SPATIO-TEMPORAL DYNAMICS OF THE MARINE AQUARIUM FISHERY AND RECRUITMENT OF REEF FISHES IN COASTAL KENYA

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY (FISHERIES MANAGEMENT)
IN THE SCHOOL OF NATURAL RESOURCE MANAGEMENT
UNIVERSITY OF ELDORET, KENYA

NOVEMBER, 2017

DECLARATION

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DEDICATION

This thesis is dedicated to my parents, my late father Benson Matangi Okemwa and Milcah Kemunto Matangi for guiding and supporting my love and appreciation for biological sciences since I was a young girl. Dad, I know you would have been proud to witness this personal and academic milestone; and Mom, your unwavering moral support and positive energy kept me focused throughout the field work and writing of this thesis. Lastly, I dedicate this to my son, Isaac for being understanding and enduring through my physical and sometimes emotional absence.

ABSTRACT

Sustainable management of the marine aquarium fisheries in Kenya is challenged by limited information on the fishery and recruitment dynamics of target species at sufficient spatial, temporal and taxonomic scales. In order to bridge these information gaps, this study used a combination of data from fisher catches and ecological monitoring to assess spatial and temporal patterns of aquarium fishery and recruitment variability on shallow coral reef lagoons in coastal Kenya. Aquarium fisher catches spanning 6 years (October 2006 to December 2011) from 11 fishing grounds along the coast were examined for spatial and temporal variability. Catches were further monitored between September 2010 and December 2014 to assess potential gear-based overlaps in species selectivity. Underwater visual census surveys were conducted at five shallow coral reef lagoon sites for spatial and temporal patterns of juvenile reef fish recruitment.

Results indicated 220 fish species in 36 fish families are exploited by the aquarium fishery, numerically dominated by Labridae (32%) and Pomacentridae (14%). Thirty-two species made up 80% of the aquarium fisher catches with the cleaner wrasse, *Labroides dimidiatus* being the most collected. Detrended Correspondence Analysis (DCA) associated some target species to specific fishing grounds, while results of nonmetric multidimensional scaling (nMDS) ordination revealed an influence of fishing modes (SCUBA vs snorkeling) on the species composition of the catches in all the sites. Results of Productivity and Susceptibility Analysis (PSA) performed to evaluate the vulnerability risk of 102 target species to the fishery ranked four species: *Pomacanthus maculosus*, *Pomacanthus chrysurus*, *Amphiprion allardi*, and *Amphiprion akallopisos* as highly vulnerable to the fishery, while seven species were at moderate risk of overfishing. Target aquarium species constituted approximately 12% of artisanal landings by weight and 8% by numerical abundance. Handlines and spearguns had the highest overlap in species selectivity with the aquarium fishery; while aquarium snorkel fishers had the highest potential overlap with the artisanal gears. Recruitment was observed all year-round peaking during December to March, but varied in intensity among species between years, seasons and months. Canonical Correspondence Analysis showed that live coral and reef rugosity as the main habitat predictors of reef fish recruit abundance. Dentrended Correspondence Analysis further showed that habitat associations were species-specific. The study addresses critical information gaps relevant to the management of the fishery. Overall, the study addresses critical information gaps relevant to the management of the marine aquarium fishery in Kenya and recommends measures for sustainable exploitation of the fisheries.

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ACKNOWLEDGEMENTS

First and foremost, my greatest appreciation goes to God for his faithfulness in seeing me through this journey. Many thanks go to the University of Eldoret, and in particular the faculty and staff of the School of Natural Resource Management. Initial funding support for this study was provided through a WWF Russell E. Train Postgraduate Fellowship award (2010 – 2012). Data collection was also supported through a WIOMSA-MASMA Grant and the Kenya Coastal Development Project (KCDP).

I am indebted to my principal supervisor Professor Boaz Kaunda-Arara for his guidance, and persistence in challenging me to a higher level of critical thinking and scientific writing. I'm also very grateful to my second supervisor Dr Edward Kimani for his enduring scientific and moral support. Thank you both for motivating and believing in me!

I thank the Director KMFRI for providing me with an enabling environment which gave me the flexibility to balance official duties with being a student. Benrick Ogutu and Rene Jorgensen provided me with access to aquarium fishery catch and export data. Thank you Clay Obota, Mary Ontomwa, Daniel Ocharo and Kenneth Omondi for assisting in fish catch data collection. I acknowledge my skilled underwater team: Masudi Zamu, Mohamed Jira and Jimmy Tunje. They were the '*dream team'* that faithfully assisted me every month through sunshine and rain. I also thank the Kuruwitu Community Conservation Group for granting me access to the study site and logistical arrangements during the entire study period. Thank you Paul Sitinei for your reliable taxi services throughout my studentship while on campus at the University.

I wish to thank Harrison Ong'anda assisted in developing maps of my study sites. Many other friends and colleagues encouraged me. To my siblings Eliud, Justin, Samson, and Judy, thank you for your overwhelming support. Lastly, my deepest thanks to baba Isaac (Christopher Fung) and Ping-Ann Addo for the extra mile taken in supporting me throughout this entire process. *Asante sana, baraka kwa Mungu!!*

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Coral reefs are among the most biologically rich and productive ecosystems on earth, supporting an estimated 4,000 species of fish, representing 18% of all living fishes (Lieske & Myers, 2001). Most coral reefs are located in tropical developing countries in the Indo-Pacific region and are directly depended on as a source of food and economic activity by more than 275 million people who reside within 30 km of the reefs (Burke *et al.*, 2011). Coastal communities living within the Western Indian Ocean (WIO) region rely heavily on small-scale coral reef fisheries as most have limited alternative livelihood opportunities; thus, fishing pressure within coral reefs remains intense and continues to increase (Mahongo & Mwaipopo, 2015). The fishing grounds in the nearshore shallow lagoon reefs of the WIO region are primarily fished by artisanal fishers targeting fish for consumption and aquarium fishers who target live fish and invertebrates for trade in international markets and display in aquaria.

The trade in live coral reef aquarium fish supports one of the highest products that can be harvested from coral reefs, bringing a higher economic return than most other reef fisheries (Olivier, 2001). An estimated 14 - 30 million live reef fish are collected annually worldwide for the aquarium trade, having a total import value of approximately US$ 200 - 330 million and a retail value of about US $500 million (Wood, 2001a; Wabnitz *et al.*, 2003; Rhyne *et al.*, 2012). At least 90% of species exploited for the global marine aquarium trade are collected directly from the reef (Wabnitz *et al.*, 2003; Lecchini *et al.*, 2006). The aquarium trade continues to grow in terms of the diversity of fish species. Over 1,800 fish species representing 125 families were reported to enter the aquarium fish trade in the United States, the world's largest importer of live reef fish (Rhyne *et al.*, 2012), reflecting a 22% increase in the number of species traded from a previous global estimate of 1,471 fish species representing 50 families (Wabnitz *et al*., 2003).

Kenya is among 45 source countries that supply marine aquarium fish to the global trade and is a major supplier among countries of the WIO region (Wood, 2001a; Bruckner, 2005). Kenya's fishery has existed since the early 1960s, and has since experienced widespread growth in terms of fishing effort and the diversity of aquarium fish species collected which has increased from 48 in 1980s (Samoilys, 1988) to over 190 in 2005 (Okemwa *et al*., 2009). Despite the socioeconomic importance of the marine aquarium fishery, the scope of the fishery and associated impacts remain underappreciated or inadequately represented in Kenya and the Western Indian Ocean (WIO) region.

