (wrasse), and Acanthuridae (surgeonfish) (Figure 3.3.). PC Axis 1 explained 57.5% of variation and separates sites with high abundance of pomacentrid, carangid and labrid species from sites with high acanthurid abundance. Axis 2 explained a further 20.4% of the variation and separates sites with high abundance of pomacentrids from those with high abundance of carangids, labrids and acanthurids. Other fish families were all located around the centre of the PC plot, contributing less to the variation.

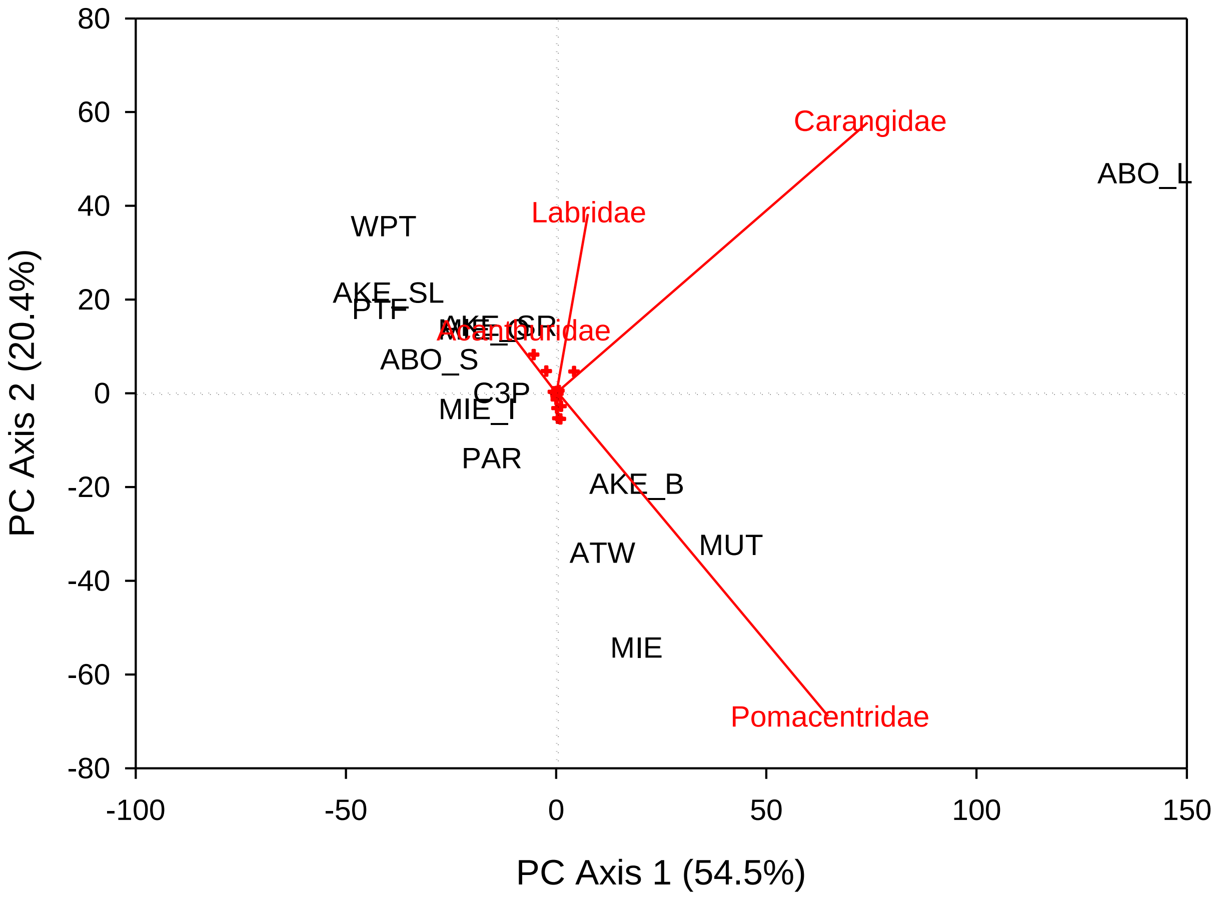


Figure 3.3. Principal Component (PC) plot on distribution of fish family abundance. Fish families responsible for the observed variation in taxa-site associations indicated.

Overall the largest contribution to fish abundance was from the family Pomacentridae (35.95%) followed closely by Labridae (23.54%), Carangidae (11.25%) and Acanthuridae (8.83%). Scaridae contributed 4.1% while Serranidae (grouper) and Lutjanidae (snapper) contributed just 2.89 and 1.15% respectively (Figure 3.4.).

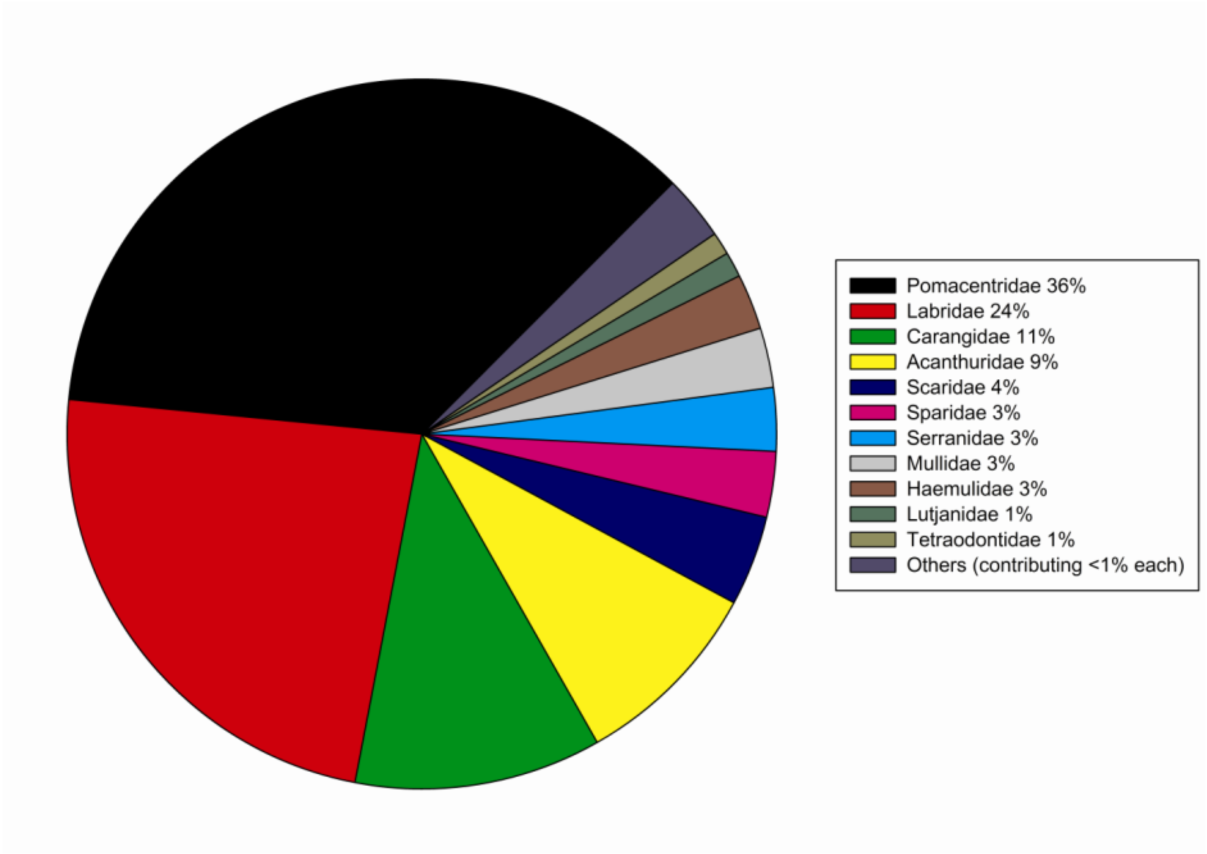


Figure 3.4. Contribution (%) of each fish family to total abundance.

Acanthurids were represented by a single species *Acanthurus monroviae* and varied significantly between sites (χ^2 = 29.92; p = 0.005) with the lowest abundance observed at Miemia Outer (1.33 ± 1.33 fish transect^{-1}) and the highest at Akitakyi Small (65.50 ± 3.5) (Figure 3.5.a). Abundance of acanthurids varied significantly with exposure (χ^2 = 6.68; p = 0.04) and fishing pressure (χ^2 = 13.72; p = 0.001). It was significantly higher in semi-exposed sites than in both exposed and sheltered sites, with no difference between sheltered and exposed sites (Appendix 4). Abundance was lower at medium levels of fishing pressure than at both high and low levels of fishing pressure (Appendix 6).

Acanthurid abundance had significant relationship with cover of blue-green algal mat (+ve relationship) and crustose coralline algae (-ve relationship) among the benthic habitat variables (Table 3.1.).

Table 3.1. Multiple regression analysis results on relationships between acanthurid abundance and benthic habitat variables.

Predictor	**R^2**	**F**	**t**	**p**
Intercept	**0.27**	**10.96**	**4.10**	**0.0001**
BGA-mat		9.38	3.06	**0.004**
CCA		7.00	- 2.65	**0.011**

Three carangid species (*Chloroscombrus chrysurus*, *Pseudocaranx dentex* and *Selar crumenophthalmus)* comprised 45.81%, 18.64% and 35.56% respectively of the total (11%) carangid abundance. Abundance varied significantly between sites (χ^2 = 24.19, p = 0.029). They were absent at 8 of the 14 survey sites, and had highest abundance (150.0 ± 150.0 fish transect^{-1}) at Abokwe Seaward (Figure 3.5.b). There was no significant difference in carangid abundance across the selected environmental settings (habitat, exposure, wave action and fishing pressure). Multiple stepwise regression showed that only sand had a significant effect (+ve) on carangid abundance (R^2 = 0.06, F = 4.864; p = 0.03).

Labrid abundance varied significantly between survey sites (χ^2 = 39.51; p <0.0001). Labrids had five species observed during the current study. They were dominated by *Thalassoma newtoni* (80.49% of observations), with *Coris atlantica* and *Bodianus speciousus* comprising 10.08% and 5.59% respectively. The highest abundance of labrids was seen at Akitakyi Small (79.67 ± 13.78 individuals transect^{-1}) and West Point (63.17 ± 5.71), with the lowest abundance at Miemia Inner (8.00 ± 2.32) (Figure 3.5.c). There was significant difference in labrid abundance by habitat type (χ^2 = 14.64; p = 0.002) with patch sites having significantly lower abundance than bay and headland sites, and bay sites had lower abundance than headland sites (Appendix 3). Islands had larger variability and did not differ significantly from other habitat types.

Labrid abundance differed significantly between different levels of exposure (χ^2 = 12.56; p = 0.002), with sheltered and exposed sites having significantly higher abundance than semi exposed sites (Appendix 4). Abundance of labrids was also significantly different between levels of fishing pressure (χ^2 = 15.78, p = 0.0004), high and low fishing pressure sites had significantly higher abundance than medium fishing pressure sites (Appendix 6). Depth, complexity, rugosity, crustose coralline and fleshy algal cover explained 40% of the variation in labrid abundance (Table 3.2.).

Table 3.2. Multiple regression analysis results on relationships between labrid abundance and benthic habitat variables.

Predictor	R^2	F	t	p
Intercept	**0.48**	**10.93**	**1.6**	**<0.0001**
Depth		15.15	3.89	**0.0003**
Complexity		15.47	- 3.93	**0.0003**
Rugosity		4.64	2.15	**0.04**
Crustose coralline		11.07	- 3.33	**0.002**
Fleshy Algae		8.27	2.88	**0.01**

Pomacentrid abundance (Figure 3.5.d) was significantly different between sites (χ^2 = 27.74; p = 0.010) with highest abundance at Abokwe Seaward (109.00 ± 15.37 individuals transect^{-1}) and the lowest abundance observed at Akitakyi Small (4.00 ± 1.37). Pomacentrids were also the most specious fish family with six species observed. Of these, *Stegastes imbricatus* was the dominant species comprising 58.7% of observations within the family. *Chromis multilineata* was also common comprising 22.5% of observations and *Abudefduf saxatilis* (15%). Other species included *Abudefduf taurus, Chromis limbata*, and *Microspathadon frontatus*.

Pomacentrid abundance varied significantly across levels of exposure and wave action (χ^2 = 10.51; p = 0.005 and χ^2 = 12.84; p = 0.002 respectively). Sheltered sites had a significantly higher abundance than both semi exposed and exposed sites, which did not significantly differ from one another (Appendix 4). Sites with medium levels of wave action had significantly higher abundance of pomacentrids than sites of low or high levels of wave action while these last two did not differ (Appendix 5). Stepwise multiple regression did not show a significant relationship between abundance of pomacentrids and habitat variables.

Scarid abundance did not show significant difference between sites (χ^2 = 18.43; p = 0.142) despite a maximum of 21.17 ± 7.83 fish transect^{-1} at Akitakyi Big and a minimum of 1.33 ± 0.42 at West Point (Figure 3.5.e). Abundance of this group was dominated by *Scarus hoefleri* contributing 67.42% of observations within the family, with *Sparisoma cretense* contributing a further 30.83%. *Sparisoma axillare* and *Sparisoma rubripinne* contributed <1% of observations respectively. Scarid abundance differed significantly between different levels of exposure (χ^2 = 7.80, p = 0.02), with sheltered sites having significantly higher abundance than both semi exposed and exposed sites (Appendix 4). Abundance of scarids also differed significantly between different levels of fishing pressure, with sites exposed to low fishing pressure having significantly higher abundance than sites with both medium and high levels of fishing pressure (Appendix 6). Depth and rugosity predicted 16.2% of the variation in scarid abundance, which was negatively related to depth but positively related to rugosity (Table 3.1).

Table 3.1. Results of multiple regression analysis on relationships between scarid abundance and benthic habitat variables.

Predictor	R^2	F	t	p
Intercept	**0.16**	**6.22**	**0.53**	**0.004**
Depth		4.96	-2.23	**0.03**
Rugosity		8.88	2.98	**0.004**

Serranid abundance differed significantly between surveys sites (χ^2 = 35.28; p = 0.001) with highest abundance observed at Abokwe Seaward (11.67 ± 1.20 fish transect-1), and lowest abundance observed at Akitakyi Bay Small Left (0.50 ± 0.50) and Paradise Beach (0.83 ± 0.54) (Figure 3.5.f). Abundance was dominated by *Cephalopholis nigri* (99.70%) while *Cephalopholis taeniops* and *Rypticus saponaceus* were rarely observed, accounting for 0.15% each. There was significant difference between habitat types (χ^2 = 20.62; p = 0.0001), headlands had significantly higher abundance than bay and patch sites. Abundance at headland sites did not differ significantly from island sites. Bay, patch and island sites did not differ from one another (Appendix 3).

There was a significant difference in serranid abundance by exposure (χ^2 = 8.49; p = 0.01), with exposed sites having significantly higher abundance than sheltered and semi exposed sites (Appendix 4). Abundance also differed significantly between levels of wave exposure (χ^2 = 11.07; p = 0.004) and fishing pressure (χ^2 = 8.36; p

= 0.02). Sites with both high and low levels of wave action had significantly lower abundance than sites with medium levels of wave action (Appendix 5). Abundance was higher at sites with high levels of fishing pressure than at sites experiencing medium and low fishing pressure (Appendix 6). Serranid abundance was significantly related to depth (+ve) and complexity (-ve) (Table 3.4.).

Table 3.4. Results of multiple regression analysis on relationships between serranid abundance and benthic habitat variables.

Predictor	R^2	F	t	p
Intercept	**0.27**	**10.74**	**2.26**	**0.0001**
Depth		12.69	3.56	**0.001**
Rugosity		9.37	-3.06	**0.004**

Lutjanidae were composed predominantly of two main species, *Lutjanus goreensis* and *Lutjanus agennes* (50.09% and 49.52% within the family respectively). A third species, *Apsilus fuscus* was rarely observed and comprised only 0.40% of observations. Abundance of lutjanids did not vary significantly between sites (χ^2 = 18.33; p = 0.145) and ranged from being absent at five of the survey sites to highest at Miemia Inner and Atwiwa (5.40 ± 5.40 fish transect^{-1} and 5.33 ± 2.73 respectively). Abundance did not differ between habitat types, levels of exposure or fishing pressure, however there was significant difference between levels of wave action (χ^2 = 10.38; p = 0.006). There was higher abundance at sites of medium wave action than at high or low levels (Appendix 5). Approximately 9% of the observed variance in lutjanid abundance was explained by % rock (R^2 = 0.089, F = 6.28, t = -2.51, p = 0.02) and the remaining variables were excluded by the model.

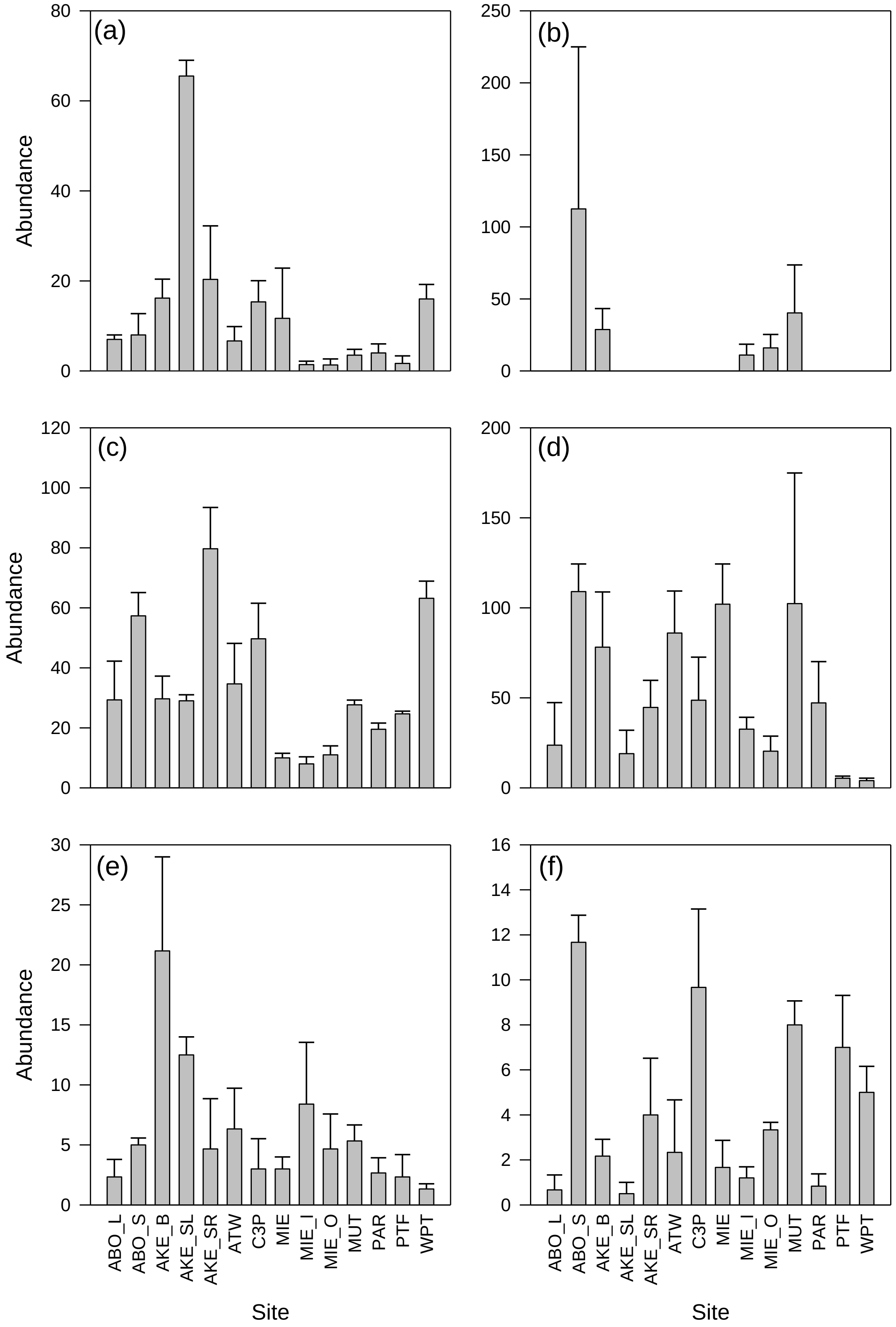


Figure 3.5. Abundance (mean individuals transect-1 ± SE) by site of major fish families: (a) acanthuridae, (b) carangidae (c) labridae (d) pomacentridae (e) scaridae and (f) serranidae.

Fish species richness

Mean fish species richness and diversity were compared across all sites (Figure 3.6.) and varied significantly (χ^2 = 28.18; p = 0.009). Overall species richness was 11.69 ± 0.52 species transect^{-1} across all sites, with the highest number of species observed at Akitakyi Bay Big (16.17 ± 2.48 no. of species per transect) and the lowest observed at Abokwe Seaward (7.67 ± 1.67). There was a significant difference in SpR between sites of different exposure (χ^2 = 13.44; p = 0.001) and wave action (χ^2 = 17.24; p = 0.0002). SpR was significantly higher in sheltered sites than in both semi-exposed and exposed sites (Appendix 4), and higher in low wave action sites than in sites with medium or high levels of wave action (Appendix 5). About 16.4% of variation in species richness was explained by %Rock, complexity and sand, SpR having a positive relationship with both variables (Table 3.5.).

Table 3.5. Summary of multiple regression analysis results on the relationship between species richness and benthic habitat variables.

Predictor	R^2	F	t	p
Overall	**0.16**	**4.53**	**1.36**	**0.01**
% Rock		4.72	2.17	**0.03**
Complexity		8.54	2.92	**0.01**
Sand		6.58	2.57	**0.01**

Fish species diversity

Simpson's diversity (SDI) did not significantly differ between sites (χ^2 = 21.35; p = 0.07). Overall SDI was 0.64 ± 0.02. The highest SDI was observed at Princess Town Fort (0.83 ± 0.03), with other sites including Miemia, Miemia Inner, Akitakyi Small (left and right), exhibiting diversity index >8. The lowest diversity index was observed at Miemia Outer (0.587 ± 0.03 SDI) (Figure 3.6.).

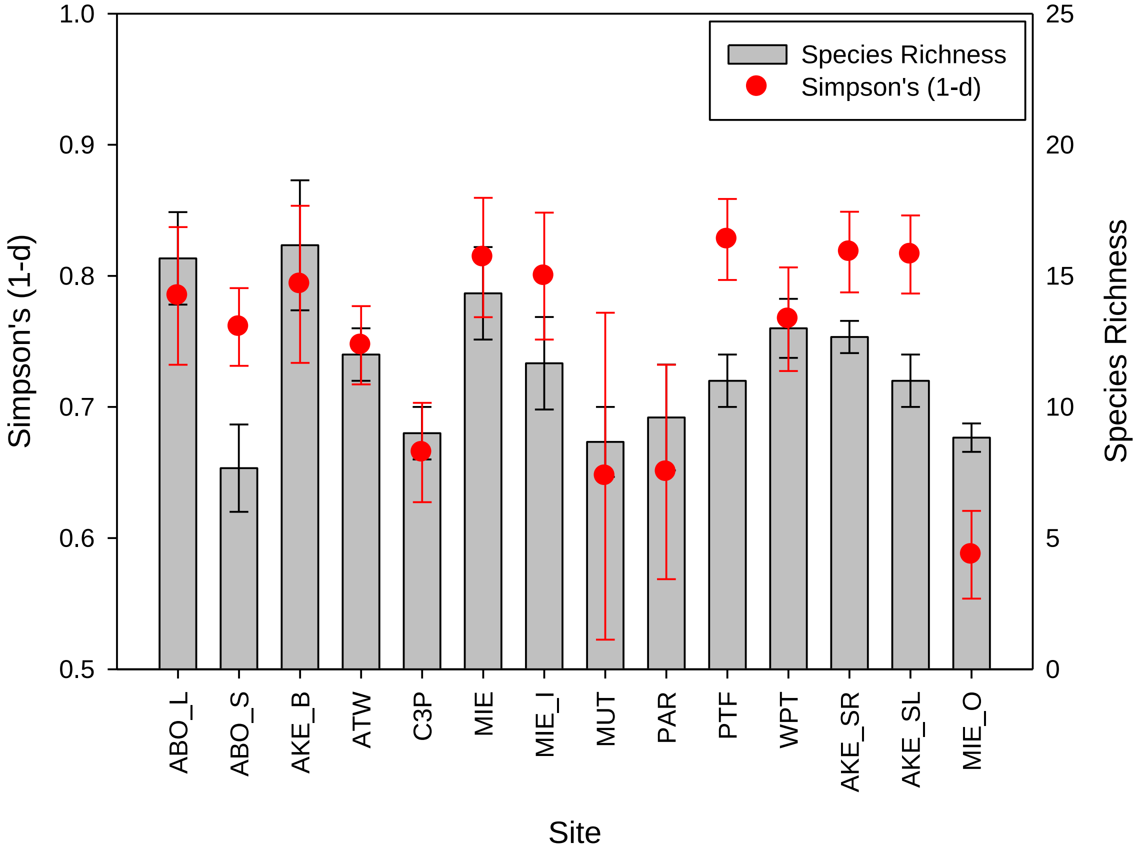


Figure 3.6. Diversity distribution in the study area.