The impact of the increasing fishing pressure on aquarium fish species is virtually unknown in most of the WIO region but may be significant. Additionally, the influence of habitats and seasonality on recruitment of juvenile fish to reefs has not been studied in Kenya. However, these may have synergistic effects on fish supply to the reefs and hence community structure of adult populations (Kaunda-Arara *et al*., 2009). Therefore, this work aimed to generate information that will contribute to bridging existing information gaps for science-based decision-making on the sustainable management of Kenya's marine aquarium fishery and other associated coral reef resources, in particular the spatio-temporal dynamics and recruitment of reef fishes.

1.2. Statement of the Problem

The aquarium fishery selectively targets juveniles and small-bodied reef fish of specific species, sizes and often sex; with rare species and those that are difficult to collect commanding the highest prices (Wood, 2001a, b; Sadovy & Vincent, 2002). Most of the species have a relatively site-attached juvenile benthic phase which can make them particularly vulnerable to localized depletion (Gasparini *et al*., 2005; Shuman *et al*., 2005; Almany *et al*., 2007). As a result, the sustainability of the global marine aquarium trade has been questioned with concerns raised about population declines of some target species, loss of biodiversity, habitat damage and ecological changes (Andrews, 1990; Wood, 2001a, b; Smith *et al*., 2009; Rhyne *et al*., 2012; Dee *et al*., 2014).

A number of quantitative studies have shown that targeted fisheries for the aquarium trade can lead to localized depletions of some target species and general changes in the community structure of the fished populations (Kolm & Berglund, 2003; Tissot & Hallacher, 2003; Shuman *et al*., 2005; Jones *et al*., 2008). Factors that contribute to over-collection of fish by aquarium fishers include high post-capture mortalities from poor handling and husbandry practices, and collection of species that do not survive well in aquarium conditions (Wood 2001a, b; Thornill, 2012). Species that have been locally depleted due to the aquaruim fishery include the angelfish, *Pomacanthus imperator*, and the Pallete surgeonfish, *Paracanthurus hepatus* in the Phillipines (Rubec, 1987), the Yellow tang, *Zebrassoma flavescens* in Hawaii (Tissot & Hallacher, 1999), and the Bangai cardinalfish, *Pterapogon kaudernii* (Kolm & Berglund, 2003) in Indonesia. The accruing evidence on the impacts of the marine aquarium fishery continues to incite global debate on how best to regulate it to ensure ecological sustainability (Andrews, 1990; Edwards & Shepherd, 1992; Shuman *et al*., 2004; Rhyne *et al*., 2012; Dee *et al*., 2014).

There have been calls by stakeholders in Kenya for enhanced regulation and management of the fishery, instigated by resource use conflicts (Tunje *et al*., 2016); particularly associated with the eco-tourism industry. However, management of the fishery has been challenged by a poor understanding of the status and spatio-temporal dynamics of the fishery. This has been further constrained by limited resources to undertake rigorous quantitative stock assessment surveys to gauge the status and vulnerability of target species to overfishing. However, anecdotal information from aquarium fishers suggests that declines in the abundance of some target species are evident (Okemwa *et al*., 2016). Additionally, little is known on the recruitment dynamics of target species in Kenya. This study therefore investigates the spatio-temporal dynamics of marine aquarium fishery and recruitment variability of juvenile reef fishes at different scales.

1.3. Justification of the Study

The marine aquarium fishery remains inadequately studied in Kenya and most countries of the WIO (Okemwa *et al*., 2016). Despite the socio-ecological importance of the aquarium fishery, there is paucity of information available on how fishing may be affecting aquarium fish populations as well as the spatial and temporal dynamics of the fishery. This includes data on catch and effort, gear use and biological characteristics of catches. There have been limited quantitative studies to assess the spatio-temporal dynamics the marine aquarium fishery or impacts on targeted populations. Thus, the status and impacts of the fishery on targeted reef fish populations remains poorly understood in the WIO.

The assessment and management of tropical multigear and multispecies reef fisheries has historically presented a challenge to fisheries scientists and managers (Sadovy & Vincent, 2002). This is further compounded by the open-access nature of reef fisheries, where access to fishing grounds is diffuse and shared among fishers targeting reef fish resources either for consumption or for the aquarium trade. Thus, the likelihood of interactions between artisanal and aquarium fishers in shared fishing grounds is high. Various studies have assessed interactions in species selectivity among artisanal gears (McClanahan & Mangi, 2004; Nunes *et al*., 2009; Stergiou *et al*., 2002, Tuda *et al*., 2016), between artisanal and industrial fisheries (e.g. Munga *et al*., 2014; Leroy *et al*., 2016), and between recreational and commercial fisheries (Cooke & Cowks, 2006). However, the potential interactions between artisanal and aquarium fisheries are not well understood.

This study explores potential gear interactions with artisanal fisheries to provide a better understanding on other sources of fishing mortality that may be leading to localized serial depletion of aquarium fish populations. Such information is useful in making informed decisions on the development of sustainable management strategies. In data-poor fisheries where quantitative data is either lacking or inadequate, the identification of species with vulnerable life history characteristics is vital for closer monitoring and precautionary management action (Jennings *et al*.,1999). The vulnerability of a species to overfishing is generally influenced by its biological or productivity characteristics and susceptibility to a fishery or gear (Stobutzki *et al*., 2001; McCully *et al*., 2013).

Productivity is defined as "the capacity of the stock to recover once the population is depleted" and susceptibility is defined as "the potential for a stock to be impacted by the fishery" (Stobutzki *et al*., 2001). PSA is a semi-quantitative risk assessment approach that is suitable for assessing data-poor fisheries (Fujita *et al*., 2013). Semi-quantitative risk assessment approaches are useful in rapidly evaluating the vulnerability of a species or stock to overfishing, especially when financial resources limit undertaking of rigorous quantitative stock assessments (Zhang *et al*., 2009; Hobday *et al*., 2011; Swaleh *et al*., 2015). Such methods also help to prioritize the implementation of precautionary fisheries management interventions (Fletcher, 2005).

The PSA method was originally developed in Australia to assess the impacts of prawn fisheries on bycatch species (Milton, 2001; Fletcher *et al*., 2005; Stobutzki *et al*., 2001; Hobday *et al*., 2007, 2011). The PSA methodology has since been successfully applied to other fisheries such as elasmobranchs (McCully *et al*., 2013), tuna (Patrick *et al*., 2010; Arrizabalaga *et al*., 2011), deepwater trawl fisheries (Dransfeld *et al*., 2013), groundfish (Cope *et al*., 2011), reef fisheries (Micheli *et al*., 2014) and aquarium fisheries (Fujita *et al*., 2013).

Recruitment of juvenile reef fish plays an important role in the structure and replenishment of coral reef fish populations (Jones, 1990; Doherty, 1991; Caley *et al*., 1996; Lewis, 1997; Hixon, 2011). Knowledge of the recruitment patterns of juvenile reef fish is particularly important in the assessment of aquarium fisheries because they are highly dependent on the supply of newly recruited juveniles (Barratt & Medley, 1990). Studies on recruitment patterns of juvenile reef fishes have been extensively done on a wide variety of temporal and spatial scales, with a large number focusing on the Pacific region (see reviews by Sale, 1984a; Doherty, 1991; Booth & Brosnan, 1995; Caley *et al*., 1996; Hixon, 2011 and papers therein). Such studies are necessary for explaining variations in species replenishment and adult community structure and providing insights for predicting responses of fished populations to fishing pressure and environmental changes. However, similar studies in Kenya and the WIO are limited.

Moreover, despite the known potential effects of fishing on biodiversity, there is limited information on the potential effects of aquarium fishing, the recruitment dynamics and habitat preferences of targeted species in Kenya and the WIO. Understanding stage-specific habitat associations is important in assessing the impacts of fishing on fish stocks (Begg *et al*., 1999). Furthermore, shallow lagoon reefs face numerous anthropogenic impacts along the Kenya coast due to their proximity to land; thus, understanding the important role they play in replenishing reef fish populations will provide a basis for conserving them.

This study contributes to bridging the existing information gaps by providing new information on spatial and temporal dynamics of the marine aquarium fishery and recruitment of target species in coastal Kenya. This information will be useful in formulating precautionary management measures such as catch quotas, size limits, species bans, closed seasons and area restrictions; which have been implemented elsewhere to enhance the sustainability of marine aquarium fisheries (Wood, 2001a; Wabnitz *et al*., 2003). The information will also provide a baseline for monitoring future changes in aquarium reef fish populations in the face of increasing exploitation and global climate change effects in coastal Kenya. The aim of this research was therefore to generate information that will contribute to bridging existing information gaps for science-based decision-making on the sustainable management of Kenya’s marine aquarium fishery and other associated coral reef resources.

1.4. Objectives of the Study

The objectives of the study were to:

1. Describe spatial and temporal patterns in the exploitation of coral reef fishes by the marine aquarium fishery in Kenya,
2. Determine vulnerability risk levels of coral reef fish species exploited by the marine aquarium fishery in Kenya,
3. Quantify gear-based overlaps in species selectivity and potential interactions between artisanal and aquarium fisheries along the Kenya coast,
4. Describe spatial and temporal patterns of abundance and recruitment of juvenile coral reef fishes and determine habitat associations in shallow lagoon reefs along the Kenya coast.

1.5. Research Questions

The following questions were addressed in this research:

1. How does the species composition, fishing effort and catch rates of the marine aquarium fishery vary spatially and temporally along the Kenyan coast?
2. What is the relative vulnerability of targeted fish species to being depleted by the marine aquarium fishery in Kenya?
3. Are there interactions in species selectivity between artisanal and aquarium fisheries along the Kenya coast, and if so what are the possible implications on reef fisheries management?
4. How does the recruitment of juvenile coral reef fishes in shallow lagoon reefs vary along the Kenya coast?

5. What are the benthic habitat characteristics that influence the distribution of recruit and juvenile coral reef fish in shallow lagoon reefs along the Kenya coast?

CHAPTER TWO

LITERATURE REVIEW

2.1. Impacts of Fishing on Coral Reef Fish Populations

Fishing remains one of the largest and widespread factors directly threatening and modifying coral reef ecosystems on a global scale (Worm *et al*., 2009; Burke *et al*., 2011; Fenner, 2012). Globally, coral reef fisheries are persistently documented to be overfished, with estimates by Burke *et al*. (2011) indicating that over 55% of the world's reefs and 65% of the reefs in the Indian Ocean are threatened by overfishing, This situation is exacerbated by the increasing use of destructive and efficient fishing gears degradation of benthic habitats (Kaunda-Arara *et al*., 2003; Mangi & Roberts, 2006; McClanahan *et al*., 2008; Worm *et al*., 2009; Graham *et al*., 2011; Fenner, 2012).

Overfishing and selective fishing of juveniles is known to lead to loss of biodiversity and alteration of population demography reflected as changes in age and size structure, maturity, skewed sex ratios, and loss of genetic diversity (Heino & Godø, 2002). Overfishing has led to changes in the species diversity and composition of fished communities (Koslow *et al*., 1988; Roberts, 1995; Wilson, *et al*., 2008b; Zhou *et al*., 2010), as well as trophic cascades which occur when predator-prey relationships are imbalanced resulting in changes in ecosystem functioning and services (Dulvy *et al*., 2003; Campbell & Pardede, 2006; Worm *et al*., 2009; O'Leary & McClanahan 2010; Zhou *et al*., 2010; Burke *et al*., 2011; Fenner, 2012). Such population changes eventually influence the plasticity, productivity, and sustainability of exploited fish stocks (Jennings *et al*., 1999; Heino & Godø 2002; Shuman *et al*., 2005; Ottersen *et al*., 2006; Jørgensen *et al*., 2007; Locham *et al*., 2015). Despite the potential effects on biodiversity, there is little data on how fishing may be affecting the diversity and distribution of aquarium species in Kenya.

Along the Kenya coast, coral reef fish are heavily exploited by artisanal fishers using simple traditional fishing gears such as basket traps, gillnets and handlines, and non-motorized vessels such as canoes, dhows and outriggers (Samoilys *et al*., 2011). Most artisanal fishing activities are limited to nearshore areas within shallow lagoon reefs, mangrove creeks, and sea grass beds (Mangi *et al*., 2008). A high diversity of reef fish species (at least 163 species belonging to 38 families) are captured (McClanahan & Mangi, 2004; Tuda *et al*., 2016), and a high volume of juvenile reef fish estimated to constitute about 50% of the total artisanal catches (Mangi & Roberts, 2006).

Fishing pressure in shallow lagoon reefs has increasingly become unsustainabe to a level termed as Malthusian overfishing (when fishing effort and use of competitive or destructive gear increases proportionally to human population growth and declining fish resources (McClanahan *et al*., 2008). Quantitative assessments along the Kenya coast further provide strong evidence of declining fish catches, changes in the community structure (abundance and species diversity, size structure), habitat degradation, and a disruption of food web dynamics (McClanahan & Muthiga, 1988; Watson & Ormond, 1994; McClanahan & Obura, 1995; McClanahan & Kaunda-Arara, 1996; Kaunda-Arara *et al*., 2003; Mangi & Roberts, 2006).

Fishing also results in the degradation of coral reef habitats, especially when destructive techniques such as beach seines and dynamite are used, leading to changes in habitat structure and fish assemblage composition (Jennings & Keiser, 1998; Mangi & Roberts, 2006; Wells, 2009; Burke *et al*., 2011). Use of highly efficient fishing gears such as beachseines is driven by high rates of poverty, increasing human population levels and increasing dependence on fishing as a source of livelihood (Ochiewo, 2004; Mangi *et al*., 2008). Based on the most recent population census of Kenya carried out in 2009 the coastal population increased from 2.5 million people in 1999 to 3.3 million people (Government of Kenya, 2010). Results from fisheries frame surveys indicate that the number of artisanal fishers exploiting coastal fisheries has increased from 9,000 in 2008 to 14,000 in 2014 and annual fish production is estimated to be about 9000 metric tonnes (Government of Kenya, 2014).

Apart from artisanal gears, aquarium fishers also contribute to degrading the reef habitats by breaking corals when herding fish from coral crevices (Stevenson *et al*., 2011). Coral substrate termed as ‘live rock’ is also collected for use in aquarium tanks. Harvesting of ‘live rock’ is a concern as these are fundamental to building the coral reef ecosystem. The extraction of ‘live rock’ is cited as a contributing factor to coral reef degradation throughout the world (Bruckner, 2005).

The loss of coral cover is documented to lead to a decline in reef fish abundance, biomass and biodiversity (McClanahan & Obura, 1995; Jones *et al*., 2004; Pratchett *et al*., 2011; Komyakova *et al*., 2013). Site-attached and sedentary species, which are the main target of the aquarium fishery, are particularly vulnerable to a reduction in coral cover and habitat complexity due to the loss of hiding places and refugea (Graham & Nash, 2013; Graham, 2014). Significant declines in coral reef fish species that exclusively rely on coral for food or shelter, including some damselfishes, gobies and butterflyfishes, have been documented following extensive damage to hard corals (Kokita & Nakazono, 2001; Munday 2004; Pratchett *et al*., 2008a).