Princess Town Fort had a lower than average SpR (11.00 ± 1.00 species transect^{-1}), however, with the abundance of each species evenly distributed the diversity of this site was higher than in other sites of the same or higher richness. Akitakyi Small Left similarly had average SpR of 11.00 ± 0.62 species transect^{-1} but the mean SDI at this site was also high 0.82 ± 0.03 due to the even distribution of individuals across the 11 species. On the other hand, some sites with high SpR such as Atwiwa (12 ± 1.00 species transect^{-1}), West Point (13 ± 1.00) and MIE (14.33 ± 1.00) had low SDI because of the high abundance of one or a few species. Atwiwa and Miemia were both dominated by high abundance of pomacentrid species, contributing 56.70% and 73.30% to the total abundance at these two sites respectively. West Point on the other hand had high dominance of labrids, contributing 62.64% to the total abundance at the site.

Simpson's diversity differed significantly with levels of wave action (χ^2 = 9.07, p = 0.01), and sites with low levels of wave action exhibited higher diversity than both medium and high wave action sites (Appendix 5). Multiple regression analysis on Simpsons diversity index did not show significant relationship with any of the benthic and habitat variables considered (p = 0.1).

Fish trophic level

Mean trophic level across all sites was 3.02 troph ± 0.04 and varied significantly among sites ($\chi^2 = 32.89$; $p = 0.002$), with highest value recorded at Miemia Outer (3.36 troph ± 0.17) and the lowest at Miemia (2.51 troph ± 0.10) (Figure 3.7.). It also varied significantly between habitat types, exposure, wave action and fishing pressure (Figure 3.8.). Headland sites had a higher trophic level than bays and patch sites, but did not differ from island sites. Bay, patch and island sites did not differ from one another (Appendix 3). Trophic level was significantly higher in exposed sites than in sheltered or semi-exposed sites (Appendix 4).

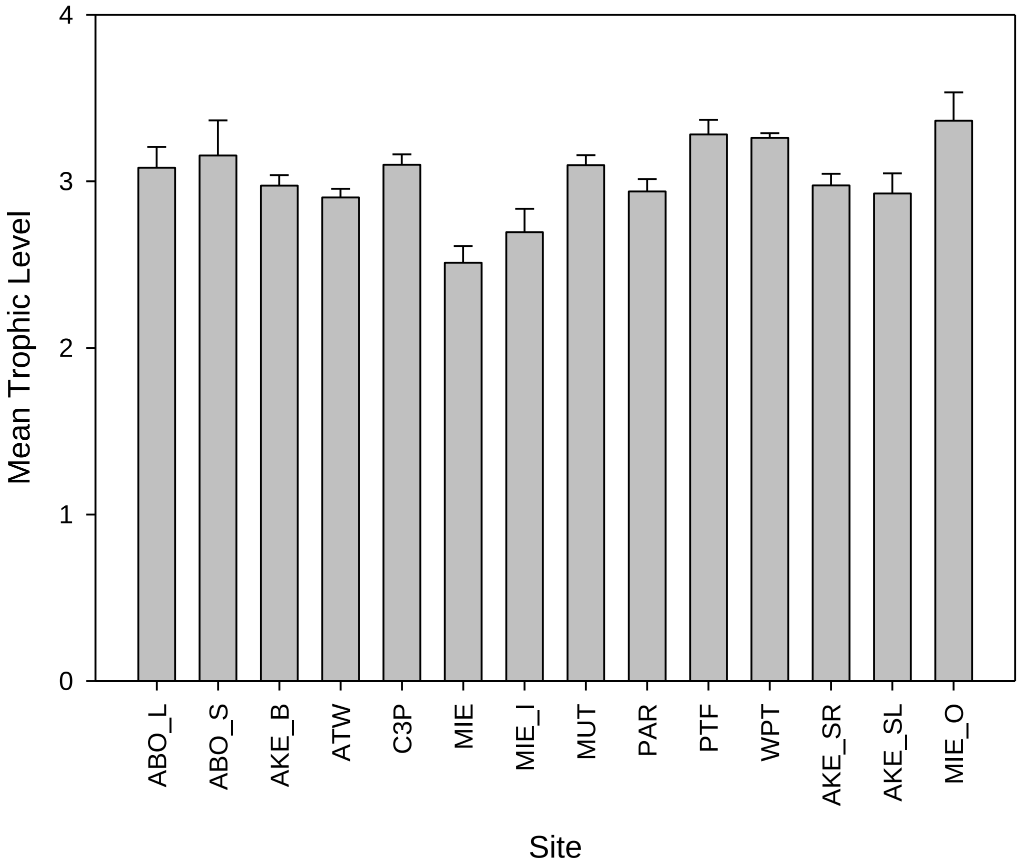


Figure 3.7. Mean trophic level (TL) of fish community in the study area.

Trophic level was significantly higher in medium wave action sites than in both low and high wave action sites. It was also higher in sites with low wave action than sites with high wave action (Appendix 5). Sites with high fishing pressure exhibited higher trophic level than low fishing pressure sites but did not vary significantly from sites of medium levels of fishing pressure (Appendix 6). Out of the benthic habitat variables, trophic level showed significant relationship only with depth. It increased with depth ($R^2 = 0.32$, $F = 26.43$, $t = 5.14$, $p < 0.0001$; Figure 3.9.).

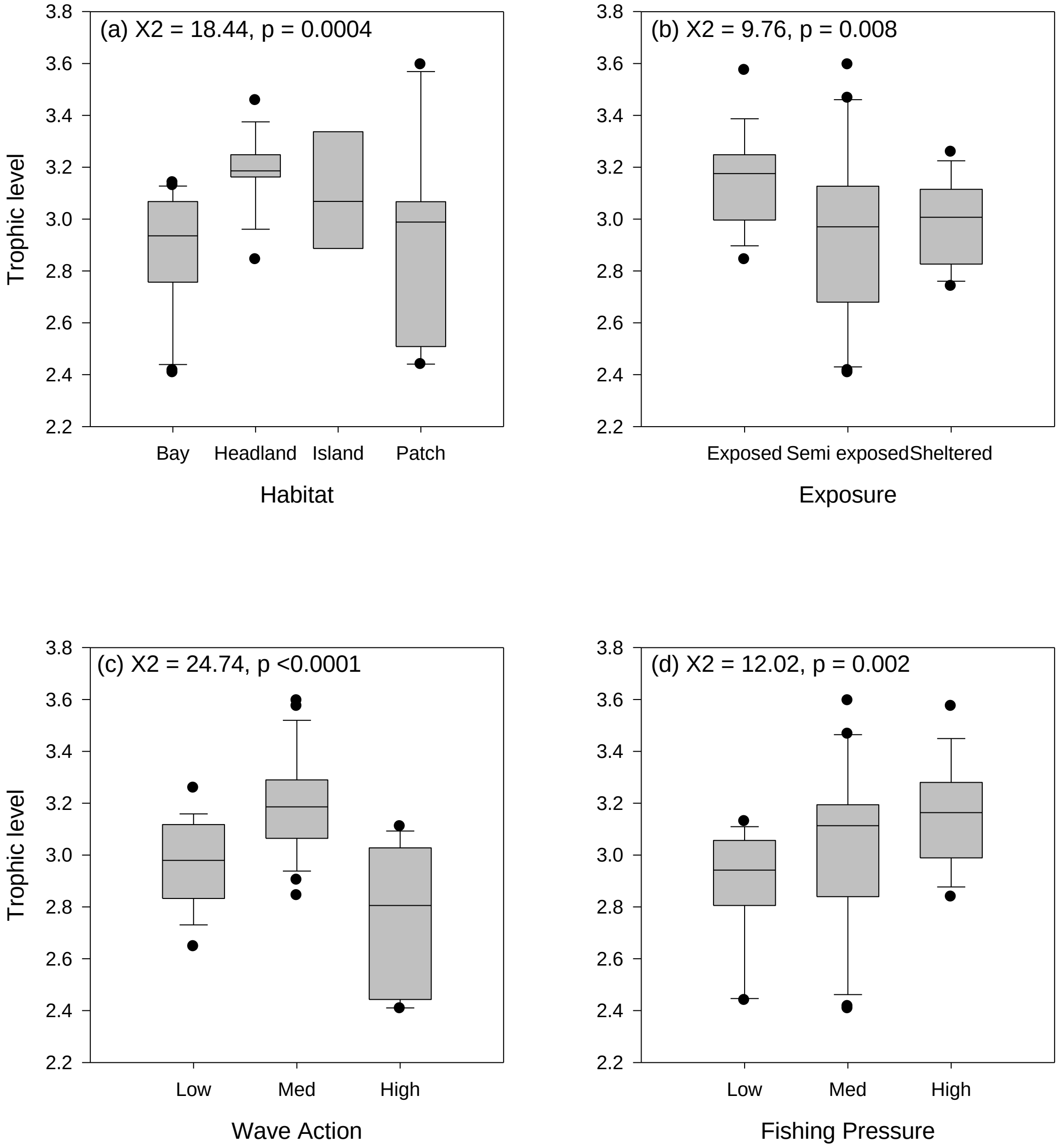


Figure 3.8. Comparison of trophic levels between (a) habitat types, (b) levels of exposure, (c) wave action and (d) fishing pressure. Lower and upper boundaries of a box represent the interquartile range (25% to 75% values) and is divided at the median value (50%), whiskers represent 10% and 90% and points are values outside this range

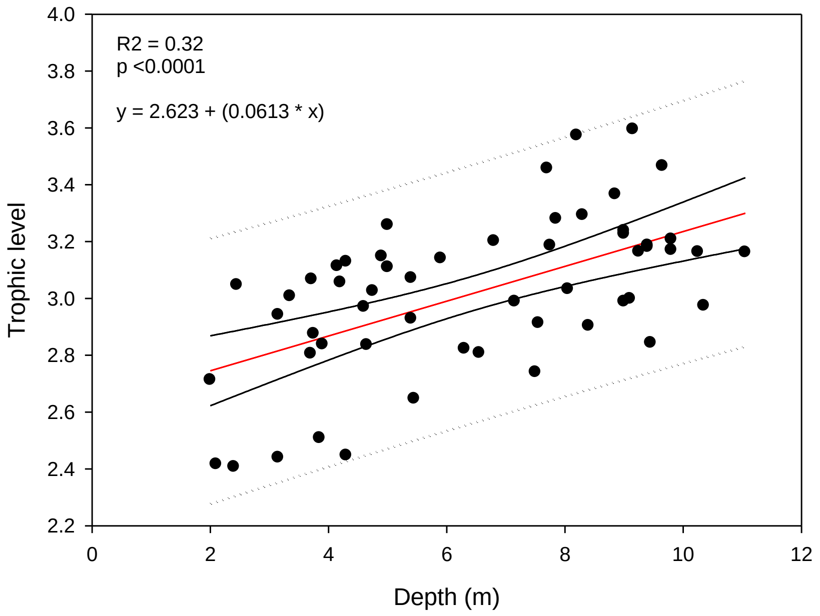


Figure 3.9. Relationship between trophic level and water depth (m)

Total fish biomass

Mean fish biomass for the survey region was 398.93 kg ha^{-1} ± 64.54 SEM. Biomass varied significantly between sites (χ^2 = 28.67; p = 0.007). It was highest at Miemia Inner (1000.58 kg ha^{-1} ± 414.11 SEM) with Atwiwa and Akitakyi Small also exhibiting high biomass relative to other sites in the area (636.60 kg ha^{-1} ± 361.66 and 629.49 kg ha^{-1} ± 62.76). The lowest biomass was observed at Abokwe Leeward (36.92 kg ha^{-1} ± 30.30), with low biomass also observed at West Point and Cape Three Points (74.22 kg ha^{-1} ± 24.71 and 83.96 kg ha^{-1} ± 00.00 respectively) (Figure 3.10.). Total fish biomass was significantly different across habitat types (Figure 3.11.a) and patch and bay sites had significantly higher biomass than headland sites, but did not differ significantly from each other, or from island sites (Appendix 3). Biomass significantly differed between levels of fishing pressure (Figure 3.11.), with significant differences across all levels of fishing pressure (Appendix 6). It was lowest on sites with high fishing pressure and highest on low fishing pressure sites with intermediate biomass observed on sites with medium fishing pressure.

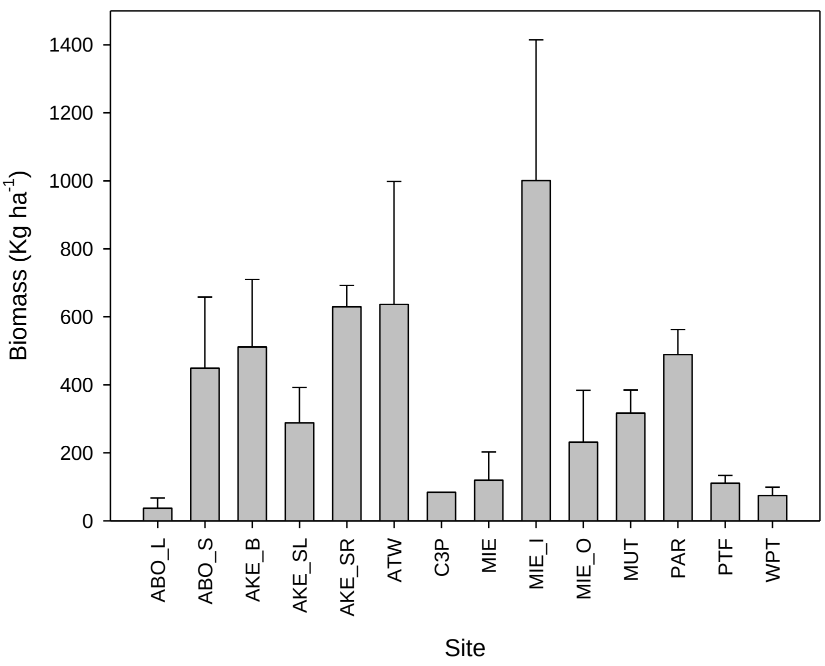


Figure 3.10. Distribution of total fish biomass by site.

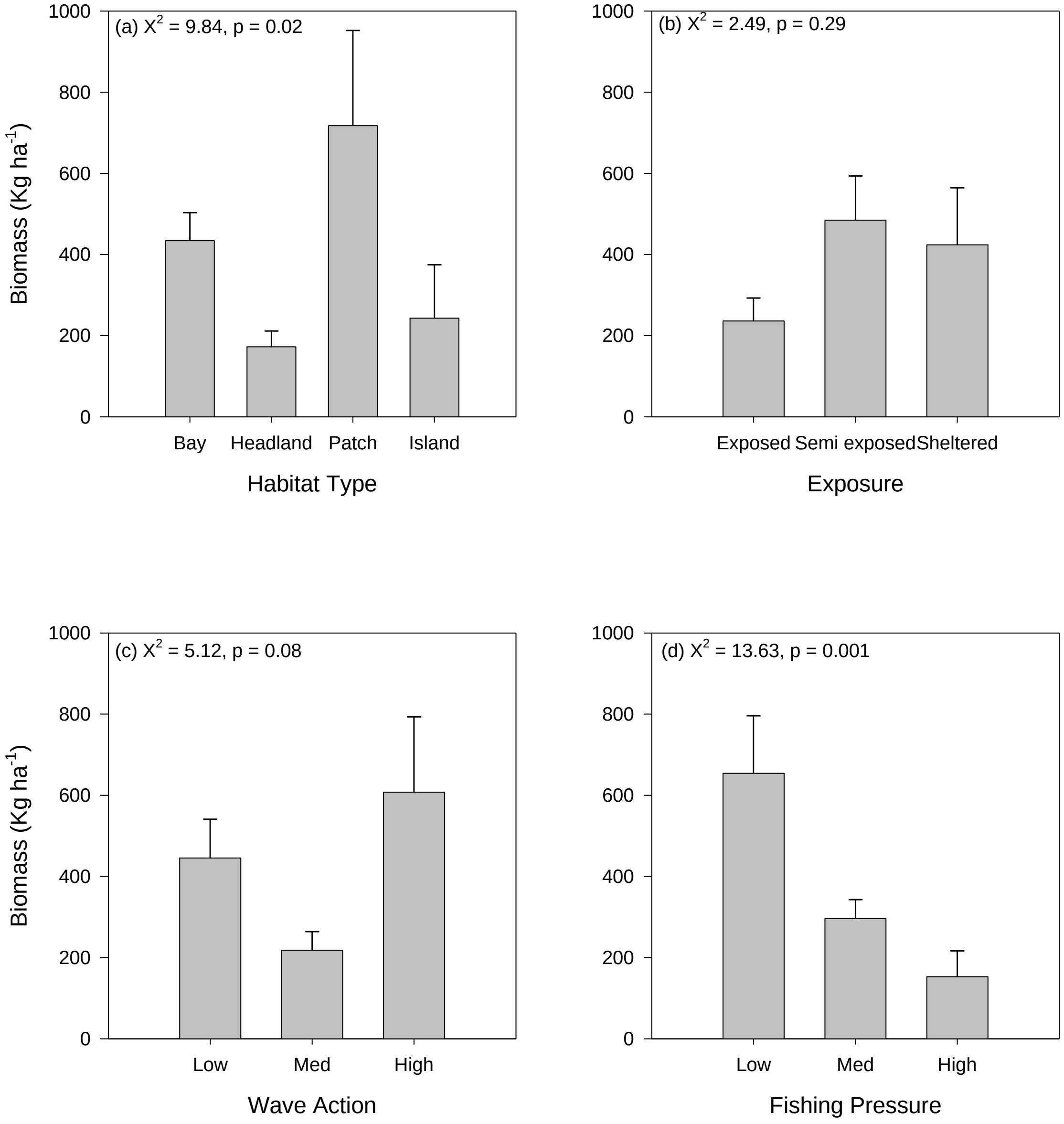


Figure 3.11. Comparison of total fish biomass across (a) habitat types, (b) exposure, (c) wave action and (d) fishing pressure

Biomass of fish families

The first Principal Component (PC) axis explained 67.55% of the variation in biomass and separated high biomass sites dominated by Acanthuridae, Scaridae and Lutjanidae from other sites that had low biomass. The 2nd PC axis explained a further 19.58% of the variation, separating sites of high acanthurid biomass from sites with high lutjanid biomass (Figure 3.12.).

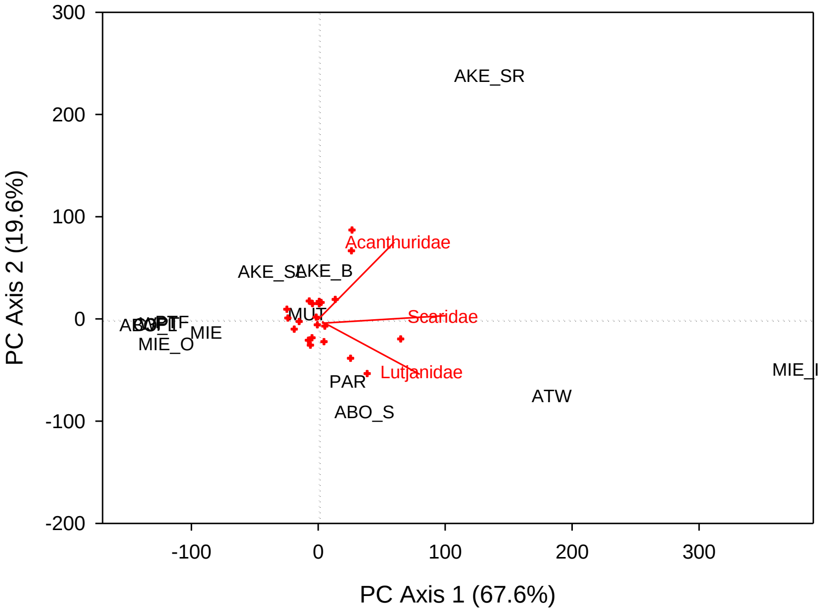
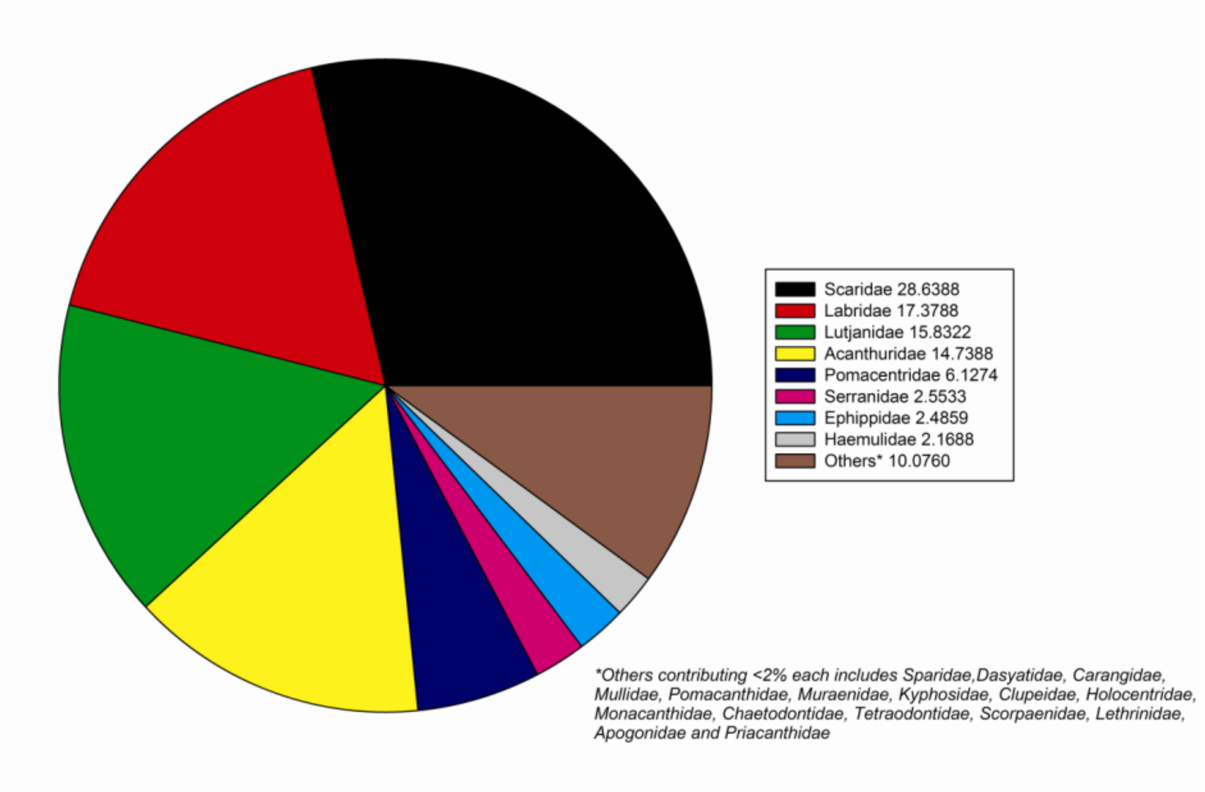


Figure 3.12. Principal Component (PC) biplot on fish family biomass-site associations. Fish families with high contribution to the variation indicated

Acanthurid biomass was highest at Akitakyi Small and Miemia Inner (304.29 kg ha^{-1} ± 53.15 and 147.12 kg ha^{-1} ± 143.04 respectively), and lowest at Miemia Outer where none was observed in any of the transects. Low biomass of acanthurids was also observed at Abokwe Leeward having only 0.316 kg ha^{-1} ± 0.190. Cape Three Points, Miemia, Princess Town Fort and West Point also each exhibited less than 5 kg ha^{-1} acanthurid biomass (Figure 3.14.a). There was a significant difference in acanthurid biomass between sites experiencing different levels of fishing pressure (χ^2 = 11.99; p = 0.003). Sites exposed to low levels of fishing pressure exhibited significantly higher biomass than sites with both medium and high levels of fishing pressure (Appendix 6).



*Others contributing <2% each includes Sparidae,Dasyatidae, Carangidae, Mullidae, Pomacanthidae, Muraenidae, Kyphosidae, Clupeidae, Holocentridae, Monacanthidae, Chaetodontidae, Tetraodontidae, Scorpaenidae, Lethrinidae, Apogonidae and Priacanthidae

Figure 3.13. Percentage contribution of major fish family groups to total biomass

Biomass of labrids was highest at both Miemia Inner (141.96 kg ha^{-1} ± 82.75) and Paradise Beach (141.67 kg ha^{-1} ± 40.50) while lowest at Abokwe Leeward (10.41 kg ha^{-1} ± 6.33) (Figure 3.14.b). There was no significant relationship between labrid biomass and the benthic habitat variables considered.

Lutjanids had highest biomass at Miemia Inner (269.12 kg ha^{-1} ± 163.96), Abokwe Seaward (181.33 kg ha^{-1} ± 181.33) and Atwiwa (159.82 kg ha^{-1} ± 82.59). The family however was absent from transects at Abokwe Leeward, Akitakyi Small, Cape Three Points and West Point, with low biomass also observed at Princess Town Fort (0.07 kg ha^{-1} ± 0.07) and Akitakyi Big (2.20 kg ha^{-1} ± 1.59) (Figure 3.14.c). Biomass differed significantly between habitat types (χ^2 = 7.94; p = 0.05) and fishing pressure (χ^2 = 7.66; p = 0.02).

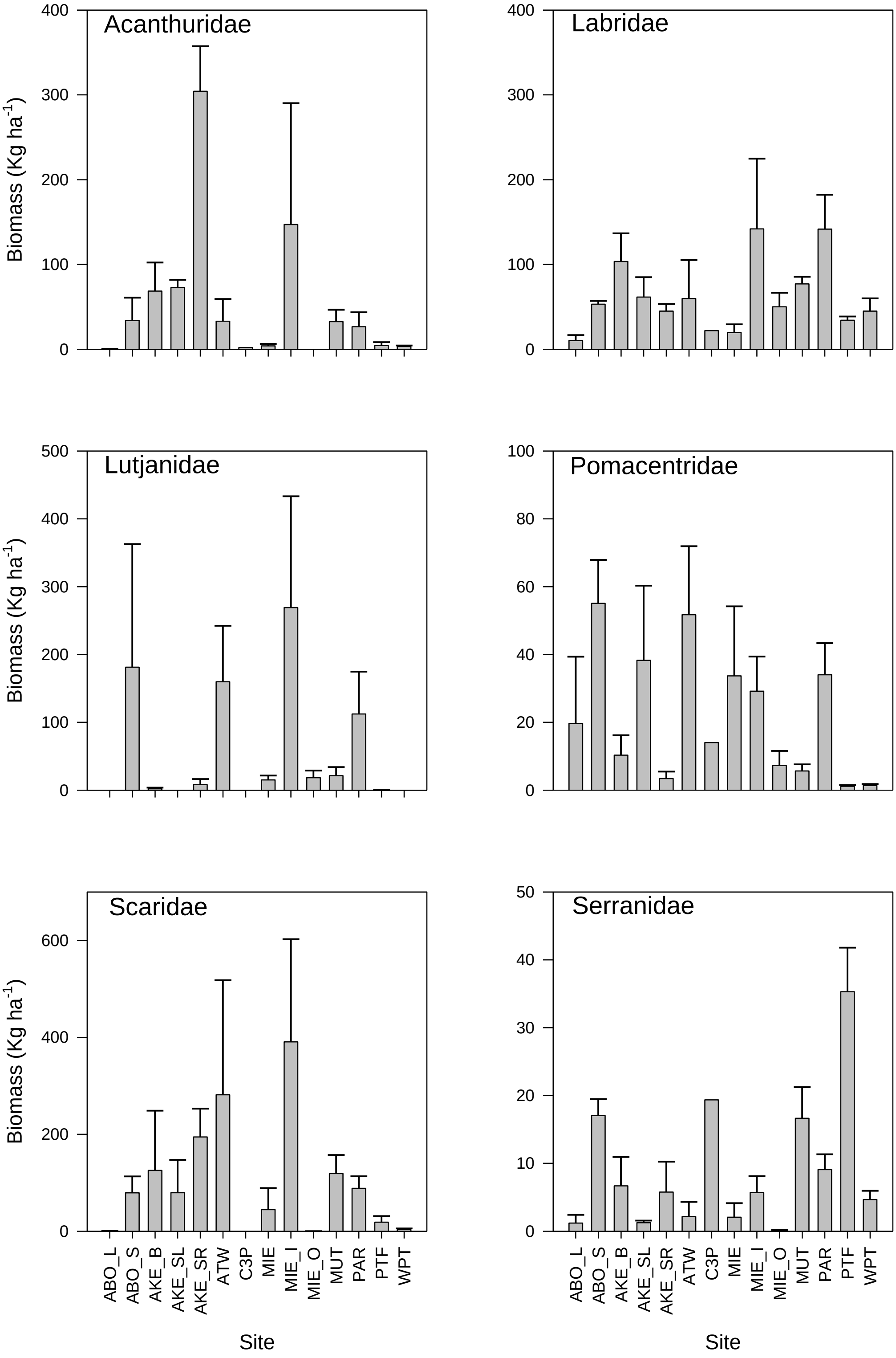


Figure 3.14. Biomass of major fish families by survey site

It was significantly different between headland and patch sites, but there was no significant difference between other types of habitat (Appendix 3). Sites experiencing low and medium levels of fishing pressure had significantly higher biomass than sites exposed to high fishing pressure (Appendix 6).

Pomacentrid biomass differed significantly between sites (χ^2 = 28.21; p = 0.01) with highest biomass observed at Abokwe Seaward (55.10 kg ha^{-1} ± 12.79) and Atwiwa (51.75 kg ha^{-1} ± 20.16) while the lowest biomass was observed at Princess Town Fort (1.16 kg ha^{-1} ± 0.36) and West Point (1.37 kg ha^{-1} ± 0.46) (Figure 3.14.d). Biomass showed significant difference between habitat types (χ^2 = 10.73; p 0.01); it was significantly lower at headland sites than at bay and patch sites but was not different from that observed at island sites (Appendix 3).

Overall scaridae contributed the largest percentage to total biomass (28.64%) while labrids, lutjanids and acanthurids contributed 17.38%, 15.83% and 14.74% respectively. Pomacentrids, despite their small body size, had a relatively high biomass and contributed 6.13% to the total biomass (Figure 3.13). Scarid biomass was highest at Miemia Inner and Atwiwa (390.73 kg ha^{-1} ± 211.84 and 281.69 kg ha^{-1} ± 236.24 respectively), while they were completely absent at Cape Three Points. Biomass was low at Miemia Outer (0.11 kg ha^{-1} ± 0.11), Abokwe Leeward (0.24 kg ha^{-1} ± 0.22) and West Point (3.47 kg ha^{-1} ± 2.25) (Figure 3.14e). There was significant difference in scarid biomass between levels of fishing pressure (χ^2 = 8.30; p = 0.02), sites experiencing low fishing pressure having significantly higher fish biomass than sites exposed to medium or high fishing pressure (Appendix 5).

Serranid biomass significantly varied between sites (χ^2 = 29.33; p = 0.006) and ranged from the lowest at Miemia Outer (0.12 kg ha^{-1} ± 0.06) to the highest at Princess Town Fort (35.30 kg ha^{-1} ± 6.49)(Figure 3.14.f). There was significant difference between habitat types (χ^2 = 11.60; p = 0.009), exposure (χ^2 = 9.69; p = 0.008) and wave action (χ^2 = 8.99; p = 0.01), but not between levels of fishing pressure (χ^2 = 4.37; p = 0.11). Biomass was significantly higher at headland sites than at bay and patch sites, which did not differ from island locations. Bay, patch and island sites did not differ from each other (Appendix 3). It was also higher at exposed sites than sheltered or semi-exposed sites (Appendix 44) and at sites experiencing medium levels of wave action than sites of low or high levels of wave action (Appendix 5).

Fish size distributions

Fish body length ranged from 4 cm to 85 cm. The two smallest categories (3-5 cm and 5-10 cm) were the most abundant with 64.85% of fish observed being <10 cm in length, and 91.32% were <20 cm (Figure 3.15.).

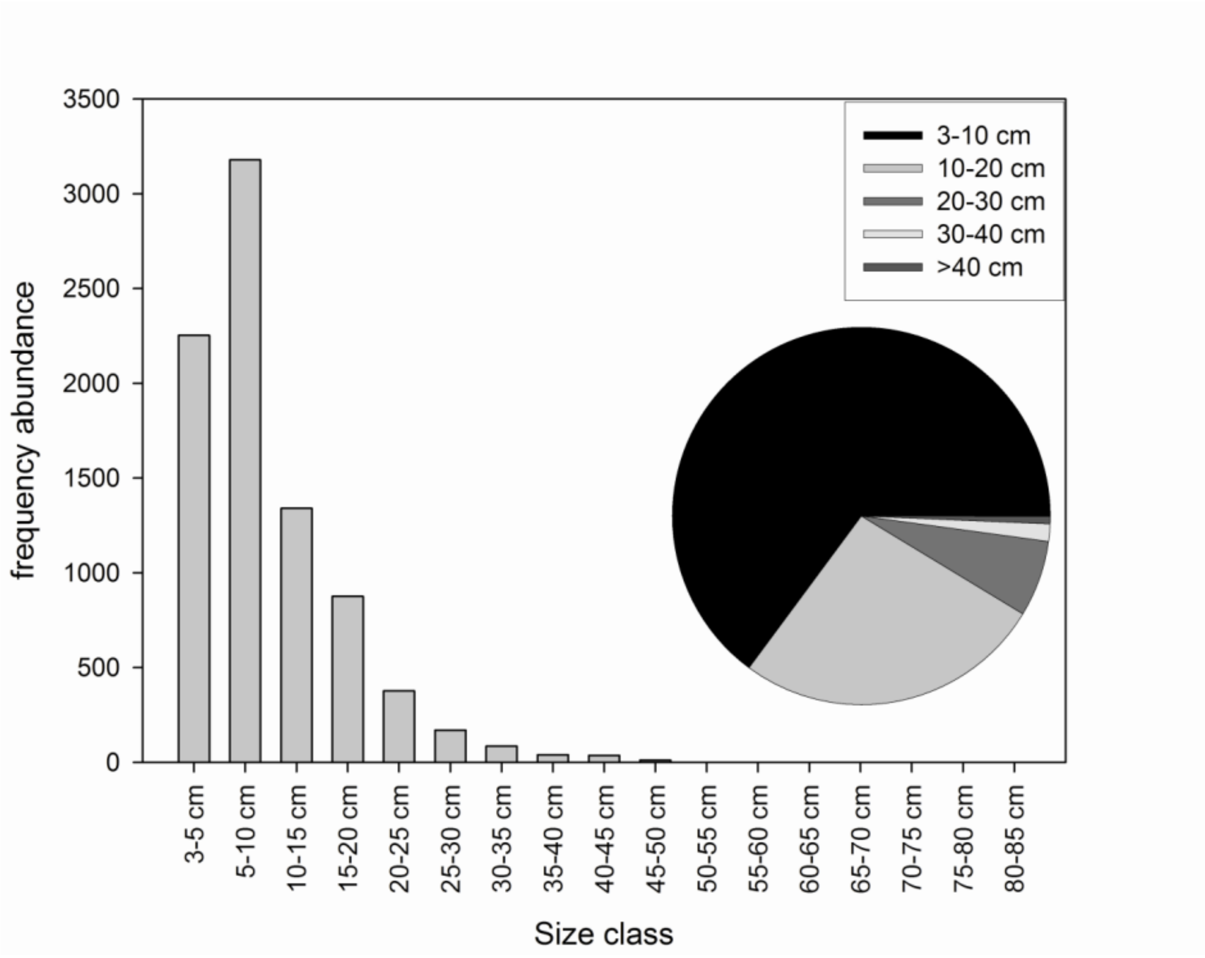


Figure 3.15. Size frequency distribution of fish in the study area

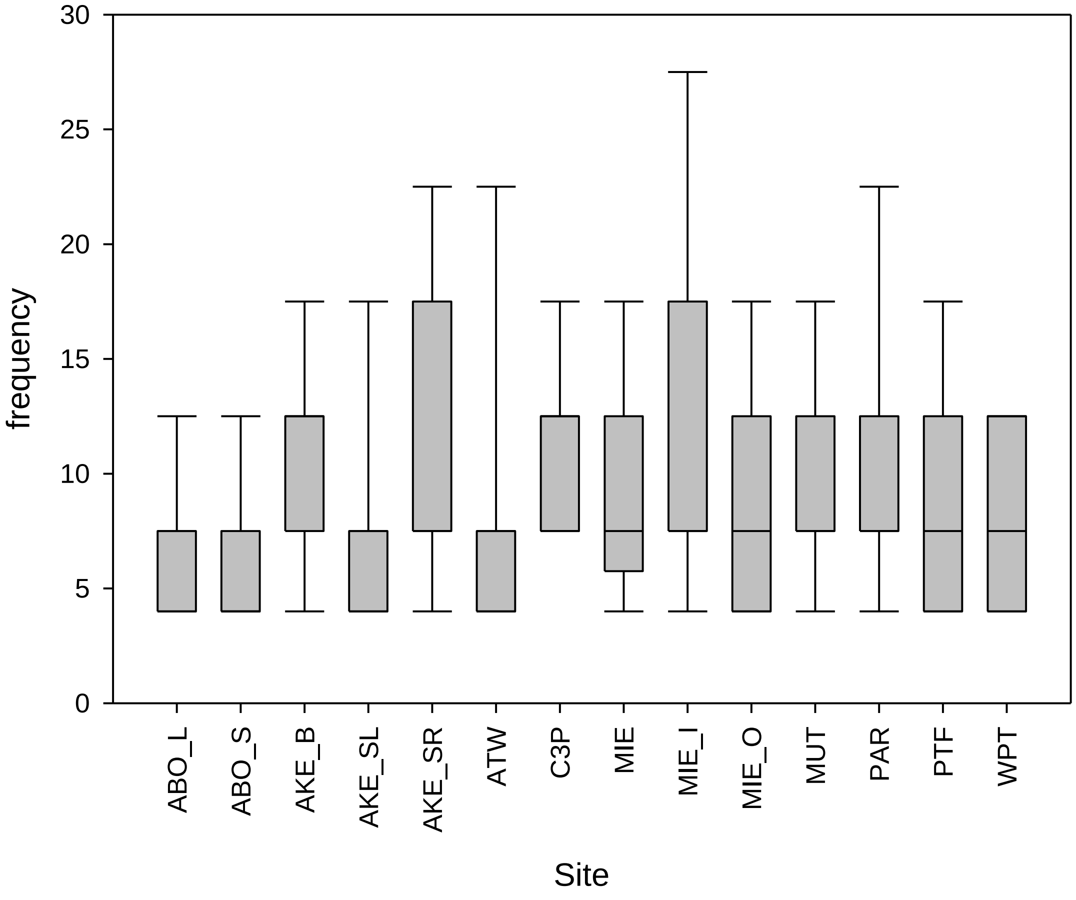


Figure 3.16. Fish size distribution by site. Lower and upper boundaries of a box represent the interquartile range (25% to 75% values) and is divided at the median value (50%), whiskers represent 10% and 90% of observations, and values outside of this range not shown

The overall mean length of fish observed was 10.15 cm ± 0.08 SEM. Length significantly varied between sites ($\chi^2 = 845.65$; $p < 0.0001$); it was highest at Akitakyi Small (12.64 cm ± 0.42 SEM) and Miemia Inner (12.58 cm ± 0.25 SEM) and smallest at Abokwe Seaward and Abokwe Leeward (6.80 cm ± 0.25 and 6.87cm ± 0.18 respectively). Eight of the 14 sites surveyed exhibited mean length of fish <10 cm (Figure 3.16.).

Fish size varied significantly between habitat types, and levels of exposure, wave action and fishing pressure ($p < 0.05$; Figure 3.17.). Bay and patch sites had significantly larger fish than headland and island sites, with island sites having the smallest size (Appendix 3). Semi-exposed sites had significantly larger fish than both sheltered and exposed sites, with sheltered sites also having significantly larger fish than exposed sites (Appendix 4).

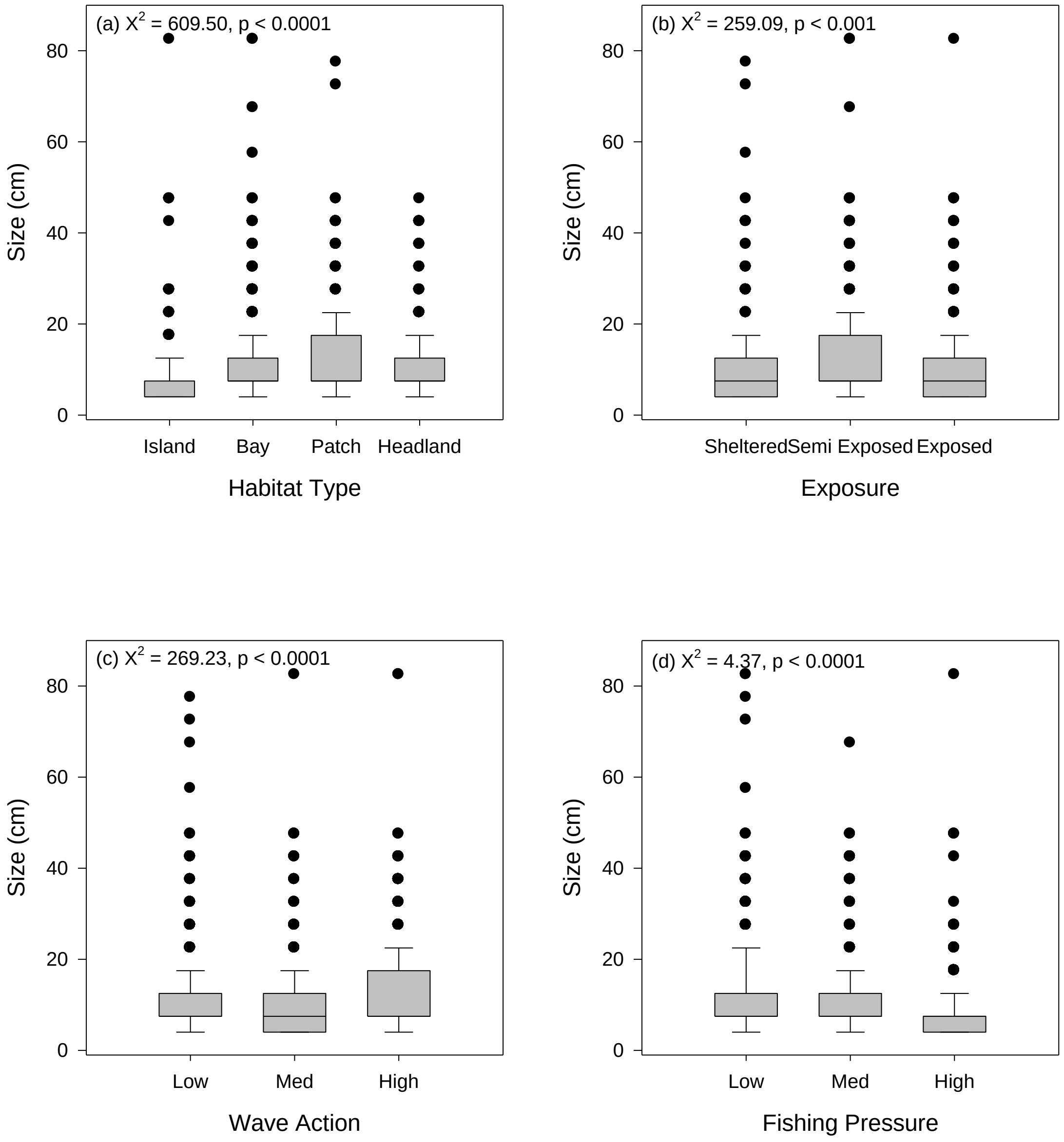


Figure 3.17. Size (length) distributions of fish by (a) Habitat type, (b) exposure, (c) wave action and (d) fishing pressure. Lower and upper boundaries of a box represent the interquartile range (25% to 75% values) and is divided at the median value (50%), whiskers represent 10% and 90% of observations.

Sites with high levels of wave action had significantly larger fish than sites with low and medium levels of wave action. Low wave action sites also exhibited larger fish size than medium wave action sites (Appendix 5). Sites experiencing low levels of fishing pressure had significantly larger fish than sites exposed to medium and high fishing pressure, while sites of medium fishing pressure had larger fish than sites with high levels of fishing pressure (Appendix 6).

Invertebrate community structure

A total of 20 discrete macro faunal taxa were recorded during the course of the survey. Of these, eight (40%) were mollusks, four were crustacean (20%), four Echinoids (20%) and there were three taxa each from three echinoderm classes (Asteroidea, Ophiuroidea and Holothuroidea, 15%). Representatives of the Polychaeta (fire worm) made up the remaining 1 taxon (5%). In terms of abundance the Echinoidea were the most dominant, contributing 53.7% of the 4582 individuals recorded in total. The second and third greatest contribution to total abundance was made by the Mollusca and Crustacea (36.5% and 9.3%, respectively). The disproportionately high abundances of echinoids and gastropods were due to dominance of the pencil urchin *Eucidaris tribuloides var Africana* and the gastropod *Cerithium sp*.

Table 3.6. Summary results of Principal Component Analysis (PCA) on invertebrate distribution. Eigen vector of the two most important taxa, *Cerithium sp.* and *Eucidaris tribuloides* presented. The remaining taxa had low eigenvector scores (-0.002 to 0.07 on the first PC axis and -0.04 to 0.01 on the second axis), hence not presented.

PC properties		**PC-Axis 1**	**PC-Axis 2**
Eigen value		4610.30	2105.05
Cum Percent		66.67	97.11
Taxon		**Contribution (Eigenvector)**	
Cerithium sp.	Gastropoda	0.93	0.37
Eucidaris tribuloides	Echinoidea	-0.36	0.93

These two taxa also made the highest contribution to the scores of the two main Principal Component axes, therefore, were identified as the most important invertebrate taxa (Table 3.6.). There was a significant difference in the distribution of both species between sites. *Eucidaris tribuloides* was most abundant at Princess Town Fort followed by the seaward side of Abokwe Island (Table 3.7). Abundance was lowest at Abokwe Island Leeward, left side of Akitakyi Small Bay and both the main bay and inner patch at Miemia. *Cerithium sp.* had the highest abundance at Paradise Beach, which was followed by Abokwe Island Leeward (Table 3.7). Akitakyi Big and Miemia Inner Patch had low abundance while *Cerithium sp.* was not observed in the remaining sites. Analysis by habitat, exposure and wave energy also showed significant effects in both species (Table 3.8). *E. tribuloides* had a higher abundance on headlands than on bays and patches, on exposed sites than on sheltered and semi-exposed sites and on areas of medium wave strength than in low and high wave action areas. *Cerithium sp.* had highest abundance in bays and no animals were recorded on headlands.

Table 3.7. Abundance of the two most dominant invertebrate taxa by site. Kruskal-Wallis Chi-Squared (K-W χ^2) and significance level (p) presented. ND: No data.

By site	*Eucidaris tribuloides*		*Cerithium sp.*	
	K-W χ^2	p	K-W χ^2	p
	32.01	0.0008	27.55	0.004
	Mean	SEM	Mean	SEM
Abokwe Isl leeward	4.3	4.3	90.0	5.8
Abokwe Isl seaward	88.7	9.5	0.0	0.0
Akitakyi Big	24.3	4.8	1.7	1.7
Akitakyi Small - Left	8.7	2.6	0.0	0.0
Akitakyi Small - Right	ND	ND	ND	ND
Atwiwa	42.4	0.7	0.0	0.0
Cape Three Points	ND	ND	ND	ND
Miemia Bay	4.7	0.3	0.0	0.0
Miemia Inner Patch	5.0	1.7	6.5	4.4
Miemia Outer Patch	37.7	11.1	0.0	0.0
Mutrakni Point	42.3	16.9	0.0	0.0
Paradise Beach	17.8	7.5	216.7	101.4
Princess Town	175.0	32.4	0.0	0.0
West Point	67.8	13.2	0.0	0.0

Abundance was higher on exposed and semi-exposed sites than sheltered sites and was highest in low energy sites while no animals were recorded in sites of medium wave energy strength. Results of step-wise multiple regression on the relationship between abundance of *E. tribuloides* and *Cerithium sp.* and biotic and abiotic factors are provided on Table 3.9.. Abundance of *E. tribuloides* was mainly explained by sponge cover and lethrinid and serranid biomass (Table 3.9A). The relationship with sponge cover and lethrinid biomass was positively strong while that with lethrinid biomass strongly negative. There was also a significant relationship with barnacle (-ve) and gorgonian cover (+ve). *Cerithium sp.* had a positive relationship with monacanthid biomass and fleshy algal cover and a negative relationship with pomacentrid biomass (Table 3.9.B).

Table 3.8. Abundance of the two most abundant invertebrate taxa by habitat type (A), exposure (B) and wave strength (C). Kruskal-Wallis Chi-Squared (K-W χ2) and significance level (p) indicated.