The vulnerability of a species to overfishing is influenced by its life-history characteristics, termed as ‘intrinsic vulnerability’ (King & McFarlane, 2003; Dulvy *et al*., 2003; Cheung *et al*., 2005, 2007). The life-history traits include fecundity, gestation period, body size, growth rates, maturity size, longevity, natural mortality, dispersal ability, or reproduction and recruitment (Munro, 1996). Species that are long lived, slow growing with large maximum body size, with a high age at maturity, and low reproductive rates are particularly vulnerable to fishing pressure as they are less able to sustain the effects of high fishing pressure (Russ & Alcala, 1996; Musick, 1999; Cheung *et al*., 2007). Some fish species may also have social behaviours such as spawning or feeding aggregations, which increases vulnerability to fishing (Sadovy & Vincent, 2002; Sadovy de Mitcheson *et al*., 2013).

2.2. Recruitment Dynamics of Coral Reef Fish

Recruitment is broadly defined as the addition of individuals that have newly settled from the pelagic larval phase to the benthic or demersal early juvenile phase of local populations (Caley *et al*., 1996). Recruitment is an essential component of the life history of coral reef fishes, and is among the most fundamental of demographic processes in the replenishment and structuring of coral reef fish populations (Jones, 1990; Doherty, 2002; Sponaugle *et al*., 2012). The general life cycle of reef fishes involves an initial planktonic larval stage followed by a benthic relatively sedentary juvenile and adult stage (Leis, 1991). The two life stages are coupled through a "settlement" phase in which larvae are dispersed to potential recruitment sites by oceanographic processes at scales ranging from metres to thousands of kilometres (Leis, 1991; Cowen & Castro, 1994; Schmitt & Holbrook, 1996).

2.2.1. Biological Factors Influencing Recruitment

Generally, there is a complex interaction of biological, ecological, environmental, and anthropogenic factors that influence all life cycle phases of coral reef fishes (Clua *et al*., 2005). The variable nature of reef fish recruitment is widely acknowledged (Caley *et al*., 1996; Doherty, 2002; Sponaugle *et al*., 2012). According to Dixson (2012), locating the correct habitat is the most important biological factor during settlement from the pelagic larval phase. Numerous studies have shown the importance of chemical, visual, olfactory and auditory cues in locating suitable benthic substrates (Shulman *et al*., 1983; Booth & Brosnan, 1995; Doherty, 2002; Lecchini *et al*., 2007; Dixson *et al*., 2008; Pratchett *et al*., 2008b; Rankin & Sponaugle, 2014; Roux *et al*., 2015). In particular, chemical cues from adult conspecifics (Sweatman, 1985; Lecchini *et al*., 2007; Lecchini & Nakamura, 2013) and olfactory cues from predators (Dixson, 2012) play a major role in either attracting or retracting settlement to a specific site.

Recruitment of juvenile reef fish is also influenced by the spawning patterns of adult fish (Robertson *et al*., 1988; Sadovy, 1996). Other factors include the condition of the spawned eggs (Leis & McCormick, 2006), and habitat preferences due to ontogenic changes in dietary requirements as fish mature (Lirman, 1994; Nagelkerken *et al*., 2000; Lecchini & Galzin, 2005; Lugendo *et al*., 2005; Mellin *et al*., 2007; Gratwicke *et al*., 2008; Grol *et al*., 2014). Varying ontogenic patterns of habitat use over time among juvenile and adult stages have been observed by Lecchini & Tsuchiya (2008), with some species showing no changes, others showing an increase in the number of habitats used, and others exhibiting a relatively exclusive use of specific habitats.

Holbrook *et al*. (2000) observed ontogenic changes for specific coral morphologies among some Pomacentridae species; while Ticzon *et al*. (2012) observed strong habitat association among juveniles of Pomacentridae species, which became weaker with ontogeny. Predation is another natural processes that influences the growth, condition and survival of settling larvae and recruitment (Carr & Hixon, 1995; Holbrook & Schmitt, 1997; Hixon, 1991, 2011; Almany, 2004). Almany & Webster, (2006) observed a dramatic reduction in the recruitment of newly settled damselfish, surgeonfish, butterflyfish, and rabbitfish due to the presence of predators. Some species (e.g. the apogon *Pterapogon kauderni*) also exhibit cannibalism of post settlement recruits (Vagelli, 1999).

2.2.2. Environmental Factors Influencing Recruitment

Habitat structure, defined as the physical arrangement of objects in space, is an important characteristic of coral reef habitats (McCoy & Bell, 1991). The structure of coral reef habitats is three-dimensional and is distinguished into a vertical component described as 'habitat complexity' and a 'horizontal component' described as 'habitat heterogeneity' (McCoy & Bell, 1991). There is a high diversity of substrate types including live coral, seagrass, sand, coral rubble and algae within coral reefs, which support the survival and growth of juvenile reef fish, and are thus considered as essential nursery habitats (Beck *et al*., 2001).

The diversity of coral reef substrate types substantially contributes to increasing biodiversity and productivity of coral reef ecosystems (Sale *et al*., 2005; Graham & Nash, 2013). The composition of these substrate types, also termed as 'structural complexity' is highly variable over a wide range of spatial and temporal scales and strongly influences the structure of reef fish assemblages (McClanahan & Arthur, 2001; Aburto-Oropeza & Balart, 2001; Garpe & Öhman, 2003; Gratwicke & Speight, 2005; Komyakova *et al*., 2013), as well as the productivity of associated fisheries (Graham, 2014; Rogers *et al*., 2014).

Structural complexity of the reef habitat plays an important role in regulating the predation of reef fish (Ticzon *et al*., 2012). Consequently, declining structural complexity and quality of settling habitats has been reported to increase the vulnerability of site-attached species to depletion (Sale *et al*., 2005; Pratchet *et al*., 2008a, b). Declining structural complexity leads to competition for microhabitat space, and is another factor influences recruitment patterns on coral reefs (Schmitt & Holbrook, 1996, 1999; Almany *et al*., 2007; Bonin *et al*., 2009).

At large spatial scales, seasonal variability in local hydrodynamics (e.g. currents, wind stress, upwelling, and sea temperature) is known to influence the recruitment dynamics of coral reef fish (Shulman, 1984; Sponaugle & Cowen, 1996; Dower *et al*., 1997; Doherty, 2002; Sale *et al*., 2005; Leis & McCormick, 2006, Abesamis & Russ, 2010; McClanahan, 2015). Some sites continuously receive high levels of larval supply and become “recruitment hotspots” (Fowler *et al*., 1992; Sponaugle & Cowen, 1996). At smaller spatial scales, timing of larval settlement has been associated with food availability as well as tidal and lunar cycles (Robertson, 1992; Jones *et al*., 2005; Ranking & Sponaugle 2014).

2.3. Overview of the Marine Aquarium Fishery

2.3.1. The Global Trade in Marine Aquarium Fish

The capture and export of tropical aquarium organisms has been traced as far back as the 1930s in Sri Lanka (Wood, 2001a). Since then, the practice has grown immensely to emerge as a worldwide trade of financial significance (Wood, 2001a, Dee *et al*., 2014). The aquarium industry involves the farming or harvest, sale and use of live marine and freshwater animals for display in home and public aquaria. The largest markets for aquarium fish are in the USA, Europe (Germany being the leading country), supplied from about 80 countries, the most important being Indonesia and the Philippines (Chan & Sadovy 1998; Wood, 2001a; Sadovy & Vincent 2002). An estimated 1.5 to 2 million people worldwide keep marine aquaria, with 50% in the United States alone (Wabnitz *et al*., 2003; Wood, 2001a). Ninety nine percent of the demand for aquarium fish comes from home hobbyists, and the remaining 1% from public aquaria and research institutes (Wabnitz *et al*., 2003).

The global trade in aquarium fish has been estimated to involve 350 million fish annually, of which 90% are freshwater fish comprising more than 4,000 species (Whittington & Chong, 2007); however, marine species have increasingly become popular in the trade (Olivier, 2001). Unlike freshwater species which are mostly farmed, at least 95% of marine fish are collected directly from reefs (Andrews, 1990; Wabnitz *et al*., 2003; Lecchini *et al*., 2006). Although there is a high diversity of fish species in the global trade, a large portion is concentrated on certain families and species dominated by damselfishes (Pomacentridae) which account for 43% of all fish traded worldwide (Wabnitz *et al*., 2003).

The trade is not heavily regulated, although several international agreements are of relevance. The 1982 United Nations Convention on the Law of the Sea (UNCLOS) and the FAO Code of Conduct for Responsible Fisheries are instruments that provide frameworks for the management and conservation of marine living resources.

Additionally, the United Nations Convention on Biological Diversity (CBD), which is legally binding, is the most all-encompassing of the biodiversity-related agreements and has near universal participation (188 countries). The Convention enshrines the principle of sustainable use, and recognises the importance of conserving biodiversity for the livelihoods of the poor. Another high-profile environmental agreement, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) aims to ensure that international trade in wild animals and plants does not threaten survival of these species. The main goal of CITES is to prevent species extinctions by putting bans or restrictions (quotas) on the trade in vulnerable species (CITES, 2016). Species are listed in any of the following three appendices according to their biological status and the impact that the international trade may have upon this status:

> **Appendix I** provides the highest level of protection and includes species that are threatened with extinction. International trade for commercial purposes is not permitted except only in exceptional circumstances.
>
> **Appendix II** includes species not necessarily threatened with extinction, but in which trade must be controlled in order to avoid utilization incompatible with their survival.
>
> **Appendix II** includes species not necessarily threatened with extinction, but in which trade must be controlled to protect species that are threatened by over-exploitation.

There are some marine aquarium species listed as threatened or endangered on CITES. All seahorse species (once highly targeted by aquarium, curio and medicinal value) are listed in Appendix II. The Banggai cardinalfish (*Pterapogon kauderni*), which is endemic to Indonesia, was the first saltwater species listed as threatened in the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species in 2007 (Allen & Donaldson, 2007) and more recently in 2016 as endangered (IUCN, 2016). The species has been subject to heavy collection pressure for the aquarium trade, and has biological characteristics that make it highly vulnerable to overexploitation e.g. low fecundity, extended parental care, and a lack of pelagic phase (Vagelli, 2011).

2.3.2. State of Knowledge on the Marine Aquarium Fishery in the WIO Region and Kenya

Within the WIO region, Kenya, Mauritius, South Africa and Madagascar are reported as suppliers of live marine aquarium reef fish, of which Kenya is the largest (Wood, 2001a; Bruckner, 2005). Kenya exports aquarium reef fish and invertebrates to various international markets including the USA, UK, Hong Kong and Europe (Okemwa *et al.*, 2009). There are 10 established companies exporting marine aquarium fishery products from Kenya, who are supplied by 145 licensed collectors having more than doubled in number from 65 fishers in 2000 (State Department of Fisheries, 2016). The fishers either snorkel in shallow areas or dive using self-contained underwater breathing apparatus (SCUBA) to collect fish using a combination of scoop nets and barrier nets of varying mesh sizes (Okemwa, personal observation). No chemicals including cyanide are used to stun the fish before collection. However, metal rods are sometimes used to tickle or chase fish out of crevices and corals (Okemwa, personal observation).

The fishers are engaged informally by the aquarium fish dealers who provide them with the necessary fishing gears and equipment. However, there are also ‘freelance’ or independent fishers who use their own gears and are not attached or obligated to fish for any dealer. The fishers regularly shift between fishing grounds along the coastline, influenced by their knowledge on the availability and distribution of target species. The choice of fishing grounds is further influenced by site accessibility (e.g. depth range, distance from shore, and wave action) which may change with season due to variations in oceanographic conditions.

The State Department for Fisheries is responsible for managing the exploitation of fisheries resources in Kenya and has incorporated several management instruments derived from the FAO Code of Conduct in its national legislation and policies. The overarching legislative framework for managing the marine aquarium fishery is the Fisheries Management and Development Act No 35 (GoK, 2016). However, the Act stipulates pre-licensing conditions to better monitor the fishery which include declaration of intended fishing areas, declaration of all employed fishermen; registration with Beach Management Units (BMUs) based in their areas of operation, provision of marine aquarium fish returns for the active year, facilitation of inspection of fish handling facilities and equipment, and submission of monthly returns of their catches and exports. The licensing requirements for aquarium fish traders also include the maintenance of logbooks containing the catch records of their fishers. However, there are no other specific regulations to control fishing effort such as size or catch limits, species bans or closed seasons. Apart from this, there are general restrictions on the use of destructive fishing methods or gear such as beach seines and spearguns as well as the collection and dealing in hard corals.

There are documented concerns about the impacts of the marine aquarium fishery in Kenya with the earliest being by Lubbock & Polunin (1975) who asserted that unmonitored collection of fish by the marine aquarium industry in the WIO would lead to local extirpations thereby adding to the range of existing ecological impacts from other anthropogenic activities on coral reef fish populations. Since then there have been some limited efforts to assess the status and impacts of marine aquarium fisheries in some WIO countries in Kenya (Samoilys, 1988; Okemwa *et al*., 2006, 2009), Mozambique (Whittington *et al*., 2000), Eritrea (Daw *et al*., 2001) and Maldives (Edwards & Shepherd, 1992). These studies have shown that collection of aquarium fish is potentially having negative impacts in some locations.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Area

The study focused on selected shallow lagoon reefs spread along the Kenyan coast (Fig. 3.1). The Kenyan coast is located between latitudes 1º41’S and 5º40’S, extends to about 600 km, and has a relatively narrow (5 to 10 km wide) continental shelf estimated to be about 19,120 km^2 (UNEP, 1998). The coastline is dominated by fringing reefs, which extend to about 20 - 25 m depths (Obura *et al*., 2000). There is an almost continuous shallow fringing reef system (approximately l00 m - 3 km in width from the shore) along the southern coast from Msambweni to Malindi (approximately 200 km of shoreline) in the northcoast. Patchy reefs are typical northwards from Malindi to the Lamu archipelago (approximately 100 km) and southwards from Msambweni to Shimoni (Obura *et al*., 2000; Fig. 3.1).

The shallow fringing lagoon reefs contain a mosaic of substrate types including coral, algal turf, seagrass beds, seaweeds, sand, rubble, and rocky substrates. Water depth within the lagoon reefs is variable but generally ranges up to a maximum of about 12 metres during spring low tide. Seasonality along the Kenya coast is strongly influenced by cyclical climatic conditions driven by the Inter-Tropical Convergence Zone (ITCZ), which creates two distinct seasons, namely the northeast monsoon (NEM) season occurring from November to March and the southeast monsoon (SEM) season from April to October (McClanahan, 1988; Schott & McCreary, 2001).