	Eucidaris tribuloides		*Cerithium sp.*	
A. By habitat type				
	K-W χ^2	p	K-W χ^2	p
	11.8	0.008	8.07	0.05
	Mean	SEM	Mean	SEM
Bay	16.3	3.3	72.8	40.2
Headland	77.7	15.0	0.0	0.0
Island	46.5	19.4	45.0	20.3
Patch	20.7	6.1	3.5	2.5
B. By exposure				
	K-W χ^2	p	K-W χ^2	p
	8.24	0.02	6.34	0.04
	Mean	SEM	Mean	SEM
Exposed	62.5	9.3	0.0	0.0
Semi-exposed	34.0	12.0	55.8	30.6
Sheltered	22.2	4.9	25.5	12.6
C. By wave strength				
	K-W χ^2	p	K-W χ^2	p
	20.7	<0.0001	11.4	0.003
	Mean	SEM	Mean	SEM
Low	20.6	4.0	92.9	41.5
Medium	73.9	11.5	0.0	0.0
High	5.8	1.1	3.3	2.3

None of the taxa were universally present throughout the survey area, with 16 of the 20 taxa absent from 80% of the sites. The most frequently recorded taxon, occurring in 50 of the 52 transects, was the pencil urchin *Eucidaris tribuloides var Africana*, with a frequency of 96%, whilst the talon crab *Percnon gibbesi* was also frequently encountered (75% of transects). The generally low frequencies of occurrence indicated that the vast majority of taxa were either rare or patchily distributed throughout the survey area.

The degree of variability seen in the number of taxa was small, with between 4 and 11 taxa recorded per site (Table 3.10.)

Table 3.9. Summary of step-wise multiple regression analysis on A) *Eucidaris tribuloides* and B) *Cerithium sp*. in western Ghana.

A. Eucidaris tribuloides var Africana			
R^2_{adj}	**ANOVA F**	**p**	
0.37	9.08	<0.0001	
Term	**Estimate**	**F Ratio**	**p**
Ephippidae	-0.14	4.68	0.04
Depth	7.65	8.27	0.007
Gorgonia	77.62	10.85	0.002

B. Cerithium sp.			
R^2_{adj}	**ANOVA F**	**p**	
0.26	5.19	<0.0001	
Term	**Estimate**	**F Ratio**	**p**
Percent rock	-1.81	14.72	0.0004
Rugosity	4.55	0.51	0.48
Labridae	0.04	3.86	0.06
Lutjanidae	-0.01	5.61	0.02

Table 3.10. Diversity of invertebrates by site

Site	Number of Taxa [S]	Species richness [D_{MG}]	Pielou's equitability [*J'*]	Simpson's dominance *D* [1-λ]	Shannon-Wiener diversity [*H'*]
Abokwe Leeward	5	0.806	0.536	0.863	0.507
Abokwe Seaward	11	2.167	0.256	0.615	0.229
Akitakyi Big	8	1.956	0.465	0.968	0.502
Akitakyi Small Left	7	2.415	0.533	1.038	0.502
Atwiwa	11	2.432	0.490	1.174	0.505
Miemia	4	0.921	0.469	0.650	0.370
Miemia Inner	6	1.610	0.820	1.470	0.793
Miemia Outer	4	0.731	0.705	0.977	0.555
Mutrakni Point	8	1.638	0.255	0.530	0.235
Paradise Beach	10	1.622	0.292	0.673	0.284
Princess Town	4	0.580	0.053	0.073	0.023
West Point	10	2.103	0.144	0.331	0.121
Mean	**7**	**1.582**	**0.418**	**0.780**	**0.385**
SD	**2.74**	**0.67**	**0.23**	**0.38**	**0.22**

Dominance curves showed that most sites were highly dominated by a single or a few species, with dominant species contributing between 60%-98% (Figure 3.18.). Miemia Inner was an exception having a more even (less dominated) community.

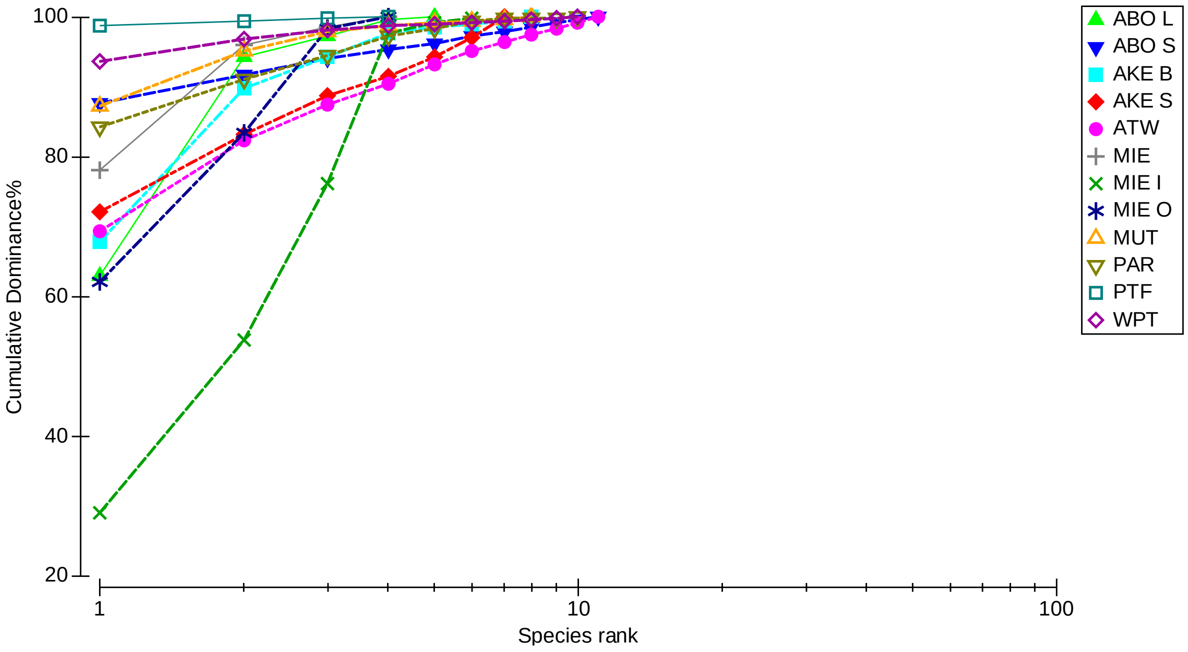


Figure 3.18. Dominance curves for site data

Benthic / substrate cover

Overall crustose coralline algae had the highest cover, followed by turf algae, sand, fleshy algae and blue green algae (Figure 3.19.). Crustose corallines also made the highest contribution to the first PC axis that explained 59% of the variation, followed by turf and sand (Figure 3.20). There was a very strong negative relationship between this axis and coralline cover ($R^2 = 0.98$; ANOVA F = 2651.7, $p < 0.0001$; Figure 3.20B). The second axis explained 19% of the variation and represented mostly turf algae and sand, which had a strong negative relationship with each other (Figure 3.20D). Further univariate and multivariate analyses were carried out on the above five important benthic/substrate groups identified by PCA. No further analysis was carried out on the remaining groups, which had lower cover and contributed the least to the pattern in benthic/site and substrate associations.

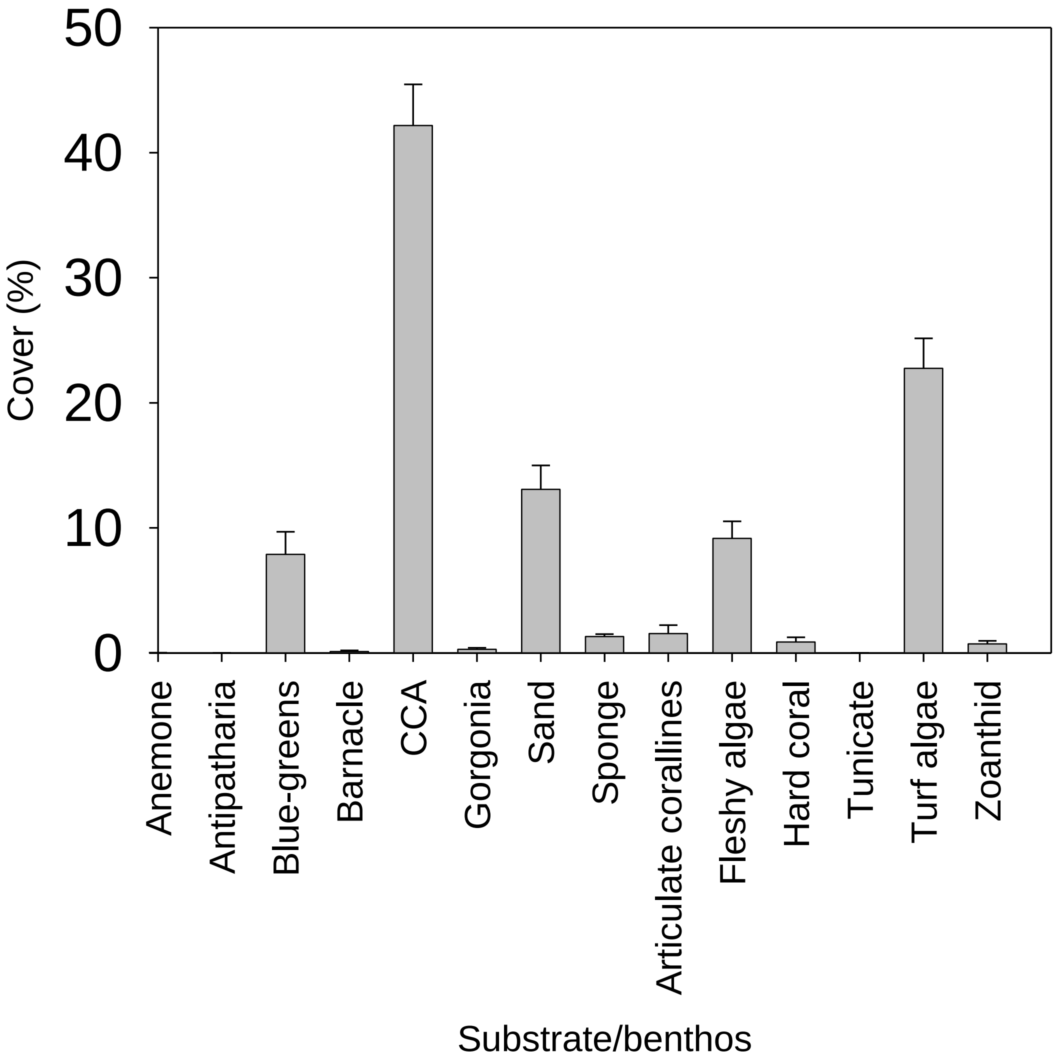


Figure 3.19. Mean cover (SEM) of major benthic groups.

Four distinct site groups were identified based on PCA (Figure 3.20,Table 3.11.). The leeward side of Abokwe Island and Miemia Outer Patch form separate clusters. The remaining sites are classified into two distinct groups. Abokwe leeward side had the highest cover of sand and fleshy algae. Although coralline cover was relatively higher than the other benthic/substrate groups in most sites, it was particularly high at Miemia Outer Patch, making the site a distinct cluster of its own. Sites in cluster 2 had the highest cover of turf and blue-green algae. Sites in cluster 3 did not associate with a specific benthic/substrate group but had relatively high cover of corallines, turf and blue-green algae.

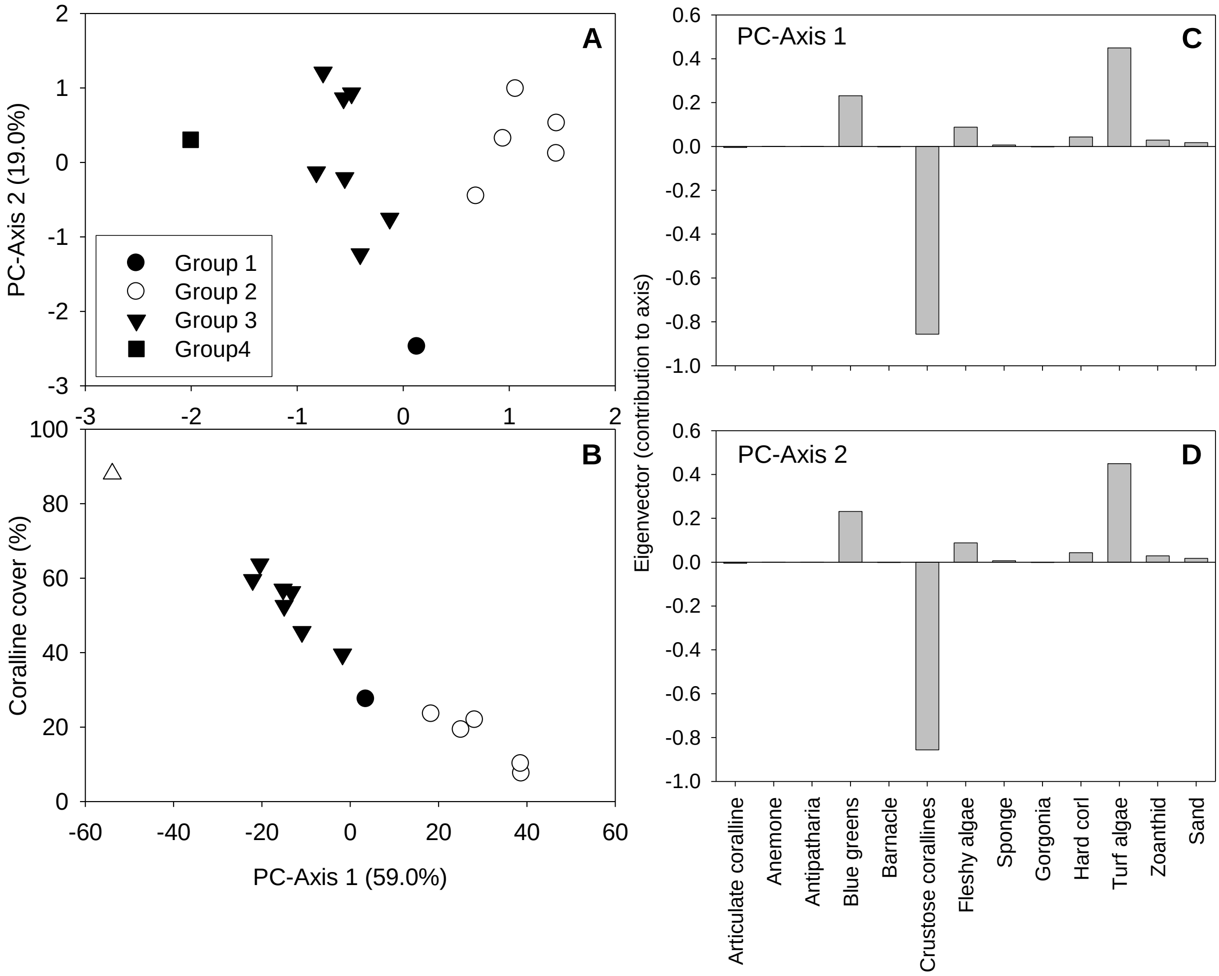


Figure 3.20. Principal Component (PC) analysis results on benthic/substrate and site associations (A). Relationship between crustose coralline cover and scores of the first PC-Axis (B). Eigenvector (contribution) scores of benthic/substrate groups to the first (C) and second PC axes (D).

Table 3.11. Composition of the major benthic/substrate groups by site clusters identified by Principal Component Analysis (PCA)

	Crustose corallines		Turf algae		Fleshy algae		Blue-green algae		Sand	
Group	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
1	27.5	9.7	7.4	8.1	21.7	5.7	0.0	0.0	40.9	7.6
2	18.2	4.1	39.4	3.4	10.6	2.4	12.7	3.3	12.1	3.2
3	51.4	2.9	17.8	2.4	8.2	1.7	6.7	2.3	11.4	2.3
4	88.0	9.7	0.0	0.0	0.0	0.0	1.5	7.7	9.3	7.6

There was significant variation between sites in all the main five substrate/benthic groups identified by PCA (Table 3.11.). Crustose coralline cover was highest at Miemia Outer Patch and lowest at Akitakyi Small. Sites with low coralline cover generally had high cover of turf algae with the exception of the exposed site at Abokwe Island. At this site and the left side of Akitakyi Small, sand and blue green algae were the respective dominant benthic groups. Mutrakni Point and the right side of Akitakyi Small had a relatively high cover of blue green algae.

We also analysed the variation in benthic/substrate groups among bays, headlands, patch and islands (Table 3.13.A). Significant variation was detected in corallines, blue-green and fleshy algae. Turf algae and sand did not reveal any significant difference. Blue-green cover was higher in bay and headland than in island and patch while corallines and fleshy algae had opposite patterns, corallines having higher cover in headland and patch than in bays and islands.

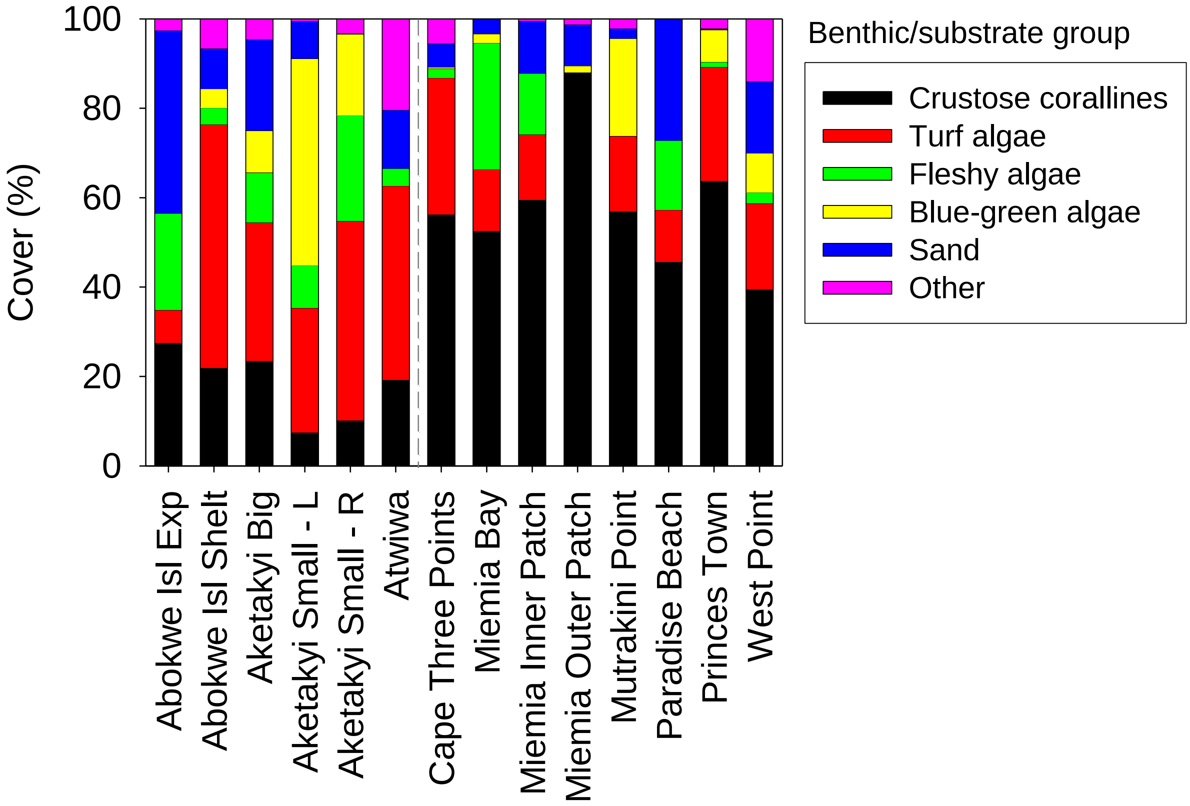


Figure 3.21. Percentage cover proportions of the main benthic/substrate groups in the study area. The vertical line in the middle separates the six sites with low coralline cover to the left from the eight high coralline cover sites (right).

The distribution of crustose corallines, fleshy algae and sand was significantly influenced by exposure, corallines and fleshy algae showing the strongest response (Table 3.13.B). Corallines had higher cover on exposed and semi-exposed sites than on sheltered sites while both fleshy algae and sand were higher on sheltered and semi-exposed areas. Turf and blue-green algae didn’t respond to variations in exposure.

Table 3.13. Composition of major benthic groups on near shore rocky reefs of Western Ghana. Kruskal-Wallis (K-W) χ^2 and probability (p) provided.

	Crustose corallines		**Turf algae**		**Fleshy algae**		**Blue-green algae**		**Sand**	
	K-W χ^2	p	K-W χ^2	p	K-W χ^2	p	K-W χ^2	p	K-W χ^2	p
	36.47	0.0005	29.91	0.005	40.34	0.0001	35.18	0.0008	34.18	0.001
Site	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**
Abokwe Isl Exposed	27.5	9.7	7.4	7.9	21.7	3.8	0.0	5.8	40.9	6.5
Abokwe Isl Sheltered	21.9	9.7	54.5	7.9	3.7	3.8	4.3	5.8	9.0	6.5
Akitakyi Big	23.5	6.9	31.0	5.6	11.2	2.7	9.4	4.1	20.4	4.6
Akitakyi Small - Left	7.6	11.9	27.8	9.7	9.6	4.6	46.2	7.1	8.5	8.0
Akitakyi Small - Right	10.1	9.7	44.7	7.9	23.6	3.8	18.2	5.8	0.2	6.5
Atwiwa	19.3	9.7	43.4	7.9	3.9	3.8	0.0	5.8	13.1	6.5
Cape Three Points	56.3	9.7	30.5	7.9	2.1	3.8	0.3	5.8	5.2	6.5
Miemia Bay	52.6	9.7	13.7	7.9	28.3	3.8	2.0	5.8	3.3	6.5
Miemia Inner Patch	59.5	7.5	14.6	6.1	13.7	2.9	0.0	4.5	11.7	5.1
Miemia Outer Patch	88.0	9.7	0.0	7.9	0.0	3.8	1.5	5.8	9.3	6.5
Mutrakni Point	57.0	6.9	16.8	5.6	0.1	2.7	21.8	4.1	2.3	4.6
Paradise Beach	45.6	6.9	11.7	5.6	15.6	2.7	0.0	4.1	27.1	4.6
Princess Town	63.7	9.7	25.5	7.9	1.1	3.8	7.2	5.8	0.2	6.5
West Point	39.5	5.9	19.2	4.8	2.6	2.3	8.8	3.6	16.0	4.0

Table 3.13. Distribution of major benthic groups on near shore rocky reefs of Western Ghana by habitat type (A), exposure (B) and wave strength (C). Kruskal-Wallis (K-W) χ^2 and probability (p) provided.

	Crustose corallines		**Turf algae**		**Fleshy algae**		**Blue-green algae**		**Sand**	
A. By habitat type										
	K-W χ^2	**p**	**K-W χ^2**	**p**	**K-W χ^2**	**p**	**K-W χ^2**	**p**	**K-W χ^2**	**p**
	11.3	0	13.2	0.004	5.4	0.2	23.3	<0.0001	1.9	0.6
Habitat type	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**
Bay	30.9	5	24.3	4.1	16.8	1.8	10.5	2.9	15.6	3.1
Headland	50.9	5	21.1	4.1	1.5	1.8	11.2	2.9	7.9	3.1
Island	24.7	9.1	30.9	7.4	12.7	3.4	2.1	5.4	24.9	5.7
Patch	56.3	6.8	18.5	5.5	7.3	2.5	0.4	4	11.4	4.2
B. By exposure										
	K-W χ^2	**p**	**K-W χ^2**	**p**	**K-W χ^2**	**p**	**K-W χ^2**	**p**	**K-W χ^2**	**p**
	8.1	0.02	3.21	0.2	13.41	0.001	2.65	0.27	11.14	0.004
Exposure level	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**
Exposed	44.6	5.2	25.5	4	1.9	2.0098	10.7	3	9.2	3
Semi-exposed	49.2	4.6	18	3.6	13.6	1.7976	7.2	2.7	11.1	2.7
Sheltered	23.4	6.7	28.2	5.2	12	2.5946	4.7	3.9	23.7	3.9
C. By wave strength										
	K-W χ^2	**p**	**K-W χ^2**	**p**	**K-W χ^2**	**p**	**K-W χ^2**	**p**	**K-W χ^2**	**p**
	7.8	0.02	0.2	0.9	29.7	<0.0001	5.6	0.06	18.1	0.0001
Wave strength	**Mean**	**Std Error**	**Mean**	**Std Error**	**Mean**	**Std Error**	**Mean**	**Std Error**	**Mean**	**Std Error**
Low	30.8	5.5	22.7	4.3	13.2	1.8	3.1	3.1	24.9	2.9
Medium	51.8	4.6	22.5	3.6	1.6	1.5	9.3	2.6	8.2	2.4
High	38.5	6.5	23.4	5.1	18.7	2.1	11.8	3.7	6.6	3.4

Wave strength had significant effects on coralline, fleshy algal and sand distributions, with strongest effect on fleshy algae and sand (Table 3.13.C). Fleshy algae had higher cover on both low and high wave action areas, corallines in areas with medium wave action while sand associated mainly with low wave action areas. Wave action had only marginal effect on blue-green algal distribution, areas with medium and high wave action having higher cover than those with low wave action. Wave action had no effect on turf algal distribution.

Multiple regression results showed that acanthurid biomass was the main variable influencing blue-green algal and coralline distribution (Table 3.14.). Blue green algal cover increased while coralline cover decreased with acanthurid biomass. Cover of turf algae was mainly influenced by wave action showing a negative relationship. Distribution in cover of sand was mainly explained by wave action, cover decreased as wave action increased. Fleshy algal distribution was explained by several variables with depth, rugosity and pomacentrid biomass having negative effects whereas exposure, acanthurid, scarid and chaetodontid biomass all had positive effects.