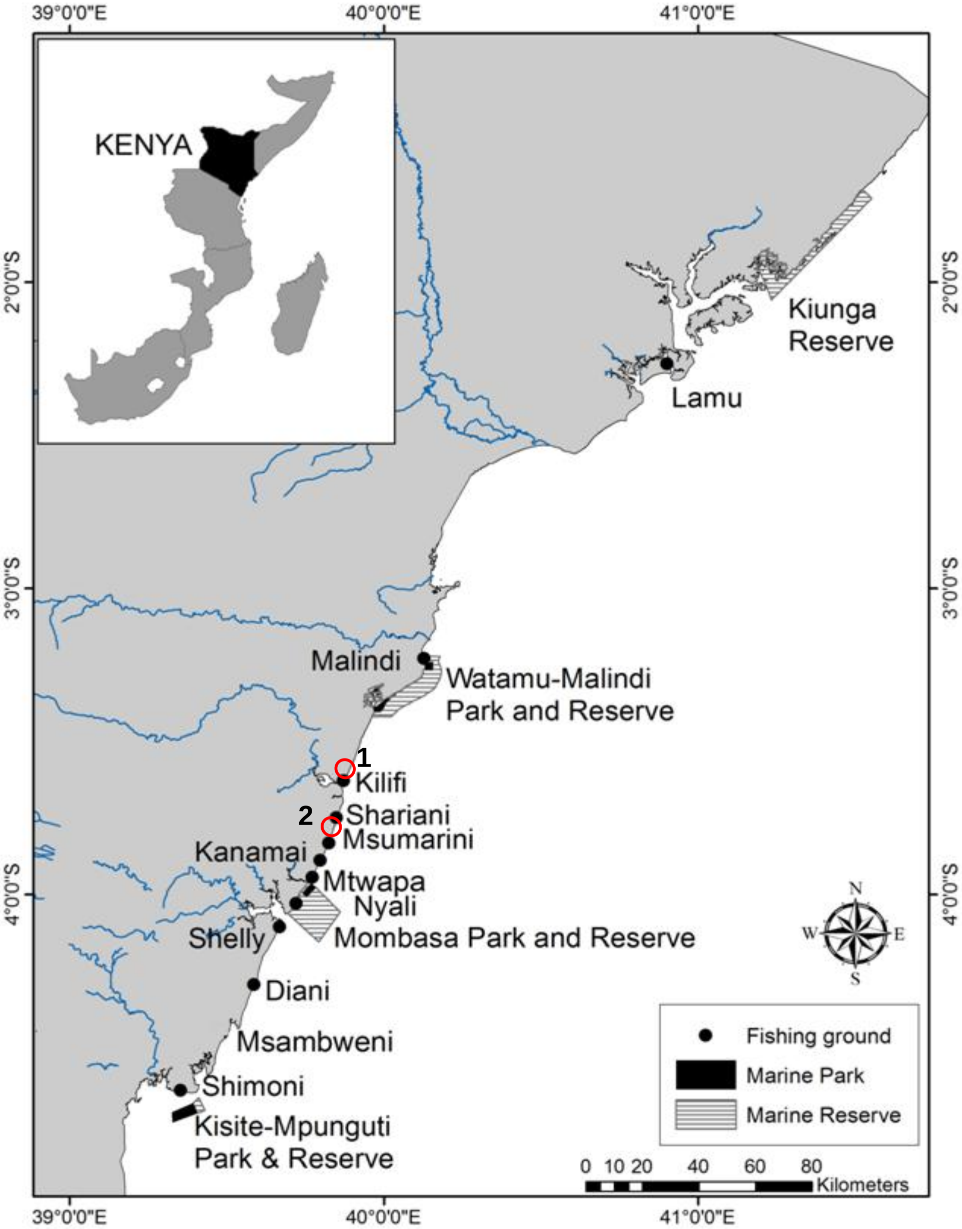


Figure 3.1. Map of Kenyan coast showing the location of the assessed aquarium fishing grounds (black dots) and their proximity to marine protected areas. Study sites where recruitment was monitored are indicated in red circles and numbered as 1=Kilifi, and 2=Kuruwitu (located between Msumarini and Shariani.

(Source: Author, 2016)

Temperatures within the coral reef waters generally range between 25 and 31°C (Obura *et al*., 2000). The NEM season is characterized by warmer temperatures (mean = 28.4°C), short rains (8 - 84 mm month^{-1}), calm seas and light winds (<0.25 m s^{-1}); while the SEM season is characterized by cooler temperatures (mean = 26.4°C), long heavy rains (55 - 272 mm/month), strong currents, high wave energy and strong winds (0.5- 0.75 ms^{-1}) (McClanahan, 1988; Obura, 2001). Fishing effort generally increases during the NEM season, and the catches are more productive (McClanahan, 1988).

Evaluation of spatial and temporal patterns of the marine aquarium fishery was based on fisher catch data from 11 sites: Shimoni, Diani, Shelly, Nyali, Mtwapa, Kanamai, Kilifi, Shariani, Msumarini, Malindi, and Lamu (see Fig. 3.1 for locations). Data for examination of gear and fishery interactions between artisanal and aquarium fisheries was collected from Shimoni area (Fig. 3.1). The Shimoni area contains the Kisite Marine National Park (KMNP), a no-take zone where all fishing activities are restricted, and the Mpunguti Marine National Reserve (MMNR) (Fig. 3.1), which serves as a buffer zone where only use of traditional fishing methods such as basket traps and handlines are allowed.

Investigation of recruitment patterns was done in two sites located in Kilifi and Kuruwitu, shown in Figure 3.1 as Site 1 and 2 respectively, and three additional sites; Sii, Mwipwa and Wasini within the Shimoni area, shown in Figure 3.2as Site 3, 4, and 5 respectively.

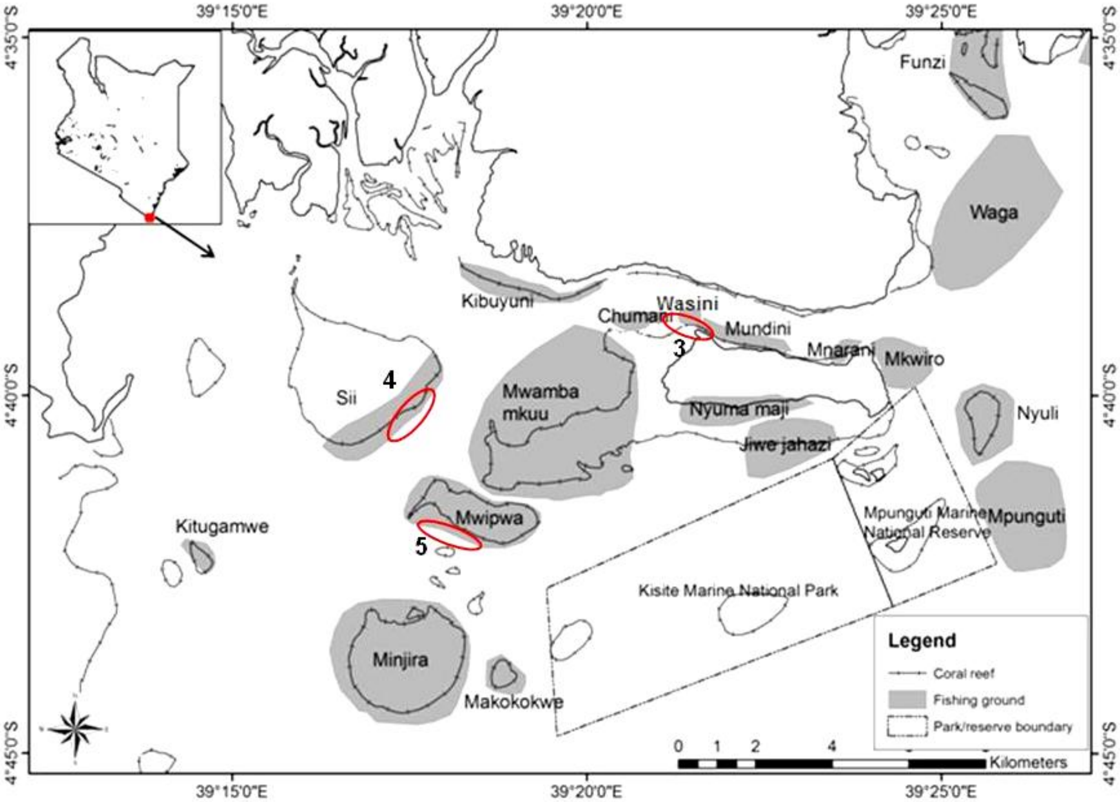


Figure 3.2. Map of the Shimoni area, southcoast of Kenya showing fishing grounds where artisanal and aquarium fishers fished, and the recruitment study sites which are highlighted in red circles (3=Wasini, 4= Sii, 5 = Mwipwa).