Table 3.14. Summary of multiple regression results on the relationship between benthic/substrate and environmental and biotic variables.

Dependent	R^2adj	ANOVA F	p	Main explanatory factor	Relationship
Corallines	0.62	4.62	0.032	Acanthuridae	-ve
Turf algae	0.21	4.35	0.06	Wave action	-ve
Fleshy algae	0.99	502.52	0.0001	Depth	-ve
				Exposure	+ve
				Rugosity	-ve
				Acanthuridae	+ve
				Chaetodontidae	+ve
				Pomacentridae	-ve
				Scaridae	+ve
Blue-greens	0.88	16.65	0.0008	Acanthuridae	+ve
Sand	0.71	8.53	0.004	Urchin abundance	-ve

4. Discussion

This study investigated the general status of the marine habitat and fisheries of the shallow near shore rocky reefs of western Ghana. It followed a holistic approach that included key ecological variables and indicators of ecosystem health and provides baseline information on the fish, invertebrate and benthic communities of this less studied environment. Although it represents only a small proportion of Ghana's coastal area (2%) (Berncsek 1986; Armah and Amlalo 1998) and probably contributes less to the local fisheries, notably dominated by pelagic and to some extent soft bottom fish stocks, it could play a significant role in contributing to the productivity and marine biodiversity of the area. Situated at the interface between the terrestrial environment, intertidal zone and the deep sea, it is thought to play a critical ecological role in linking these different environments and it also supports a small artisanal fishing community. This study provides insight into the impact fishing has had within this habitat, drawing a parallel with the well documented declining status of Ghana's pelagic and demersal fisheries.

Fish community structure and biomass

Fish community structure and biomass varied by site in relation to fishing and physical environmental parameters. The dominance of low trophic level and small bodied fish and near absence of large sized carnivorous fishes suggests that fishing pressure plays a prominent role in structuring the community. Because all the study sites are open to fishing, including illegal and destructive fishing, and there is lack of baseline ecological data, the effects of fishing are difficult to detect. The measure of fishing pressure used in this study probably doesn't reflect historical fishing and therefore results should be interpreted with caution.

In the absence of large sized fish belonging to higher trophic levels (see above) the sites are categorised into three groups by PCA: 1) those dominated by large numbers of Acanthuridae, 2) those dominated by Pomacentridae and Carangidae and 3) those dominated by Labridae Figure 3.3.). The lack of correspondence between biomass and abundance has been reported in other ecosystems and even becomes reversed in areas where top predatory fish dominate the biomass (Newman et al. 2006). All low biomass sites had a lower contribution by one of the larger bodied fish families of scaridae, lutjanidae or acanthuridae.

The two dominant families were represented mainly by a single species each (Pomacentridae: *Stegastes imbricates*; Labridae: *Thalassoma newtonii*). This dominance by small sized fishes belonging to lower trophic groups reflects the patterns in size frequency distribution and trophic composition (Figure 3.15. and **Error! Reference source not found.**). The positive elationship between trophic level and depth is probably linked with the distribution of the grouper, *Cephalopholis nigri* (Figure 3.9). The opposite pattern may be explained by the abundance of low trophic level acanthurid and pomacentrid species in shallow sites (Figure 3.5.).

The significant positive relationship between species richness and Simpson's Diversity indicates that evenness increases (dominance decreases) with number of species. This may be due to simple correlation but may also reflect that high diversity sites were those experiencing intermediate levels of disturbance (Connell 1978). As disturbance increases, diversity decreases and dominance increases. There were probably no low disturbance areas represented in the study to show full scale of the diversity-disturbance unimodal relationship.

The low contribution to the total biomass by top predators indicates that most of the reefs are far from being in a pristine state. On coral reefs, where fish and benthic community structure is well investigated, fish biomass is considered as an indicator reef health and high biomass correlated with biomass of large-sized apex predators (Newman *et al.* 2006; Williams *et al*. 2011). On healthy pristine environments up to 80% of the biomass is composed of top predators, including sharks, barracudas, snappers and groupers (Williams *et al.* 2011). As these top predators are selectively removed by fishing, small sized predators, planktivorous and herbivorous fish increase in numbers and make greater contributions to the total biomass – a characteristic of severely fished reefs. The highest biomass observed in this study (1000 kg ha^{-1}) can be indicative of the potential of the area. However it is notable that 69% of this maximum biomass is contributed by lower trophic groups, and so potential biomass could be much higher.

The opposite relationship with depth of abundance and biomass is explained predominantly by the small sized pomacentrids and labrids that dominate abundance and occur mostly at shallower depths while larger grazers and predatory fish that contribute significantly to biomass are mainly present in deeper areas.

The three dominant carangids were all semi-pelagic planktivorous juveniles, and the positive relationship between abundance and sand cover is probably related to the occurrence of sand in more wave-swept high energy shallow areas.

Figure 4.1. ***Cephalopholis nigri*** **whose population may be growing rapidly following the removal of other larger grouper species**

Most of the fisheries in these areas are dominated by one-man unmotorised canoes using hook and line or deploying set nets at the transition between the rocky and soft bottom habitats. Hook and line fishing is known for being very selective targeting mostly carnivorous, and piscivorous fish. Large predatory fishes were virtually absent and most of the piscivore fishes encountered in the underwater visual surveys and observations of catch by local fishers were small sized groupers. The rock hind *Cephalopholis nigri* (Serranidae) was the only commercially important species observed in significantly high numbers. This is a small sized fish (Max size = 30 cm) in comparison to other targeted species but is commonly targeted by the one-man unmotorised canoes (authors' observations). Without long term time series abundance data it is difficult to establish whether the current dominance of *C.nigri* existed before or is a new observation. The high abundance of this species, in both catches and ecological surveys, probably indicates a high turn-over rate related to its size and its low vulnerability to fishing pressure. Many predatory species including groupers are known to have significant dietary overlap and shifts can occur with changes in the composition of prey species or ontogenetic changes of predatory species (Brule and Canche 1993; Renones *et al.* 2002). It is likely that the high abundance of *C.nigri* is a recent occurrence related to competitive release as other larger grouper species declined.

Box 4.1. Fishers' perception about the fisheries

Out of the fishers interviewed on their view on the fisheries, 100% believed that the total catch has significantly declined over time. About 66.7% believed that average size of fish caught has decreased, while the remaining 33.3% were of the opinion that size remained the same. Not a single fisher was of the view that the fish caught at present are larger than a decade before. All fishers interviewed (100%) believed that they travelled farther and spent more time out at sea and all agree that fishers with motorised boats, who can travel longer distances in a day, catch more and catch larger sized fish.

Invertebrate community

Eucidaris tribuloides var. *Africana* was the most abundant and most widely distributed marine invertebrate species in the study area. Due to lack of information, it cannot be ascertained if this high abundance is natural to the area or a recent occurrence associated with environmental changes. Observations in other parts of the world, both tropical and temperate, indicate that sea urchin populations show large fluctuations in response to changes in predatory fish abundance and are thought to be important ecological indicators. Sea urchins are voracious feeders and large urchin biomass is known to bring about significant changes in benthic community structure through grazing of algae and bioerosion of calcified substrate (Glynn *et al.* 1983; McClanahan and Muthiga 1989; McClanahan and Shafir 1990). In recent decades, many herbivorous sea urchin species have exhibited dominance and population explosions in both tropical and temperate waters (Lessios *et al.* 1984; Lessios 1988; Carpenter 1990). This increase is mainly associated with reduction in predation by carnivorous invertebrates (e.g. lobsters) and fish (e.g. triggerfish, wrasses, pufferfish) (Glynn *et al*. 1979; McClanahan 2000).

Cidaroid urchins are mostly omnivorous although *E. tribuloides* is believed to feed mainly on sessile invertebrates, such as corals, sponges and gorgonians (McPherson 1968; McClintock *et al*. 1982). The strong positive relationship of *E. Tribuloides* abundance with gorgonian cover and weak negative relationship with the biomass of Spadefish (Ephippidae) (Table 3.9.A) suggests that these two factors probably interact in controlling its abundance. Our data indicates that many of the sites are overfished and lack sufficient biomass of predators to control overgrowth of prey populations. This consistently low biomass of predatory fish across all sites limits the ability to detect variation in abundance of prey species.

The extremely high abundance of *E. tribuloides* is most likely a result of trophic cascades related to overfishing of predatory fish. The largest invertivorous fish observed in the study area was the black-bar hogfish (*Bodianus speciosus*). It is not known if populations of this wrasse have undergone cycles in abundance in relation to fishing pressure as observed in the grey triggerfish (*Balistes capriscus)* in the adjacent deep demersal environment. For nearly 20 years from the early 1970s to late 1970s, this triggerfish dominated the deep ecosystem displacing the big-eye grunt (*Brachydeuterus auritus*) as the most abundant fish (Koranteng 1998, 2001b). The decline of triggerfish was followed by increases in the landings of ray, sole and cuttlefish. These cycles were associated with shifts in trophic and competitive relationships related to fishing (Koranteng 2001a; Koranteng and Pauly 2004). It is possible that the NSRH have experienced similar cycles in the composition of predatory fish over different periods.

Our investigation of the marine invertebrate community also included assessment of commercially important groups, such as lobsters, shrimps and octopus. The results indicate very low densities of these groups. Lobsters are well known for being effective sea urchin predators, particularly juvenile urchins (Tegner and Levin 1983; Lafferty 2004). In conjunction with the reduced predation by fish related to overfishing, overharvesting of commercially important predatory invertebrate species could have significant effects on prey species.

In both temperate and tropical areas urchin population explosions tend to be followed by epidemics (Lessios *et al*. 1984; Scheibling and Stephenson 1984; Carpenter 1990) with those of greater proportion occurring in fished habitats rather than in reserves (Lafferty 2004). For the temperate herbivorous sea urchin, *Stronglocentrus droebachiensis* (Echinoidea), epidemic levels are reached at 74 individuals per m^2, the threshold density for the same species is believed to be 3.72 individuals m^2. Similarly, the well-publicised population explosion and subsequent collapse of the white spine sea urchin (*Diadema antillarum*) population in the Caribbean in the early 1980s was associated with overfishing. In the absence of herbivorous fish, the demise of *D. antillarum* resulted in the overgrowth and dominance of fleshy algae. *E. tribuloides* and other sea urchin species were not affected during the Caribbean wide *Diadema* mass mortality. Isolated mass mortality of *E. tribuloides* was reported in Puerto Rico in the winter of 1984-1985 but its cause was not identified (Williams 1986).

Figure 4.2. Low biomass of invertivorous fish such as Lutjanids has significant impacts on populations of prey species

The other dominant marine invertebrate was *Cerithium sp*. Members of the cerithiid gastropods are mostly deposit feeders on benthic diatoms (Whitlatch and Obrebski 1980; Barnes 2003). The present study indicates that levels of exposure and environmental factors determine the distribution of *Cerithium* (Table 3.8). The main predators of cerithiid gastropods are labrids, which have strong pharyngeal jaws capable of crushing mollusk shells (Ayal and Safriel 1982; Wainwright 1987). However, there was no significant relationship between *Cerithium* abundance and labrid biomass in this study although the relationship with lutjanid biomass (also known to be predators of gastropods) was negative (Table 3.9.). *Cerithium* is also a favoured food item for spiny lobsters (Cox *et al.* 1997); however, the latter was not included in our analysis due to their extreme low density. The low density of lobster along with that of other gastropod eating invertebrates (e.g. octopus) and fish has probably allowed *Cerithium* to become abundant in some sites. The negative relationship with lutjanid biomass probably indicates that fishing induced trophic cascades could be one of the main causes in the observed pattern of *Cerithium* distribution.

Benthic community

Crustose corallines are the most dominant feature in the benthic community of Ghana's near shore rocky reefs, followed by turf, blue-green and fleshy algae. Coralline dominance is most pronounced in exposed high energy areas dominated by boulders as observed in other environments (Chisholm *et al.* 1990). The negative relationship between coralline cover and acanthurid biomass is unexpected (Table 3.14.) as acanthurids tend to promote corallines by cropping competitive turf and fleshy algae. The results could be due to a simple correlation as acanthurids could naturally be less abundant in these areas due to high wave energy. These habitats also have the highest abundance of the herbivorous sea urchin *Arbacia lixula*. *A. lixula* is well known for its grazing effects in temperate rocky areas where corallines become dominant (Sala *et al.* 1998; Chiantore *et al.* 2008). Corallines due to their protective calcified tissue have more tolerance to grazing by urchins and fish. The giant territorial damselfish *Microspathodon frontatus* was also most abundant in these areas. Adults of this species are algal browsers and their high biomass in these areas could favour crustose corallines over fleshy and turf algae.

Crustose coralline cover followed opposite patterns to the cover of other algal groups (turf, blue-green and fleshy algae). Low wave energy areas with lower presence of large boulders have high cover of the latter groups. Fleshy algae dominate shallow depths probably due to their high requirement of light. In addition, depth has a significant negative relationship with biomass of acanthurids and pomacentrids and a positive relationship with exposure. Thus, shallow sites may be either exposed or sheltered areas. Sheltered areas may act as refugia against grazing by herbivorous fish, while exposed, high wave energy sites could be more heavily grazed. Blue-green algae respond positively to acanthurid biomass (Table 3.14.), these algae are not a target for most herbivorous fish and the high cover in sites with high herbivorous fish biomass could be due to competitive exclusion of turf and fleshy algae by grazers. Thus, dominance by turf and blue green algae or fleshy algae could be dependent on herbivore abundance.

5. Conclusions and recommendations

Summary of findings

The near shore rocky reefs of Ghana are characterised by communities typical of areas with high levels of overfishing and associated cascading trophic effects. The near complete removal of top predatory fish by overfishing has resulted in the release of prey species and high dominance of a few abundant species observed in the fish, invertebrate and benthic communities. The average biomass of about 398 kg ha-1 found in this study is considered very low taking into account the family, size and trophic composition of the community, which is dominated mostly by small to medium sized and low-trophic groups belonging to the families Acanthuridae, Labridae, Pomacentridae and Scaridae.

This is consistent with the small catches of local fishers, also dominated by small-sized fish (often groupers). Large sized fish in the catches are mainly herbivorous parrotfish and surgeonfish while large-sized predatory fish (grouper and snapper) were seldom observed. The visual surveys and catch observations support the perceptions by fisher communities on decreasing total catches, increasing effort, declining catch per unit effort (CPUE) and decreasing fish sizes and trophic levels. In addition, the limited amount of data from experimental fishing on adjacent soft bottom habitats is in agreement with these observations. About 23% of all fish caught were below the size of maturity, none of the small sized species (Atlantic Bumper and African Threadfin) was below maturity size and 33% of the medium-sized Cassava Croaker (33 cm) was below the size of maturation (Figure 5.1.).

Figure 5.1. Cassava fish (Pseudotolithus senegalensis) can reach over 1m in length; 33% of the fish caught in the experimental fishing were below length at maturity (L_{mat}).

These findings indicate that the mesh sizes of the set nets being used are below the minimum size required at least for some species. We observed that many of the fishers employ illegal monofilament nets and nets below the approved mesh size

(Ghana Fisheries-Commission 2010). In some instances these are accompanied by other illegal practices, such as dynamite and poison fishing (personal observations and focus group interviews). These observations are consistent with findings across the globe that declining fisheries lead towards desperate measures of destructive fishing (Pauly *et al.* 2002; Agnew *et al.* 2009; Worm *et al.* 2009). The high rarity in commercially important invertebrate species (lobster and octopus) in the visual surveys could also suggest that the proportion of these species in the catch has significantly declined over the years.

Dominance by corallines probably renders the reefs less productive with regard to the transfer of carbon to higher trophic levels as they only provide food to organisms with powerful jaws, e.g. sea urchins and parrotfish (Steneck 1997). The majorities of the corallines observed formed very thin encrusting layers and probably contribute little to reef formation.

Dominance by sea urchins often results in ecological disturbances through excessive bioerosion (herbivorous urchins) (Carpenter 1990; McClanahan and Shafir 1990) or predation (carnivorous urchins). Large invertebrate densities might result in disease epidemics (Carpenter 1990; Scheibling and Hennigar 1997) resulting in release and dominance of prey species (Carpenter 1990; Scheibling and Hennigar 1997). The dominance by *E. tribuloides* in Ghana's NSRH probably has caused significant shifts in the benthic composition and may continue to do so if the population is not controlled.

In addition, dominance of one or few species may render an ecosystem less resilient to natural or human induced environmental disturbances, such as climate change. For example, overfished Caribbean coral reefs with high nutrient and sediment input have become dominated by fleshy algae and suffered more from the effects of coral bleaching and diseases and have shown low post bleaching and post disease recovery (Gardner *et a*l. 2003; Côté *et al*. 2005; Schutte *et al*. 2010). Dominance by the sea urchin *Diadema antillarum* resulted in mass mortality promoting a further increase and dominance of fleshy algae over corals – phase shift.

Ecological dominance by a few taxa and reduction in the number of large-sized charismatic megafauna (e.g. sharks, turtles and marine mammals) could also have significant negative effects on the aesthetic and cultural values of the ecosystem with significant socio-economic implications.

Ecological information on near shore rocky reefs of Ghana and generally in West Africa is very limited as most studies focus on the very productive and commercially important pelagic and deep demersal fish populations (Pezennec and Koranteng 1998; Bianchi *et al.* 2000; Koranteng 2001b, 2001a; Koranteng and Pauly 2004). The coastal lagoons and estuaries are also relatively well investigated (Mensah 1979; Ntiamoa-Baidu 1991; Entsua-Mensah and Dankwa 1997; Lae 1997; Entsua-Mensah *et al.* 2000). The current study fills a knowledge gap concerning Ghana's coastal and marine environment with the findings of the present study pointing towards extreme overfishing in near shore rocky reefs of western Ghana.

Despite total fisheries catches remaining constant or showing a tendency towards decline in the pelagic and demersal fisheries, there has been significant change in catch per unit effort (CPUE), species, trophic and size composition of the fisheries landings (Koranteng and Pauly 2004; FAO 2010; Finegold *et al.* 2010). In spite of these reported declines, these two fisheries still provide large catches of top predators, such as tuna, jacks, bream and snapper (pers. obs.). The near absence of commercially targeted large-sized fishes (especially those belonging to Serranidae and Lutjanidae) in the near shore rocky reefs of Ghana suggests that these habitats may even be more overfished than the above two.

Management implications

This study is an important component of the ecological, fisheries and socio-economic assessment of the coastal and marine environment of western Ghana and intended to lead to integrated coastal management, including Ghana’s first marine protected area (MPA). It complements other recent socio-economic and ecological studies conducted by the Coastal Resources Conservation (CRC), University of Rhode Island, in collaboration with the Fisheries Commission, the World Fish Center and other local and international institutes.

As described above, the near shore rocky areas of western Ghana are characterised by dominance of some groups linked to overfishing and the ecosystem and the services that it provides will significantly benefit from the introduction of integrated management. Some of the expected results of management would be:

- Preservation of representative samples of biological diversity.
- Recovery of fish populations, including that of commercially and ecologically important top predators along with changes in fish, invertebrate and benthic community structure.
- Recovery of rare species, particularly those vulnerable to fishing.
- Protection of pristine habitats in order to maximize their resilience potential.
- Provision of adult and larval spill-over to fished stocks in adjacent areas.
- Reduction in ecological dominance.
- Increase in primary and secondary productivity.
- Increased catch for fishers and associated protein supply and income for local communities.
- Increased aesthetic and cultural value of the ecosystem.
- Reduced habitat destruction.
- Promotion for the mitigation of pollution.
- Provision of focal points for education about ecosystems and human interactions including control and reference sites serving as a baseline for scientific research and ecological evaluation of changes and impacts.

The need for integration

Ghana’s coastal area lies at the centre of the Gulf of Guinea Large Coastal Ecosystem (GCLME) and any management strategy aiming to protect a full range of life forms and populations within the GCLME will require an internationally coordinated effort among regional countries and beyond. For example, large sized migratory fish populations such as sharks, tunas and small pelagics will benefit less from local management because of the trans-boundary nature of stocks.

Management of pelagic fish is especially complex. With the incentive for each successive nation to fish as much as they can while shoals are within their waters, these stocks are successively overfished as they pass through country borders. For example, the shoals of small and large pelagic fish that rely on the seasonal upwellings within the GCLME are successively fished by 16 different countries with Ghana accounting for approximately 21% of the catches (Perry and Sumaila 2007). Management and enforcement strategies for these stocks cannot be developed at a local or country level but need to involve regional, international regulation and enforcement.

Unlike pelagic and highly migratory species, many of the species in the NSRH and other demersal habitats, are expected to have more localised distributions and substrate association, and are considered to be more responsive to local management efforts such as MPAs. An ecosystem-based management approach involving a combination of a network of small MPAs with multiple use zoning is believed to be the best model for the NSRH. The network of MPAs should include core ‘no take zones’ at their centres, surrounded by temporary closures and gear restriction zones. These core no-take-zones will allow full recovery of populations, increasing size and biomass of fish stocks and will in the long term benefit adjacent common use areas through supply of adult fish and larvae (spill-over effect).

The NSRH are spatially linked to other marine and coastal environments by currents, river discharges and larval and adult migrations. Ecosystem-based management strategies should include spatial integration that considers the biological and ecological connections at all scales ensuring sustainable exploitation does not compromise the resilience capacity of the ecosystem. Empirical data regarding the ecological interconnections between the NSRH and the adjacent shallow and deep sea habitats, the pelagic system and the lagoons and wetlands are scanty. Brief snorkelling surveys in some of the wetlands indicate that many of the species found here were the same as those observed in the underwater visual surveys. Some of the commercially important species observed in the underwater visual surveys (e.g. *Lutjanus agennes*) are the same as those reported from catches in deep demersal rocky bottom demersal fisheries (Koranteng 1998). In addition, several of the commercially important demersal (Bothidae, Elopidae, Haemulidae, Mugilidae, Sciaenidae, Sparidae) and pelagic species (Clupeidae) are known to enter rivers and estuaries at some stage of their life cycle (Whitehead 1985; Quéro *et al.* 1990). The pelagic upwelling in the offshore and inshore locations is believed to have a rippling effect on the fishery of the near shore area and other adjoining habitats. Management of NSRH will benefit these and pelagic populations that come close to the shore during the upwelling season as a result of their shoaling behaviour. For example, the Cape Three Points shoal is considered an important spawning ground for *Sardinellas* during the upwelling season (Roy 1998).

Ghana's west coast, the focus of the *Hen Mpoano* Initiative, supports some of the most biodiverse areas in the country. It is also one of the densely populated areas with major industrial, agricultural, mining, subsistence farming and fisheries activities. The beaches, cliffs, lagoons, wildlife, cultural and historical sites and coastal landscape provide great potential for tourism development. This rich coastal area is also facing several environmental challenges including overfishing, coastal deforestation, coastal erosion, pollution and rapid population growth. It is expected that MPA management will face competition with other claims on the coastal area. MPAs will need to be designed systematically, integrating the management priorities (sustainable fisheries and species conservation) with multiple stakeholder needs arising from coastal activities and services (Villa *et al.* 2002; Moffett and Sarkar 2006). MPA management should also be integrated with other existing conservation efforts, e.g. coastal forests, wetlands and wildlife, including five Ramsar sites as this will minimise costs and maximise benefits through sharing of experience and resources.

Figure 5.2. Mangrove and lagoon habitats are known to be important nursery ground for many marine fish species

6. References

Agnew, D.J., Pearce, J., Pramod, G., Peatman, T., Watson, R., Beddington, J.R., Pitcher, T.J. (2009) Estimating the worldwide extent of illegal fishing. PLoS One 4:e4570

Allison, E.H., Perry, A.L., Badjeck, M.C., Neil Adger, W., Brown, K., Conway, D., Halls, A.S., Pilling, G.M., Reynolds, J.D., Andrew, N.L. (2009) Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries* 10 (2): 173-196

Ayal, Y., Safriel, U.N. (1982) Role of competition and predation in determining habitat occupancy of Cerithiidae (Gastropoda: Prosobranchia) on the rocky, intertidal, Red Sea coasts of Sinai. *Marine Biology* 70: 305-316

Azzarello, M.Y Van Vleet, E.S. (1987) Marine birds and plastic pollution. *Marine Ecology Progress Series* 37: 295-303

Bannerman, P., Quartey, R. (2005) Report on the observations on the commercial light fishing operation in Ghana. Ghana *Marine Research Division* (MFRD), Tema. 8 pp

Barnes, R,S,K. (2003) Interactions between benthic mollusks in a Sulawesi mangal, Indonesia: the cerithiid mud-creeper *Cerithium coralium* and potamidid mud-whelks, *Terebralia* spp. *Journal of the Marine Biological Association of the UK* 83: 483-487

Bianchi, G., Gislason, H., Graham, K., Hil,l L., Jin, X., Koranteng, K., Manickchand-Heileman, S., Paya, I., Sainsbury, K., Sanchez, F. (2000) Impact of fishing on size composition and diversity of demersal fish communities. *ICES Journal of Marine Science* 57: 558-571

Binet, D. (1997) Climate and pelagic fisheries in the Canary and Guinea currents 1964-1993: The role of trade winds and the southern oscillation. Montreuil, France, Gauthier-Villars. *Oceanologica Acta* 20: 177-190

Binet, D., Marchal, E. (1993) The large marine ecosystem of shelf areas in the Gulf of Guinea: long-term variability induced by climatic changes. In: *Large marine ecosystems: stress, mitigation and sustainability*. American Association for the Advancement of Science, Washington, DC (USA) 104-118 pp.

Brule, T., Canche, L.R.G. (1993) Food habits of juvenile red groupers, *Epinephelus morio* (Valenciennes, 1828), from Campeche Bank, Yucatan, Mexico. *Bulletin of Marine Science* 52: 772-779

Burnham, K.P., Anderson, D.R. (2002) Model selection and multimodel inference: a practical information-theoretic approach. Springer Verlag, 2nd ed 485 pp

Carpenter, R.C. (1990) Mass mortality of *Diadema antillarum*. I. Long-term effects on sea urchin population-dynamics and coral reef algal communities. *Marine biology* 104: 67-77

Chiantore, M., Vielmini, I., Privitera, D., Mangialajo, L., Cattaneo-Vietti, R. (2008) Habitat effects on the population structure of *Paracentrotus lividus* and *Arbacia lixula*. *Chemistry and Ecology* 24: 145-157

Chisholm, J.R.M., Collingwood, J.C., Gill, E.F. (1990) A novel in situ respirometer for investigating photosynthesis and calcification in crustose coralline algae. *Journal of Experimental Marine Biology and Ecology* 141: 15-29

Choi, O., Fisher, A. (2003) The impacts of socioeconomic development and climate change on severe weather catastrophe losses: *Mid-Atlantic Region (MAR) and the US. Climatic Change* 58: 149-170

Chukwuone, N.A., Ukwe, C.N., Onugu, A., Ibe, C.A. (2009) Valuing the Guinea current large marine ecosystem: Estimates of direct output impact of relevant marine activities. *Ocean and Coastal Management* 52: 189-196

Claudet, J., Pelletier, D., Jouvenel, J.Y., Bachet, F., Galzin, R. (2006) Assessing the effects of marine protected area (MPA) on a reef fish assemblage in a northwestern Mediterranean marine reserve: Identifying community-based indicators. *Biological Conservation* 130: 349-369

Connell, J.H. (1978) Diversity in tropical rain forests and coral reefs*. Science* 199: 1302-1310

Côté, I.M., Gill, J.A., Gardner, T.A., Watkinson, A.R. (2005) Measuring coral reef decline through meta-analyses. *Philosophical Transactions* 360: 385-395

Cox, C., Hunt, J.H., Lyons, W.G., Davis, G.E. (1997) Nocturnal foraging of the Caribbean spiny lobster (*Panulirus argus*) on offshore reefs of Florida, USA. *Marine and Freshwater Research* 48: 671-680

Creel L (2003) Ripple effects: population and coastal regions. Population Reference Bureau Measure Communication, Washington. 8 pp

Cundell, A.M. (1974) Plastics in the marine environment. *Environmental Conservation* 1: 63-68

Dankwa, H.R., Gordon, C. (2002) The fish and fisheries of the lower Volta mangrove swamps in Ghana. *African Journal of Science and Technology* 3: 25-32

Edgar, G.J., Stuart-Smith, R.D. (2009) Ecological effects of marine protected areas on rocky reef communities - a continental-scale analysis. *Marine Ecology Progress Series* 388: 51-62

Entsua-Mensah, M., Dankwa, H. (1997) Traditional knowledge and management of lagoon fisheries in Ghana. Water Research Resources Institute , CSIR. Report no. 160, 31 pp

Entsua-Mensah, M., Ofori-Danson, P.K., Koranteng, K.A. (2000) Management issues for the sustainable use of lagoon fish resources. *Proceedings of the International Workshop on Biodiversity and Sustainable Use of Fish in the Coastal Zone* 24-27 pp

EPA/UNOPS (2004) Environmental Sensitivity Map for Coastal Areas of Ghana, Vol 2: Coastal Environment

World Resources Institute (WRI) (2003) Earth trends; country profiles: Ghana (http://earthtrends.wri.org/country_profiles/index.php?theme=8)

FAO (2011) FAO Yearbook 2009 - Fishery and aquaculture statistics. FAO, Rome 107 pp FAO (2010) FishStat Plus - www.fao.org/fishery/statistics/en

Finegold, C., Gordon, A., Mills, D., Curtis, L., Pulis, A. (2010) Western Region Fisheries Sector Review, WorldFish Center

Fisheries-Commission (2010) Fisheries regulations 2010. Ghana Fisheries Commission, Accra, Ghana.

Froese, R., Pauly, D., 2000. FishBase: a global information system on fishes (http://www.fishbase.org)

Gardner, T.A., Côté, I.M., Gill, J.A., Grant, A., Watkinson, A.R. (2003) Long-term region-wide declines in Caribbean corals. *Science* 301: 958-960

Glynn, P.W., Wellington, G.M., Birkeland, C. (1979) Coral reef growth in the Galapagos: limitation by sea urchins. *Science* 203: 47-49

Glynn, P.W., Wellington, G.M., Wells, J.W. (1983) Corals and coral reefs of the Galapagos Islands. University of California Press, 330 pp

Gregory, M.R., Andrady, A.L. (2003) Plastics in the marine environment. In: Andrady AL (ed.), *Plastics and the Environment.* John Wiley and Sons, New Jersey pp 379-401

GSS (Ghana Statistical Service) (2007-2012) Marine fish production (http://www.statsghana.gov.gh.MFP.html)

Gulland, J., Troadec, J.P., Bayagbona, E.O. (1973) Management and development of fisheries in the eastern central Atlantic. *Journal of the Fisheries Research Board of Canada* 30: 2264–2275

Haakonsen, J.M., Diaw, M.C. (1991) Fishermen's migrations in West Africa. FAO (http://www.fao.org/library)

Harley, C.D.G., Randall-Hughes, A., Hultgren, K.M., Miner, B.G., Sorte, C.J.B., Thornber, C.S., Rodriguez, L.F., Tomanek, L., Williams, S.L. (2006) The impacts of climate change in coastal marine systems. *Ecology letters* 9: 228-241

Koranteng, K.A. (2002) Biophysical study of marine and fishery resources at Moree. *Marine Fisheries, Ecosystems and Societies in West Africa: half a century change*. Senegal, Dakar.

Koranteng, K.A. (2001a) Seasonal and long-term changes in the distribution and abundance of demersal fishery resources in continental shelf waters off Ghana, West Africa (http://www.oceandocs.net)

Koranteng, K.A. (2001b) Structure and dynamics of demersal assemblages on the continental shelf and upper slope off Ghana, West Africa. *Marine Ecology Progress Series* 20: 1-12

Koranteng, K.A. (1998) Study of the structure and dynamics of demersal fish assemblages on the continental shelf and upper slop off Ghana, West Africa (http://www.oceandocs.net)

Koranteng, K.A. (1995) The western gulf of guinea coastal upwelling-peculiarities changes, and fisheries implications: a review. *Intergovernmental Oceanographic Commission (of UNESCO*)

Koranteng, K.A., Pauly, D. (2004) Long-term trends in demersal fishery resources of Ghana in response to fishing pressure. West African marine ecosystems: models and fisheries impacts. *Fisheries Centre Research Reports* 12: 75-80

Lae, R. (1997) Does overfishing lead to a decrease in catches and yields? An example of two West African coastal lagoons. *Fisheries Management and Ecology* 4: 149-164

Lafferty, K.D. (2004) Fishing for lobsters indirectly increases epidemics in sea urchins*. Ecological Applications* 14: 1566-1573

Last, P.R., White, W.T., Gledhill, D.C., Hobday, A.J., Brown, R., Edgar, G.J., Pecl, G. (2011) Longterm shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. *Global Ecology and Biogeography* 20: 58-72

Lessios, H.A. (1988) Mass mortality of *Diadema antillarum* in the Caribbean: what have we learned? *Annual Review of Ecology and Systematics* 19:371-393

Lessios, H.A., Robertson, D.R., Cubit, J.D. (1984) Spread of Diadema mass mortality through the Caribbean. *Science* 226: 335-337

Magurran, A.E., (1988) Ecological diversity and its measurement. Princeton university press Princeton, NJ, 192 pp

Mato, Y., Isobe, T., Takada, H., Kanehiro, H., Ohtake, C., Kaminuma, T. (2001) Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. *Environmental Science and Technology* 35: 318-324

McClanahan, T.R. (2000) Recovery of a coral reef keystone predator, *Balistapus undulatus*, in East African marine parks. *Biological Conservation* 94: 191-198

McClanahan, T.R., Muthiga, N.A. (1989) Patterns of predation on a sea urchin, *Echinometra mathaei* (de Blainville), on Kenyan coral reefs. *Journal of Experimental Marine Biology and Ecology* 126: 77-94

McClanahan, T.R., Shafir, S.H. (1990) Causes and consequences of sea urchin abundance and diversity in Kenyan coral reef lagoons. *Oecologia* 83: 362-370

McClintock, J.B., Klinger, T.S., Lawrence, J.M. (1982) Feeding preferences of echinoids for plant and animal food models. *Bulletin of Marine Science* 32: 365-369

McDiarmid, J. (2012) Western Ghana's Fisherfolk Starve Amid Algae Infestation. Inter Press Service http://ipsnews.net/news.asp?idnews=107479

McPherson, B.F. (1968) Feeding and oxygen uptake of the tropical sea urchin *Eucidaris tribuloides* (Lamarck). *Biological Bulletin* 135: 308-321

Mensah, M. (1979) The hydrology and fisheries of the lagoons and estuaries of Ghana. The coastal ecosystems of West Africa: coastal lagoons, estuaries and mangroves. *A Workshop Report, UNESCO*, Dakar: 58-69

Minta, S.O. (2003) An assessment of the vulnerability of Ghana's coastal artisanal fishery to climate change. MSc Thesis, Universitetet of Tromsø, 83 pp

Moffett, A., Sarkar, S. (2006) Incorporating multiple criteria into the design of conservation area networks: a mini review with recommendations. *Diversity and Distributions* 12: 125-137

Newman, M.J.H., Paredes, G.A., Sala, E., Jackson, J.B.C. (2006) Structure of Caribbean coral reef communities across a large gradient of fish biomass. *Ecology letters* 9: 1216-1227

Ntiamoa-Baidu, Y. (1991) Conservation of coastal lagoons in Ghana: the traditional approach. *Landscape and Urban Planning* 20: 41-46

Overa, R. (2001) Institutions, mobility and resilience in the Fante migratory fisheries of West Africa. Chr. Michelsen Institute of Development Studies and Human Rights 43 pp

Pörtner, H.O. (2008) Ecosystem effects of ocean acidification in times of ocean warming: a physiologist's view. *Marine Ecology Progress Series* 373: 203-217

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., Zeller, D. (2002) Towards sustainability in world fisheries. *Nature* 418:689-695

Pauly, D., Silvestre, G., Smith, I.R. (1989) On development, fisheries and dynamite: a brief review of tropical fisheries management. *Natural Resources Modelling* 3: 307-329

Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D. (2005) Climate change and distribution shifts in marine fishes. *Science* 308: 1912-1915

Perry, R.I., Sumaila, U.R. (2007) Marine ecosystem variability and human community responses: The example of Ghana, West Africa. *Marine Policy* 31: 125-134

Pezennec, O., Koranteng, K.A. (1998) Changes in the dynamics and biology of small pelagic fisheries off Cote d'Ivoire and Ghana: an ecological puzzle. In: Durand, M.H., Mendelssohn, R., Cury, P., Roy, C., Pauly, D. *Global versus local changes in upwelling systems.* ORSTOM, Paris, pp 329-343

Quéro, J.C., Hureau, J.C., Karrer, C., Post, A., Saldanha, L. (1990) Check-list of the fishes of the eastern tropical Atlantic (CLOFETA). JNICT (Lisbon), SEI. Paris, UNESCO (Paris) 1: 1-1492

Renones, O., Polunin, N.V.C., Goni, R. (2002) Size related dietary shifts of *Epinephelus marginatus* in a western Mediterranean littoral ecosystem: an isotope and stomach content analysis. *Journal of Fish Biology* 61:122-137

Rosenzweig, C., Karoly, D., Vicarelli, M., Neofotis, P., Wu, Q., Casassa, G., Menzel, A., Root, T.L., Estrella, N., Seguin, B. (2008) Attributing physical and biological impacts to anthropogenic climate change. *Nature* 453: 353-357

Roy, C. (1998) An upwelling induced retention area off Senegal: A mechanism to link upwelling and retention processes. *South African Journal of Marine Science* 19: 89-98

Sala, E., Ribes, M., Hereu, B., Zabala, M., Alvã, V., Coma, R., Garrabou, J. (1998) Temporal variability in abundance of the sea urchins *Paracentrotus lividus* and *Arbacia lixula* in the northwestern Mediterranean: comparison between a marine reserve and an unprotected area. *Marine Ecology Progress Series* 168: 135-145

Sarpong, D.B., Quaatey, S.N.K., Harvey, S.K. (2005) The economic and social contribution of fisheries to gross domestic product and rural development in Ghana. Final Report. Accra, Ghana

Scheibling, R.E., Hennigar, A.W. (1997) Recurrent outbreaks of disease in sea urchins *Strongylocentrotus droebachiensis* in Nova Scotia: evidence for a link with large-scale meteorologic and oceanographic events. *Marine Ecology Progress Series* 152: 155-165

Scheibling, R.E., Stephenson, R.L. (1984) Mass mortality of *Strongylocentrotus droebachiensis* (Echinodermata: Echinoidea) off Nova Scotia, Canada. *Marine Biology* 78: 153-164

Schutte, V.G.W., Selig, E.R., Bruno, J.F. (2010) Regional spatio-temporal trends in Caribbean coral reef benthic communities. *Marine Ecology Progress Series* 402: 115-122

Steneck, R.S. (1997) Crustose corallines, other algal functional groups, herbivores and sediments: complex interactions along reef productivity gradients. *Proceedings of the 8th International Coral Reef Symposium*, Smithsonian Tropical Research Institute, Panama. 1:695-700.

Stobar, B., Warwick, R.M., González, C., Mallol, S., Díaz, D., Reñones, O., Goñi, R. (2009) Long-term and spillover effects of a marine protected area on an exploited fish community. *Marine Ecology Progress Series* 384: 47-60

Tegner, M.J., Levin, L.A. (1983) Spiny lobsters and sea urchins: analysis of a predator-prey interaction. *Journal of Experimental Marine Biology and Ecology* 73: 125-150

Tetteh, A.S. (2010) Profit motive and natural resource overexploitation: misperception of the bioeconomic dynamics; the case of a fishery. MSc Thesis, University of Bergen, 94 pp

Thompson, R.C., Moore, C.J., Vom Saal, F.S., Swan, S.H. (2009) Plastics, the environment and human health: current consensus and future trends. *Philosophical Transactions of the Royal Society* B 364: 2153-2166

UNEP/LME (2010) http://www.lme.noaa.gov/index.php?option=com_content&view=article&id=178:unep-lme-report&catid=39:reports&Itemid

Villa, F., Tunesi, L., Agardy, T. (2002) Zoning Marine Protected Areas through Spatial Multiple Criteria Analysis: the Case of the Asinara Island National Marine Reserve of Italy. *Conservation Biology* 16: 515-526

Wainwright, P.C. (1987) Biomechanical limits to ecological performance: mollusc crushing by the Caribbean hogfish, *Lachnolaimus maximus* (Labridae). *Journal of Zoology* 213: 283-297

Whitehead, P.J.P. (1985) FAO Species Catalogue: Vol. 7: Clupeoid Fishes of the World (suborder Clupeoidei): an Annotated and Illustrated Catalogue of the Herrings, Sardines, Pilchards, Sprats, Shads, Anchovies and Wolf-herrings: Part 1: Chirocentridae, Clupeidae and Pristigasteridae. FAO Fish. Synop. 7:303

Whitlatch, R.B., Obrebski, S. (1980) Feeding selectivity and coexistence in two deposit-feeding gastropods. *Marine Biology* 58: 219-225

Williams, L.B., Williams, E., Bunkley, A.G. (1986) Isolated mortalities of the sea urchins *Astropyga magnifica* and *Eucidaris tribuloides* in Puerto Rico. *Bulletin of Marine Science* 38: 391-393

Williams, I.D., Richards, B.L., Sandin, S.A., Baum, J.K., Schroeder, R.E., Nadon, M.O., Zgliczynski, B., Craig, P., McIlwain, J.L., Brainard, R.E. (2011) Differences in reef fish assemblages between populated and remote reefs spanning multiple archipelagos across the central and western Pacific. *Journal of Marine Biology* 2011: 1-14

Worm, B., Hilborn, R., Baum, J.K., Branch, T.A., Collie, J.S., Costello, C., Fogarty, M.J., Fulton, E.A., Hutchings, J.A., Jennings, S. (2009) Rebuilding global fisheries. *Science* 325: 578-585

7. Appendices

Appendix 1 List of fish species and sites of occurrence (survey sites labeled by code as per Table 2.1.)

Family	Scientific name	ABO_L	ABO_S	AKE_B	AKE_SL	AKE_SR	ATW	C3P	MIE	MIE_I	MIE_O	MUT	PAR	PTF	WPT
Acanthuridae	*Acanthurus monroviae*	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Apogonidae	*Apogon imberbis*									x					
Balistidae	*Balistes punctatus*	x	x	x	x	x	x	x		x	x	x	x	x	x
Blennidae	*Ophioblennius atlanticus*		x	x		x		x	x	x		x	x	x	
Carangidae	*Chloroscombrus chrysurus*		x	x						x		x			
Carangidae	*Pseudocaranx dentex*									x					
Carangidae	*Selar crumenophthalmus*		x								x				
Chaetodontidae	*Chaetodon marcellae*			x											
Chaetodontidae	*Chaetodon robustus*			x				x							x
Cirrhitidae	*Amblycirrhitus pinos*			x											
Cirrhitidae	*Cirrhitus atlanticus*			x								x		x	
Dasyatidae	*Dasyatis pastinaca*												x		
Ephippidae	*Ephippus goreensis*						x	x		x					
Haemulidae	*Parapristipoma humile*			x							x		x		
Haemulidae	*Plectorhinchus mediterraneus*			x											
Holocentridae	*Sargocentron hastatum*			x											
Kyphosidae	*Kyphosus sectatrix*			x	x										
Labridae	*Bodianus speciosus*	x	x	x	x	x	x	x		x	x	x	x	x	x
Labridae	*Coris atlantica*	x	x	x	x	x	x	x	x		x	x	x	x	x
Labridae	*Coris Julis*									x			x		
Labridae	*Symphodus roissali*				x	x									x
Labridae	*Thalassoma newtoni*	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Labrisomidae	*Labrisomus nuchipinnis*	x		x				x							
Lethrinidae	*Lethrinus atlanticus*		x												
Lutjanidae	*Apsilus fuscus*												x		
Lutjanidae	*Lutjanus agennes*		x	x			x			x	x	x	x		
Lutjanidae	*Lutjanus goreensis*			x	x				x	x	x	x	x		
Monacanthidae	*Cantherhines pullus*		x	x			x	x				x	x	x	x
Mullidae	*Pseudupeneus prayensis*	x	x	x	x	x	x	x		x	x	x	x	x	x
Pomacanthidae	*Holacanthus africanus*			x			x	x				x	x	x	
Pomacentridae	*Abudefduf saxatilis*	x	x	x	x	x	x	x	x	x	x	x	x	x	
Pomacentridae	*Abudefduf taurus*			x					x	x			x		
Pomacentridae	*Chromis limbata*			x											
Pomacentridae	*Chromis multilineata*		x	x			x	x			x	x	x		
Pomacentridae	*Microspathodon frontatus*	x		x	x		x		x	x			x		
Pomacentridae	*Stegastes imbricatus*	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Scaridae	*Scarus hoefleri*		x	x	x	x	x	x	x	x	x	x	x	x	
Scaridae	*Sparisoma axillare*		x												
Scaridae	*Sparisoma cretense*	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Scaridae	*Sparisoma rubripinne*				x	x									
Sciaenidae	*Umbrina steindachneri*						x								
Serranidae	*Cephalopholis nigri*	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Serranidae	*Cephalopholis taeniops*											x			
Serranidae	*Rypticus saponaceus*											x			
Sparidae	*Dentex maroccanus*		x	x	x		x	x			x	x		x	x
Tetraodontidae	*Canthigaster supramacula*		x	x			x	x				x	x	x	x

Appendix 2 List of species identified during experimental fishing at three fishing sites

Family	Scientific name	Miemia	Princess	Cape3points
Acanthuridae	*Acanthurus monroviae*		x	
Bothidae	*Bothus sp*			x
Bothidae	*Scyacium micrurum*	x	x	
Calappidae	*Calappa rubroguttata*		x	x
Carangidae	*Chloroscombrus chrysurus*		x	
Carangidae	*Selene dorsalis*	x	x	x
Cynoglossidae	*Cynoglossus senegalensis*	x	x	x
Drepaneidae	*Drepane africana*		x	x
Elopidae	*Elops lacerta*	x	x	
Haemulidae	*Pomadasys jubelini*			x
Lethrinidae	*Lethrinus atlanticus*	x		
Majidae	*Maja squinado*	x		
Muraenidae	*Enchelycore anatina*		x	
Panuliridae	*Panulira homarus*	x		
Penaeidae	*Penaeus kerathurus*		x	x
Polynemidae	*Galeoides decadactylus*	x	x	x
Portunidae	*Portunus validus*		x	x
Scaridae	*Scarus hoefleri*	x		
Sciaenidae	*Pseudotolithus senegalensis*	x	x	x
Sciaenidae	*Psuedotolithus sp*		x	
Sciaenidae	*Umbrina canariensis*	x		
Sciaenidae	*Umbrina steindachneri*		x	
Scorpaenidae	*Scorpaena cf. scrofa*		x	
Scorpaenidae	*Scorpaena maderensis*	x		x
Sparidae	*Dentex maroccanus*		x	x
Synodontidae	*Synodus saurus*	x		x

Appendix 3 Mann-Whitney pairwise comparisons of fish ecological variables between habitat types. Significant effects indicated in red.

Habitat		Biomass		Paired comparison (p)			
		Mean	SEM	Bay	Headland	Island	Patch
Labridae	**Bay**	31.10	5.68	-	**0.03**	0.19	**0.03**
	Headland	42.67	4.74	**0.03**	-	0.69	**0.00**
	Island	43.33	9.19	0.19	0.69	-	0.06
	Patch	16.09	4.95	**0.03**	**0.00**	0.06	-
Serranidae	**Bay**	380.50	19.03	-	**<0.0001**	0.21	0.62
	Headland	735.00	40.83	**<0.0001**	-	0.74	**0.0004**
	Island	192.00	32.00	0.21	0.74	-	0.38
	Patch	232.50	21.14	0.62	**0.0004**	0.38	-
Trophic Level	**Bay**	2.89	0.05	-	**<0.0001**	0.08	0.92
	Headland	3.18	0.03	**<0.0001**	-	0.30	**0.02**
	Island	3.12	0.11	0.08	0.30	-	0.39

	Patch	2.93	0.11	0.92	**0.02**	0.39	-
Total Biomass	**Bay**	433.97	69.07	-	**0.01**	0.12	0.81
	Headland	172.70	38.80	**0.01**	-	0.91	**0.02**
	Island	242.92	131.94	0.12	0.91	-	0.15
	Patch	717.27	234.82	0.81	**0.02**	0.15	-
Lutjanid Biomass	**Bay**	587.50	27.98	-	0.25	0.36	0.06
	Headland	369.50	23.09	0.25	-	0.71	**0.01**
	Island	133.00	22.17	0.36	0.71	-	0.12
	Patch	450.00	37.50	0.06	**0.01**	0.12	-
Pomacentrid Biomass	**Bay**	23.44	5.56	-	**0.03**	0.62	0.34
	Headland	3.74	1.12	**0.03**	-	0.22	**0.0004**
	Island	37.39	13.15	0.62	0.22	-	0.96
	Patch	29.37	8.08	0.34	**0.0004**	0.96	-

Serranid Biomass	**Bay**	5.81	1.56	-	**0.01**	0.53	0.39
	Headland	15.82	3.44	**0.01**	-	0.29	**0.001**
	Island	9.13	3.74	0.53	0.29	-	0.32
	Patch	3.42	1.44	0.39	**0.001**	0.32	-
Size/Length	**Bay**	10.76	0.12	-	**<0.0001**	**<0.0001**	0.60
	Headland	9.51	0.15	**<0.0001**	-	**<0.0001**	**<0.0001**
	Island	6.86	0.15	**<0.0001**	**<0.0001**	-	**<0.0001**
	Patch	11.56	0.19	0.60	**<0.0001**	**<0.0001**	-

Appendix 4 Mann-Whitney pairwise comparisons of fish ecological variables between exposure groups. Significant effects indicated in red.