Source: Author, 2016)

The depths at the study sites ranged from 1.5 to 2.5 metres at high tide. Kuruwitu and Wasini (see Figs. 3.1 and 3.2 respectively) are locally managed marine areas (LMMA) closed to all forms of fishing. Kuruwitu was the first LMMA established in Kenya in 2006; while Wasini was established two years later in 2008. Sii, Mwipwa and Kilifi are open to all forms of fishing.

3.2. Data Sources and Field Sampling

3.2.1. Spatio-temporal Patterns of Coral Reef Fish Exploitation by the Marine Aquarium Fishery in Kenya

Data on the total catch, species composition and fishing effort of aquarium fishers was sourced from logbooks maintained by the main aquarium fish trader in Kenya, representing approximately 70% of the number of fish exported annually as estimated by the State Department of Fisheries. The data represented 11 lagoon reef sites spread along the coast: Shimoni, Diani, Shelly, Nyali, Mtwapa, Kanamai, Kilifi, Shariani, Msumarini, Malindi and Lamu (Fig. 3.1) and spanned from October 2006 to December 2011. Details on the date of fishing, the number of fishers, fishing grounds, fishing methods used, species, and numbers of fish caught were extracted and analyzed for spatial and monthly trends. However, data for 2006 was excluded from the analysis of annual variations as it represented only 3 months. The validity of species names recorded in the logbooks was checked and updated based on Eschmeyer & Fricke (2016).

3.2.2. Vulnerability Risk Assessment of Target Species to Exploitation by the Marine Aquarium Fishery

Productivity and Susceptibility Analysis (PSA) was used to assess the vulnerability risk of 102 species targeted by Kenya’s marine aquarium fishery following methods described by Stobutzki *et al*. (2001) and Hobday *et al*. (2007, 2011). Eight life-history traits were used to score productivity: average maximum age, minimum population doubling time fecundity, average maximum size (longevity), average size at maturity, von Bertalanffy growth coefficient (K Year $^{-1}$), reproductive strategy, and trophic level. The definition of the life-history attributes assessed is presented in Appendix I.

Selection of the productivity attributes was limited to those where information for most species was available.The criteria used to score the productivity and susceptibility attributes from low to high risk (see Table 3.1) was adopted from Roelofs & Silcock (2008), and Patrick *et al*. (2009). In cases where species-specific information for scoring was not availabe, information for similar species within the same family was used. A detailed list of the information sources and references used to score the productivity attributes for each species assessed is presented in Appendix II.

Attributes used to assess the susceptibility of the selected species included: (1) Availability: the overlap of fishing effort with a species distribution; (2) Encounterability: the likelihood that a species will be encountered when a fishing gear/method is used within the geographic range of that species); (3) Selectivity: the potential of the gear/method to capture or retain species; (4) Desirability: the value of the species; and (5) Ecological niche: the ecological connection between a fish species and its habitat.

Table 3.1. Productivity and susceptibility attributes used in the risk assessment of 102 fish species targeted by the aquarium fishery in Kenya based on Hobday et al. (2007, 2011). The scoring bins were adapted from: [1]Roelofs & Silcock (2008), [2]Patrick et al. (2009) and [3]Fishbase

Productivity attributes:	Low productivity (high risk, score = 3)	Moderate productivity (moderate risk, score = 2)	High productivity (low risk, score = 1)
Minimum population doubling time[3]	>4 years	1. 4.4 years	<15 months
Average maximum age[1]	> 15 years	5 - 15 years	< 5 years
Measured fecundity[1]	<1,000 eggs	1,000 - 15,000 eggs	>15,000 eggs
Average maximum size[1]	>60 cm	30 – 60 cm	<30 cm
Average size at maturity[2]	>40 cm	15 - 40 cm	<15 cm
von Bertalanffy (*K*)[2]	<0.15	0.15 – 0.25	>0.25
Reproduction strategy[2]	Live bearer	Demersal egg layer	Broadcast spawner
Mean trophic level[2]	>3.5	2.5 - 3.5	<2.5
Susceptibility attributes:	Low susceptibility (Low risk = 1)	Moderate susceptibility (Moderate Risk = 2)	High susceptibility (High risk = 3)
Availability: global distribution[1]	Widespread (Indo-Pacific)	Spread (WIO region)	Restricted (East Africa or local)
Encounterability: depth[1]	Limited accessibility: >30m	Accessible: 10 - 30m	Readily accessible: 0 - 10m
Encounterability: ecological niche (habitat)[1]	Generalist: broad range	Restricted: three-dimensional habitats associated with coral reefs)	Very restricted: specific microhabitats e.g. branching corals or anemones)
Selectivity: desirability/market value[1]	USD 0 - 10	USD 10 - 100	>USD 100
Post capture mortality	<5%	5 – 10%	>10%

When necessary, the susceptibility attributes were scored using expert opinion and consultations with key informants (two aquarium fishers having twenty and forty years experience and two fish dealers) (see Table 3.1). Price data sourced online from two firms that import tropical aquarium fish from Kenya (LiveAquaria.com and www.masterfisch.co.uk) was used to score 'desirability/market value' of each species. The value of each species was further validated through consultations with key informants. More details of the risk assessment process is provided in Section 3.3.2).

3.2.3. Gear-based Overlaps in Species Selectivity and Potential Interactions between Artisanal and Aquarium Fisheries at the South Coast of Kenya

Artisanal fisher catches were monitored at Shimoni area (see Fig. 3.2 for location) for 5 - 7 days monthly from January to December 2014. The landings were sampled as fishers landed their catches for weighing. For each fishing operation that was sampled, the fishing gear used, boat type, fishing grounds, and number of fishers was recorded. The total weight (kg) of the entire catch for each fisher was measured. The catch was then sorted and the landed fish identified to species using identification guides by Lieske & Myers (2001) and Anam & Mostarda (2012). Digital photos were taken for fish that were not immediately identifiable and a reference identification number recorded for later identification. The individual weight of the fish was measured to the nearest 1 gram using a hand-held electronic spring balance, while total length (TL) was taken on a measuring board to the nearest 0.1 cm. In cases where the catches were large (e.g. for schooling fish), a representative sample of approximately 10-20 % of the total catch was taken and measured as described above.

The catch data for aquarium snorkel and SCUBA fishers in the Shimoni area was collected for 5-10 days monthly from September 2010 to March 2013. Aquarium fishing grounds in Shimoni (Fig. 3.2) are distant and can only be accessed by boat. Thus, the vessel captains were requested to record the fish species collected and their numbers and weight, the total number of snorkel and SCUBA fishers onboard, and the fishing grounds visited during each fishing trip. The data recorded by the captains was validated on landing before the fish were loaded into vehicles for transportation to holding facilities. In addition, secondary commercial data officially reported to the State Department for Fisheries by aquarium dealers was obtained for the period January - December 2014 detailing species and numbers collected by all licensed traders from the Shimoni area. For each fishing trip that was sampled, the fishing grounds visited by the artisanal and aquarium fishers were noted following interviews and mapped as shown in Figure 3.2.