Exposure		Abundance		Paired comparison (p)		
		Mean	SEM	Sheltered	Semi exposed	Exposed
Total Abundance	Sheltered	237.67	51.73	-	**0.01**	**0.03**
	Semi exposed	103.96	11.53	**0.01**	-	0.47
	Exposed	130.94	27.75	**0.03**	0.47	-
Acanthurid	Sheltered	11.75	2.7	-	**0.04**	0.78
	Semi exposed	10.68	3.93	**0.04**	-	**0.03**
	Exposed	10.22	1.88	0.78	**0.03**	-
Labridae	Sheltered	37.83	6.00	-	**0.03**	0.47
	Semi exposed	23.64	4.71	**0.03**	-	**0.0008**
	Exposed	43.44	4.93	0.47	**0.0008**	-
Pomacentridae	Sheltered	87.83	16.22	-	**0.01**	**0.01**
	Semi exposed	40.04	8.13	**0.01**	-	0.08
	Exposed	47.50	25.30	**0.01**	0.08	-
Scaridae	Sheltered	13.42	4.47	-	**0.03**	**0.01**
	Semi					

	Semi exposed	5.08	1.29	**0.03**	-	0.61
	Exposed	3.11	0.72	**0.01**	0.61	-
Serranidae	**Sheltered**	4.58	1.40	-	0.28	0.31
	Semi exposed	2.40	0.57	0.28	-	**0.003**
	Exposed	6.06	1.00	0.31	**0.003**	-
Species Richness	**Sheltered**	15.58	1.32	-	**0.001**	**0.002**
	Semi exposed	10.68	0.54	**0.001**	-	0.66
	Exposed	10.50	0.73	**0.002**	0.66	-
Trophic level	**Sheltered**	2.98	0.05	-	0.69	**0.01**
	Semi exposed	2.93	0.07	0.69	-	**0.01**
	Exposed	3.16	0.04	**0.01**	**0.01**	-
Serranid biomass	**Sheltered**	4.19	2.23	-	0.12	**0.005**
	Semi exposed	8.23	2.22	0.12	-	**0.03**
	Exposed	12.40	2.32	**0.005**	**0.03**	-
Size (cm)	**Sheltered**	10.29	0.14	-	**0.03**	**<0.0001**

	Semi exposed	11.14	0.13	**0.03**	-	**<0.0001**
	Exposed	8.44	0.12	**<0.0001**	**<0.0001**	-

Appendix 5 Mann-Whitney pairwise comparisons of fish ecological variables between levels of wave action. Significant effects indicated in red.

Wave Action		Abundance		Paired comparison (p)		
		Mean	SEM	Low	Med	High
Pomacentridae	**Low**	49.31	10.50	-	**0.002**	0.27
	Med	74.28	13.66	**0.002**	-	**0.01**
	High	38.83	19.13	0.27	**0.01**	-
Scaridae	**Low**	11.95	3.14	-	**0.03**	**0.02**
	Med	3.71	0.71	**0.03**	-	0.36
	High	2.60	0.64	**0.02**	0.36	-
Serranidae	**Low**	3.33	1.03	-	**0.0224**	0.7265
	Med	5.83	0.81	**0.0224**	-	**0.0014**
	High	1.85	0.68	0.73	**0.001**	-
Lutjanidae	**Low**	2.62	2.07	-	**0.002**	0.10
	Med	3.22	0.94	**0.002**	-	0.37
	High	0.38	0.22	0.10	0.37	-
SpR	**Low**	14.61	0.95	-	**0.0004**	**0.0005**

	Med	10.63	0.57	**0.0004**	-	0.38
	High	9.62	0.86	**0.001**	0.38	-
Simpson's 1-d	**Low**	0.80	0.02	-	**0.05**	**0.0048**
	Med	0.74	0.02	**0.0489**	-	0.15
	High	0.67	0.04	**0.005**	0.15	-
Trophic Level	**Low**	2.97	0.04	-	**0.0002**	**0.03**
	Med	3.20	0.04	**0.0002**	-	**<0.0001**
	High	2.75	0.08	**0.03**	**<0.0001**	-
Serranid Biomass	**Low**	5.82	1.72	-	**0.02**	0.93
	Med	13.85	2.76	**0.02**	-	**0.01**
	High	4.10	1.35	0.93	**0.01**	-
Size/Length	**Low**	10.43	0.13	-	**<0.0001**	**0.001**
	Med	8.63	0.11	**<0.0001**	-	**<0.0001**
	High	11.68	0.17	**0.001**	**<0.0001**	-

Appendix 6 Mann-Whitney pairwise comparisons of ecological variables between levels of fishing pressure. Significant effects indicated in red.

Fishing pressure		Abundance		Paired comparison (p)		
		Mean	SEM	Low	Med	High
Acanthurid	**Low**	16.6316	4.7611	-	**0.01**	0.55
	Med	4.2381	1.6632	**0.01**	-	**0.0003**
	High	12.4667	1.9877	0.55	**0.0003**	-
Labridae	**Low**	32.58	6.36	-	0.29	**0.02**
	Med	20.00	1.72	0.29	-	**<0.0001**
	High	52.53	5.15	**0.02**	**<0.0001**	-
Serranidae	**Low**	2.05	0.57	-	0.06	**0.01**
	Med	4.24	0.82	0.06	-	0.20
	High	6.40	1.29	**0.01**	0.20	-
Trophic Level	**Low**	2.88	0.05	-	**0.05**	**0.0004**
	Med	3.03	0.07	**0.05**	-	0.15
	High	3.17	0.05	**0.0004**	0.15	-
Total Biomass	**Low**	653.99	141.83	-	**0.04**	**0.001**

	Med	296.22	46.75	**0.04**	-	**0.02**
	High	152.83	63.61	**0.001**	**0.02**	-
Scarid Biomass	**Low**	226.86	76.93	-	0.22	**0.01**
	Med	68.32	16.67	0.22	-	0.06
	High	19.91	11.53	**0.01**	0.06	-
Lutjanid Biomass	**Low**	101.52	52.17	-	0.43	**0.05**
	Med	43.04	19.73	0.43	-	**0.004**
	High	41.84	41.84	**0.05**	**0.004**	-
Acanthurid Biomass	**Low**	120.22	44.21	-	**0.002**	**0.01**
	Med	18.18	6.61	**0.002**	-	0.68
	High	9.71	6.53	**0.01**	0.68	-
Size/Length	**Low**	11.26	0.12	-	**0.0052**	**<0.0001**
	Med	10.50	0.15	**0.0052**	-	**<0.0001**
	High	7.47	0.11	**<0.0001**	**<0.0001**	-

8. Supplementary Information

S1. Focus group survey results

Set net (36.6%) and purse seine net (34.2%) were the most commonly used fishing gear types, hook and line was used by 21.9% of the fishers while the remaining few used drift net (4.9%) and trolling line (2.4%) (Figure S1-1A). There were about 2140 boats in the eight villages where focus group interviews were conducted. The boats were categorized into three groups: boats without engine (38.1%), 8-25 hp engine boats (16.6%) and 25-50 hp engine boats (45.3%) (Figure S1-1B).

Most large nets (77.5%) were made of several pieces of net of different lengths and mesh sizes and joined to form a single net (Figure S1-1C). Of these, 82% were made of three or more nets while the remaining 18% were made of two pieces. The 25-50 hp boats used purse seine nets as the main fishing gear with small proportions of drift net, set net and trolling lines also used. No hook and line was used on these boats (Figure S1-1D). Set net was the main gear type in the 8-25 hp boats with a few boats using hook and line and purse seine net. Boats without engines used mainly hook and line (46.7%) and set net (53.3%).

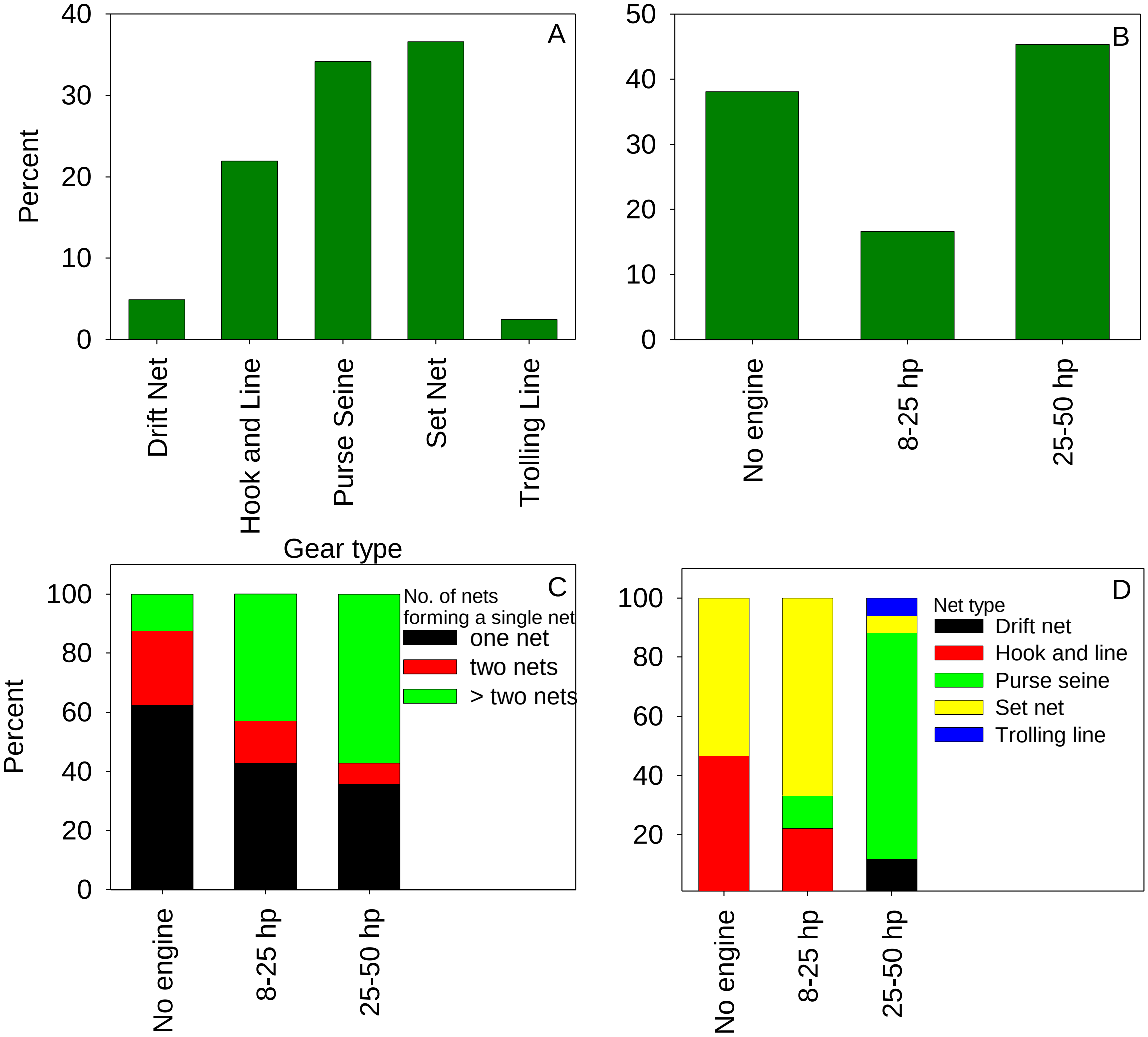


Figure S1-1. A. Distribution of gear types, B. Distribution of boat types, C. Number of nets spliced into a single net by boat type, D. Gear type by boat type.

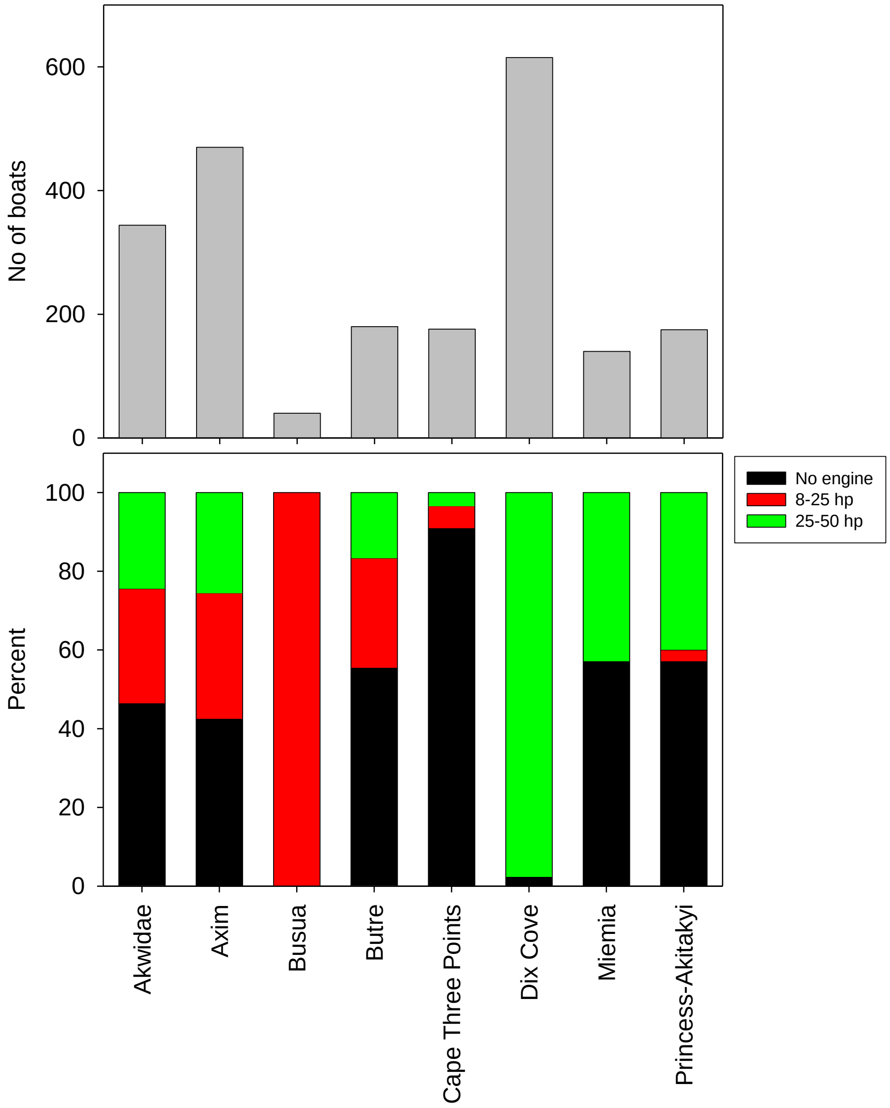


Figure S1-2. Number of boats by type and fishing village

The boats in Dixcove, the town with the largest number of boats, were predominantly composed of the 25-50 hp category while those in nearby Busua were all with 8-25 hp engines (Figure S1-2). At Cape Three Points, the boats used were predominantly without engines. In Miemia and Princess Town/Akitakyi, 57% of the boats did not have engines while the remaining were of the 25-50 hp, with a small proportion with 8-25 hp (2.9%). In Akwidae, Axim and Butre, all three boat types were represented in significant proportions, boats without engine composing the largest numbers.

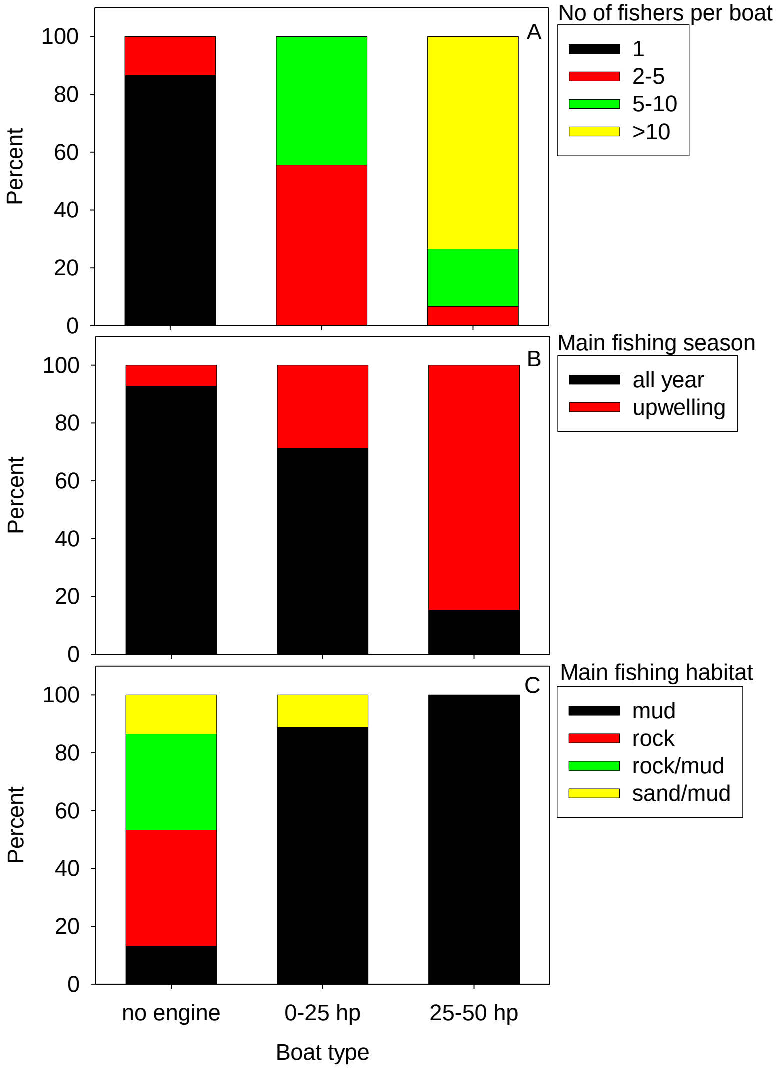


Figure S1-3. A. Number of fishers per boat, B. Seasonality in fishing, C. Fishing grounds by boat type

Almost 87% of the boats without engines were one- man canoes (locally known as dukuwas) with a few carrying 2-5 crew (Figure S1-3A). Most of the boats with 25-50 hp engine carried >10 fishers while the boats with 8-25 hp engine had between 2-5 (56%) and 5-10 (44%) fishers. Most of the canoes without engines operated all year around while those with 25-50 hp engines operated predominantly during the upwelling season, targeting pelagic species (Figure S1-3B). A higher proportion of the boats with 8-25 hp engines (71%) operated all year around; the remaining 29% being active during the upwelling season only. Boats with 8-25 hp and 25-50 hp engines fished mostly on muddy habitats (89 and 100% respectively) (Figure S1-3C). A few of the former fished on a mixed bottom of sand and mud (11%). Canoes without engines fished mostly on rocky bottoms (40%) or both rocky and muddy bottoms (33%) while the remaining (27%) fished in equal proportions either on muddy or a mix of both sandy and muddy bottoms.

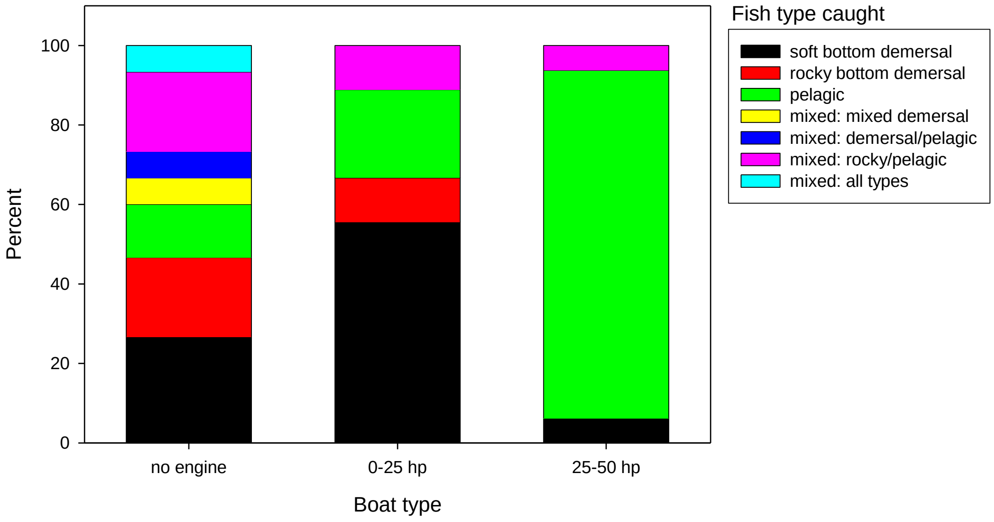


Figure S1-4. Type of fish caught by boat type

A mix of fish types was caught by the small one man dukuwas: soft bottom demersal (26.7%), rocky bottom demersal (20.0%) and a mix between rocky bottom demersal and pelagic (20%) (Figure S1-4). Most of the fish caught by fishers using boats with 8-25 hp engines were soft bottom demersal species (56%) with pelagic species also comprising a large proportion of catches (22%).

The majority of boats operated between 10 and 50 m deep (Figure S1-5A). Those that operated in shallow depths (0-10 m) were all without engine while boats fishing in waters >50 m depth were larger boats with engines of 25-50 hp (Figure S1-5B). Those with small horse power engines (8-25 hp) operated in intermediate depths of 10-50 m.

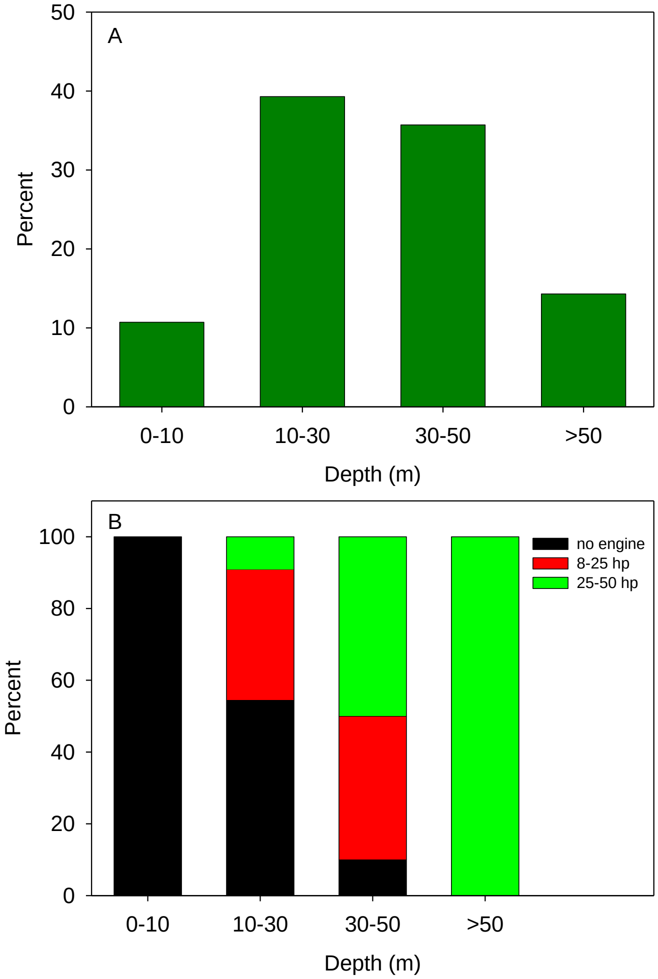


Figure S1-5. Distribution of fishing boat types by water depth

Most fishers used three nets of different mesh sizes and spliced together (Figure S1-6). Both single nets and those made of three nets were made of small (1-2 in) or small-medium (2-4 in) nets. Those made of two nets were mostly composed of small-medium or medium-large (4-10 in) nets. Nets with large mesh size made up only 13% of those made of three nets and none of these were made of single or two nets.

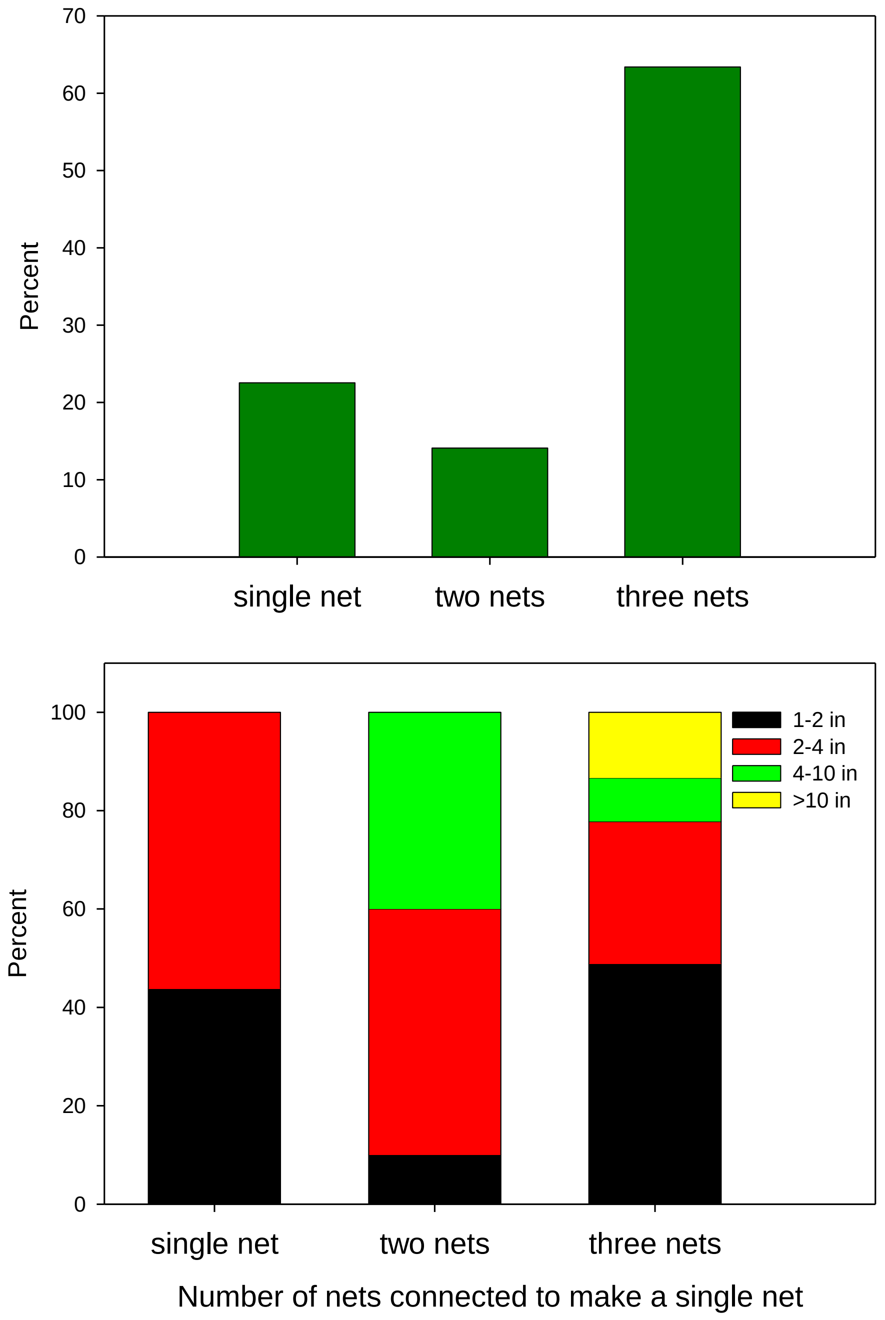


Figure S1-6. Mesh size of nets by the number of nets making a single net

S.2. Fishing Surveys

Fishing surveys conducted over the three days caught a total of 50.49 kg of fish. Twenty-one fish species representing 15 families and five crustacean families: crabs (Calappidae, Majidae, and Portunidae), Lobster (Panuliridae), and Prawn (Paeneidae) were recorded

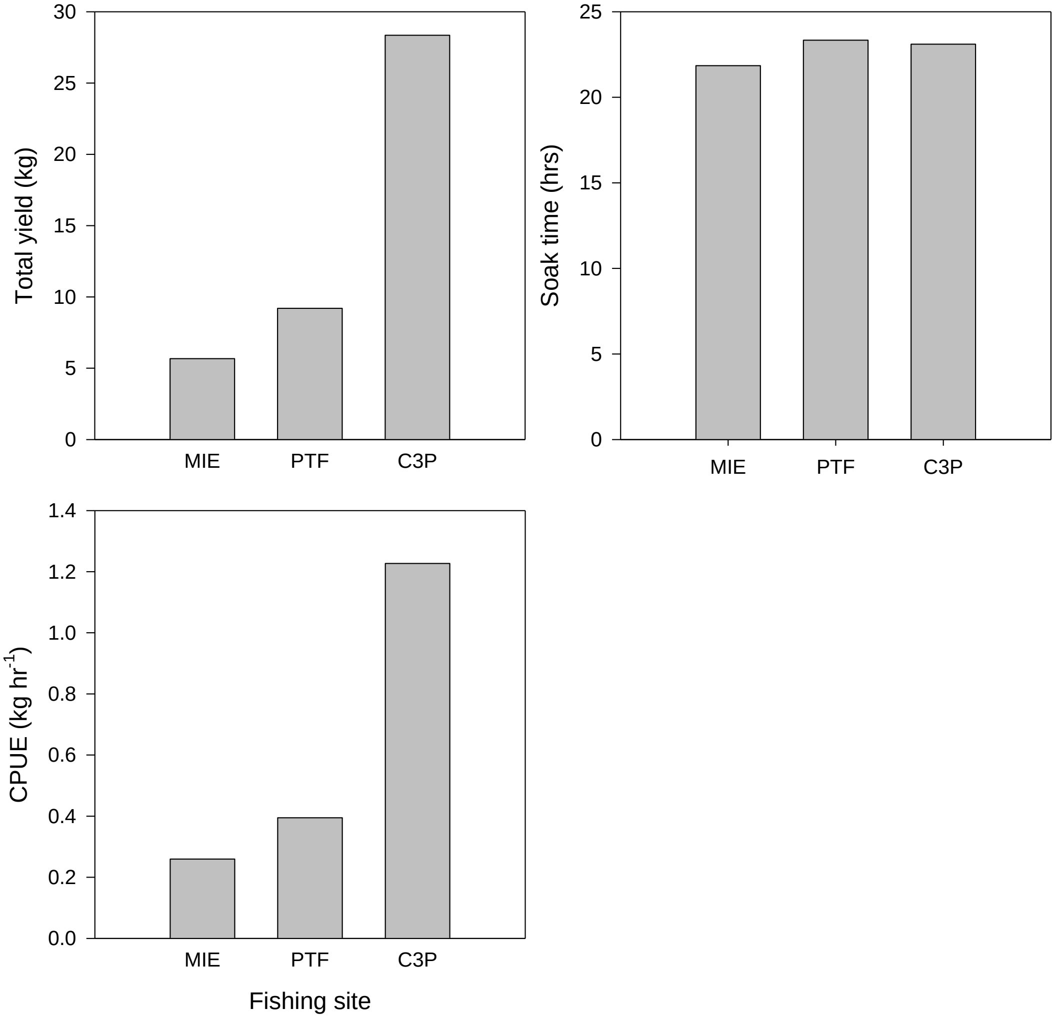


Figure S2-1. Fishing survey results by fishing site: (a) total yield (kg), (b) soak time (hrs), and (c) catch per unit effort (CPUE, kg hr-1)

S.2.1. Catch characteristics

Total yield was highest at Cape Three Points where 28.35 kg was caught compared to 9.20 kg at Princess Town and 5.67 kg at Miemia (Figure S2-1a). Soak time varied between 21 hours in Miemia and 23 hours at both Cape

Three Points and Princess town (Figure S2-1b). Mean CPUE was 0.63 kg hr^{-1} ± 0.3 ranging from the highest at Cape Three Points (1.23 kg hr^{-1}) and lowest at Miemia (0.26 kg hr^{-1}) (Figure S2-11c).

The trophic level of species caught varied between a minimum of 2.0 (Herbivore) and 4.5 (Piscivore). Along with the highest yield, Cape Three Points also had the highest mean trophic level (3.71 ± 0.03) and Miemia had the lowest (3.29 ± 0.13) (Figure S2-2), which is equivalent to omnivorous species feeding on invertebrates, decapods and fish.

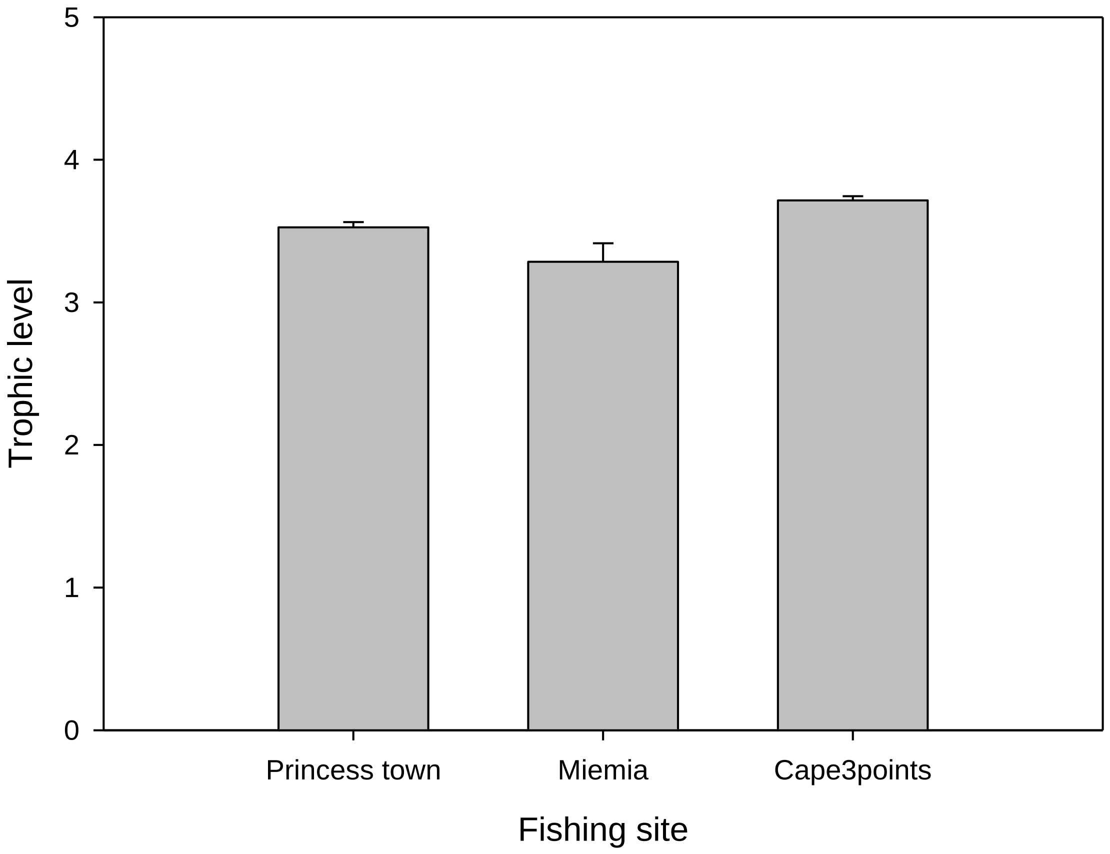


Figure S2-2. Trophic level (TL) of catches at each fishing site

Catches comprised mainly of Sciaenidae (55.67%) with three species caught: *Pseudotolithus senegalensis* (89.23%)*, Umbrina canariensis* (9.23) and *Umbrina steindachneri* (1.54%). One species of the Polynemidae (*Galeoides decadactylus)* comprised 21.95%. The remaining 22.4% was made of 17 fish species belonging to 13 different families (Figure S-3).

The average standard length (SL) of fish caught at each site varied from 19.60 ± 1.6 cm in Miemia to 31.54 ± 1.23 cm in Cape Three Points (Figure S-4). The smallest landed fish were *Dentex maroccanus* and *Scorpaena maderensis* both at 11cm SL, while the largest fish caught was a 1 m (100 cm) fangtooth moray eel (*Enchelycore anatine)*.

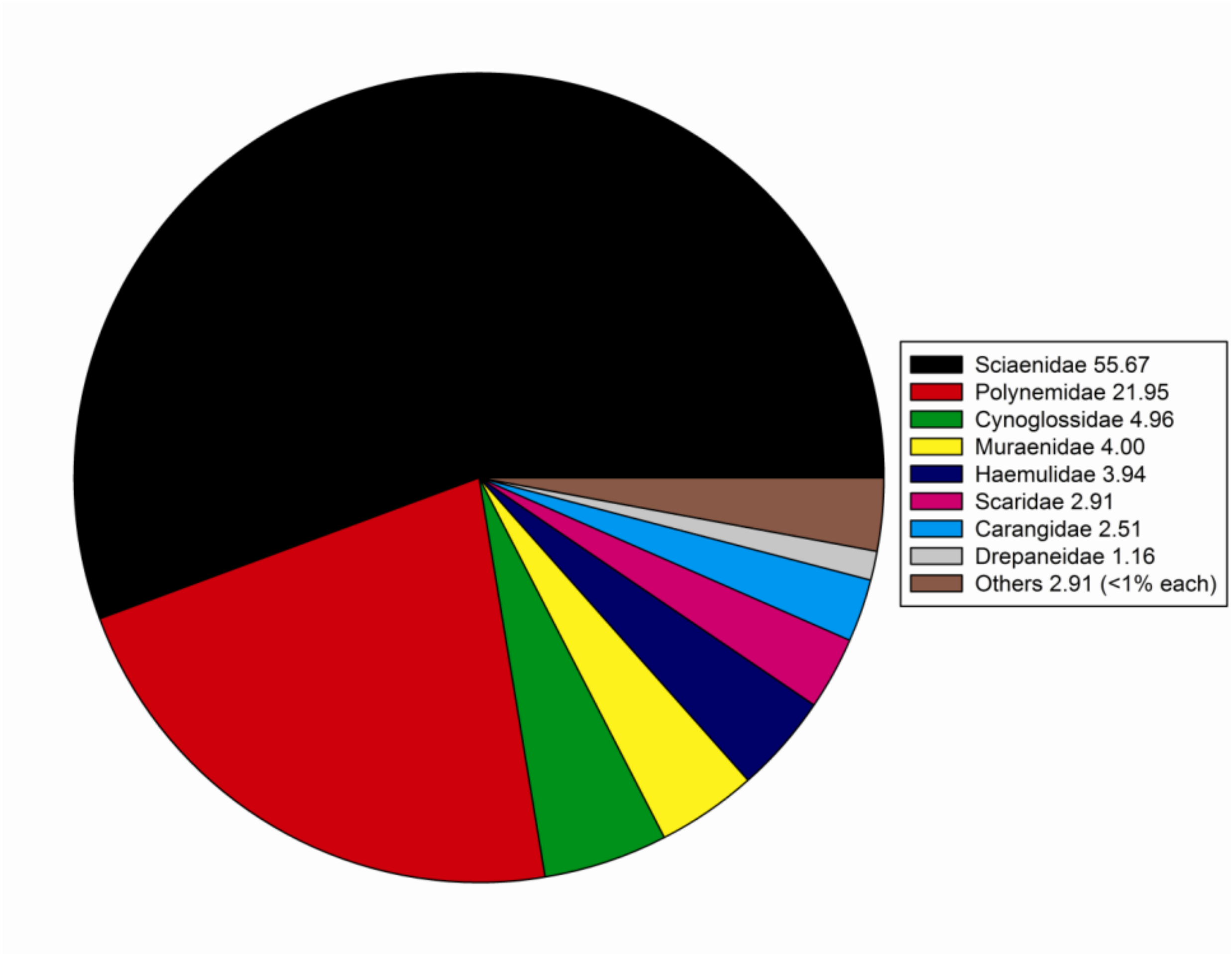


Figure S2-3. Percentage composition of fish landings by fish family.

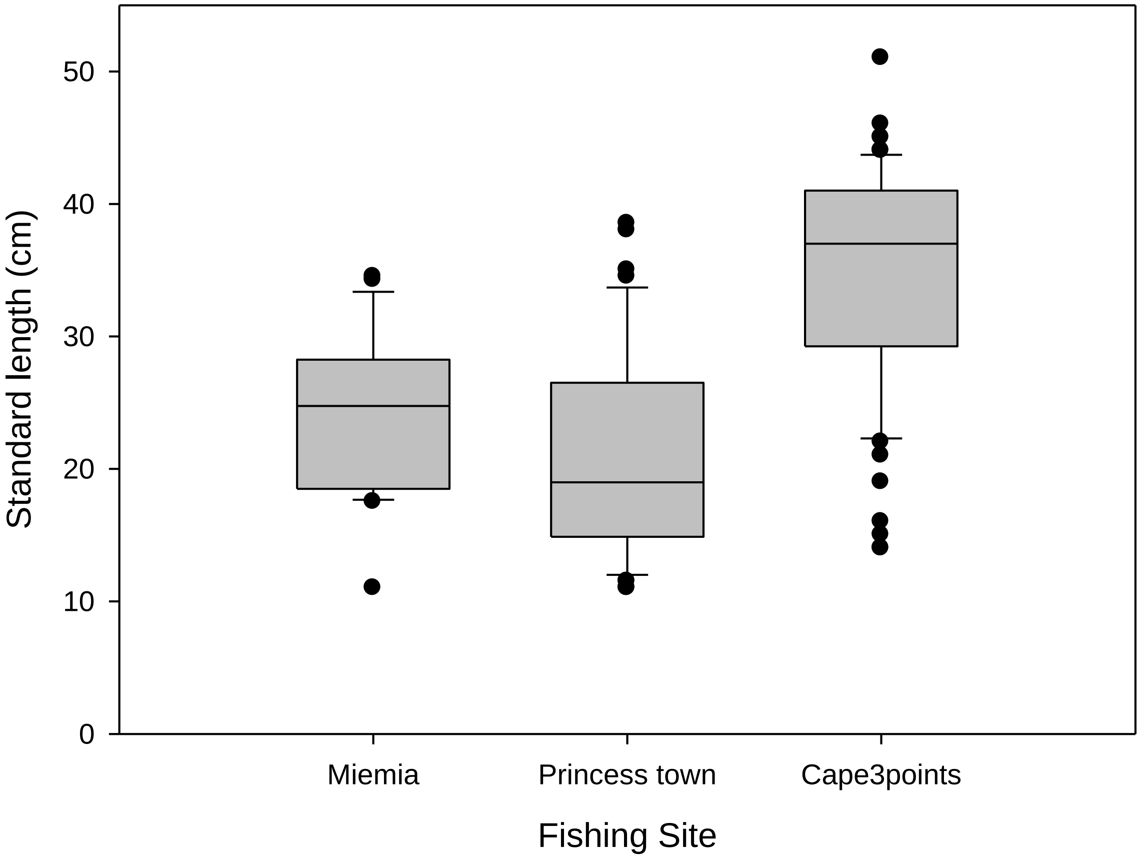


Figure S2-4. Fish standard length at each fishing site. Box indicates median line (50%) dividing the box; lower and upper boundaries of box: 25-75% of observations; whiskers 10 and 90% of observations.

Length at first maturity (L_{mat}) is an indicator of overfishing and was calculated from the catch data. Catches from Miemia had the highest abundance of juvenile fish, accounting for 34.62% of the catch while Cape Three Points had the lowest abundance of juvenile fish (12.50%) (Figure S5).

Further analysis was conducted on the most abundant species to check proportions of juvenile fish in the catch. The Cassava croaker (*Pseudotolithus senegalensis*) reportedly matures at 35 cm and 33% of individuals caught of this species were juveniles (< 35 cm in length). The African threadfin (*Galeoides decadactylus*) and the Atlantic Bumper (*Chloroscombrus chrysurus*) both mature at smaller sizes 11.6 cm and 12.4 cm respectively and all individuals caught during the study were mature (Figure S6).

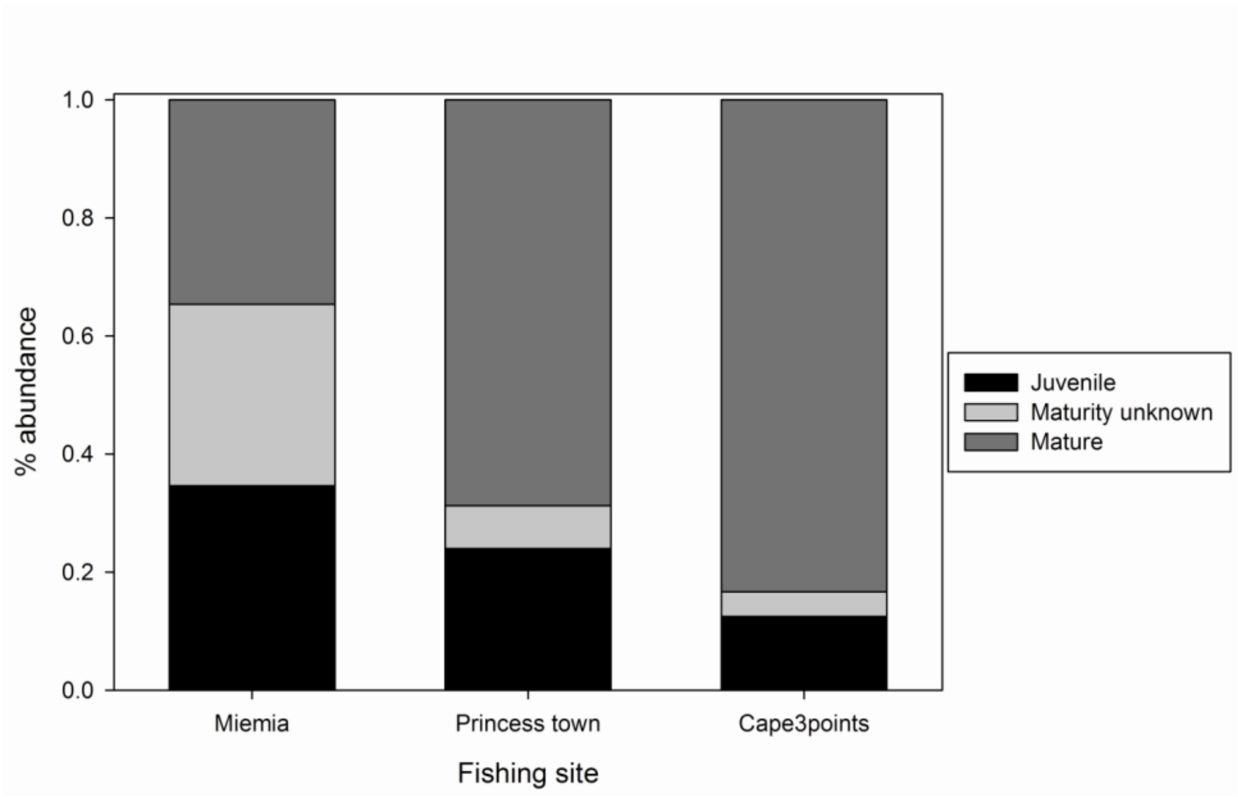


Figure S2-5. Percentage composition of mature and juvenile fish from fisheries landing

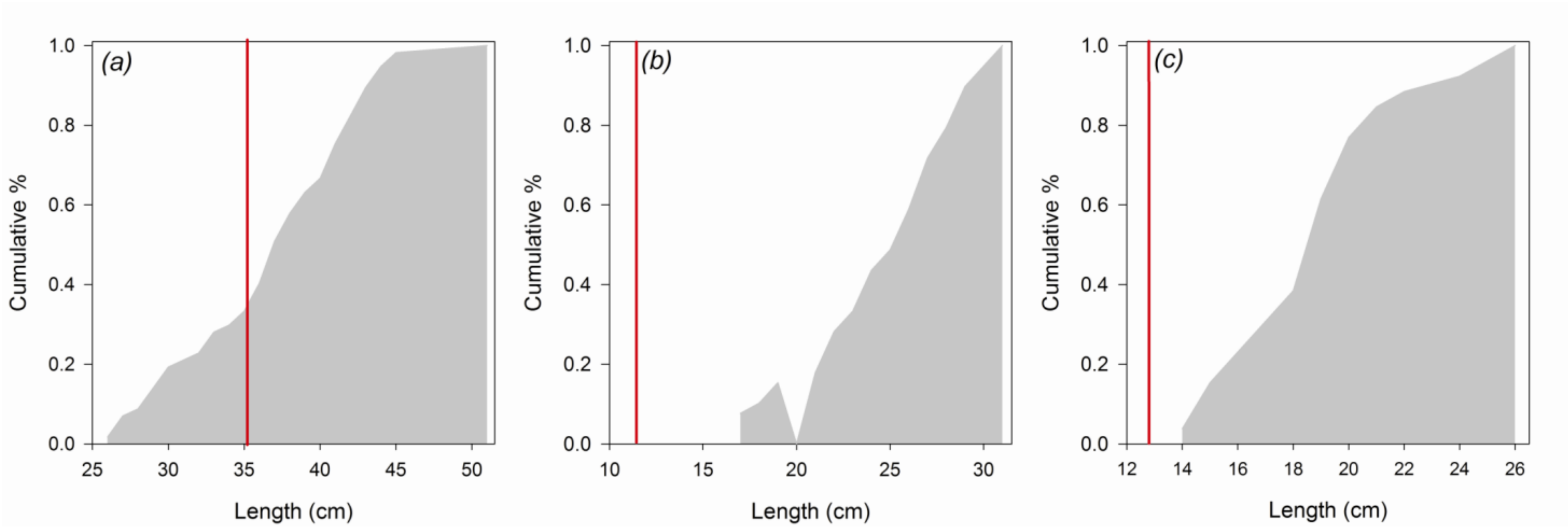


Figure S2-6. Length frequency distribution of fish. (a) *Pseudotolithus senegalensis*, (b) *Galeoides decadactylus* and (c) *Chloroscombrus chrysurus*. Vertical red line denotes length at maturity (cm).