3.2.4. Recruitment Dynamics of Juvenile Coral Reef Fishes in Coastal Kenya

Non-destructive underwater visual census (UVC) surveys were conducted at five shallow fringing coral reef lagoon sites along the coast to assess spatial and temporal patterns in the abundance of newly settled coral reef fish recruits and juveniles. Two sites were located in the northcoast (Kilifi and Kuruwitu) and the other three sites were located at the southcoast (Sii, Mwipwa and Wasini) (see Fig. 3.1 and 3.2 for locations). In each site, the fish were censused by snorkeling in shallow depths of up to 2.5 metres, which is the depth range that is most accessible to aquarium fishers. Surveys for assessing variations between the study sites were conducted over a period of 10 months at Kilifi, Sii, Mwipwa and Wasini from February 2013 to February 2015 during the NEM and SEM season.

Monitoring for fine-scale temporal patterns (monthly, seasonal and annual) focused on one study site (Kuruwitu, located between Msumarini and Shariani, see Fig 3.1) which was easily accessible throughout the year unlike the other sites. The surveys at Kuruwitu were conducted for 6 days every monthly for over a period of 24 months: from June 2012 to June 2014 and thereafter bimonthly from August to December 2014, February and March 2015, and in March 2016.

The UVC surveys were conducted using the belt transect method described by English *et al*. (1997). The method involves laying a 50-metre transect line parallel to the shoreline. After laying the line, the fish are allowed 15 minutes to settle and resume normal behaviour, after which the observer swims slowly along the transect line, thoroughly checking under rocks and crevices and recording all recruits and juvenile fishes encountered within 1-metre of either side of the line (50 m × 2m, or 100 m^2). A T-shaped PVC pipe (1 metre in width) was used to visually estimate the width of each belt transect. Each transect was surveyed twice, during the first pass the highly mobile conspicuous fish were recorded and then the smaller site attached fish were recorded during the second pass by carefully searching beneath rocks and crevices.

Encountered fish within each transect were identified to species as much as possible, and their total lengths estimated and recorded on a white perspex slate. Fish length estimation was done using a plastic 30 cm ruler attached to the perspex slate. Identification of juvenile and sub-adult/adult life stages of most species was done using colouration patterns (Russell *et al*., 1977; Walsh, 1987; Abesamis & Russ, 2010). For analysis, the censused fish were further grouped by size into three life stages (recruits, juveniles, and subadults/adults) using pre-defined length clusters based on their maximum size as reported in FishBase (Froese & Pauly, 2016). The three life-stages were grouped following criteria adopted from Russell *et al*. (1977) and Walsh (1987) as follows:

i. **Recruits** - very small and pale newly settled individuals with little or no pigmentation and a total length of 2 cm or less (except for Acanthuridae and Chaetodontidae species which were observed at much bigger sizes of up to 4 cm);

ii. **Juveniles** - distinctly coloured individuals <25% of the maximum adult total length as indicated on Fishbase;

iii. **Sub-adult and adult** – individuals with distinct adult colouration having a total length >25% of maximum adult total length.

Six replicate transects (2 metres in width, and 50 metres in length) were surveyed in Kilifi, while three replicate transects were surveyed in Wasini, Sii Island and Mwipwa, and twelve replicate transects were surveyed in Kuruwitu. Variability in transect numbers between the sites was due to the limited spatial area available for sampling without overlapping, as well as site accessibility which affected the time available for sampling sites. The transects were permanently marked with buoys and georeferenced using GPS in Kuruwitu to enable repeated sampling within the same general area. However, marking with buoys in the other sites was not possible due to the likely interference by fishers; thus, they were only marked with GPS. Each transect survey took about 45 minutes to 1 hour to conduct, and all surveys were carried out between 9 am and 3 pm when the water conditions were optimal to minimize errors due to poor visibility. Sea temperature was measured *in-situ* using a Hobo Pro Waterproof temperature logger (Onset Computer Corporation) attached to a sinker and buoy for easy retrieval.

3.2.5. Habitat Associations of Recruit and Juvenile Coral Reef Fishes

Benthic substrate cover was estimated in the five study sites (Kilifi, Kuruwitu, Sii, Mwipwa and Wasini), and surveyed for recruits and juveniles using the Line Intercept Transect (LIT) method described by English *et al*. (1997). The LIT method involves placing a 50 m tape measure within each belt transect. While snorkeling along the transect line, the length of each substrate type intercepting the tape is measured to the nearest centimetre and recorded. The percent cover of each substrate type encountered is calculated as:

$$Percent\ Cover = \frac{Total\ summed\ length\ of\ substrate\ type}{Length\ of\ transect} \times 100$$

The substrate types recorded at the study sites included live hard coral, dead coral, soft coral, rocky substrate, turf algae, macroalgae, rubble with sand, sponge, seagrass and anemones (Table 3.2). Linear rugosity, a measure of structural complexity, was assessed at the sites using the ‘chain and tape’ method (Risk, 1972). After completing the fish census, a 50 m chain with small links (1.5 cm per link) was carefully draped along the transect following the benthic contours and crevices as closely as possible. A fiberglass measuring tape was then placed parallel to the chain to measure the linear distance of the contour covered by the chain. Four to six transects were measured at each site. A rugosity index was then calculated for each transect by dividing the contour length covered by the chain with the linear distance between the chain's endpoints (50 m), with an index of 1 indicating a flat substrate of low rugosity or topographic complexity.

Table 3.2. Descriptive characteristics of the benthic substrate types recorded at the study sites

Substrate type	**Description**
Live coral	Formations consisting of calcium based skeleton with live coral polyps
Dead coral	Hard coral with identifiable morphology and dead coral polyps, usually white to dirty white in colour , and may also be encrusted with algae
Rocky substrate	Standing rock with no visible skeletal structure
Turf algae	Lush filamentous algae, often found inside crevices
Macroalgae	Fleshy red and brown algae e.g. Sargassum
Rubble with sand	Unconsolidated and unidentifiable broken dead coral fragments usually interspersed within sandy areas

Fish encountered along the belt transects were identified to species and the habitat immediately beneath each individual was recorded to assess the habitat associations of recruit and juvenile reef fishes following methods based on methods adopted from Wilson *et al*. (2010). The range of habitats encountered is shown in Table 3.2. The number of transects surveyed at each site ranged from 6 to 16 as follows: Sii Island (6), Wasini (8), Mwipwa (6) and Kuruwitu (16). The surveys to assess habitat associatons were conducted during the NEM season in January 2014 at all the study sites except Kilifi which was aborted due to poor water visibility.

3.3. Data Analyses

3.3.1. Spatial and Temporal Patterns of Coral Reef Fish Exploitation by the Marine Aquarium Fishery

Catch and effort trends

Fishing effort was calculated for each of the 11 aquarium fishing grounds (Fig. 3.1) as the total sum of fisher days (1 fisher day = 1 fisher fishing for one day), while the mean catch per unit effort (CPUE) was calculated as the number of fish per fisher per day (fish fisher $^{-1}$ day $^{-1}$). In deriving the CPUE estimates, the efficiency of the fishers was assumed not to differ significantly between individuals; although it is expected that more experienced fishers will be more efficient. Simple linear regression was used to explore the relationship between catch and effort and the significance of temporal trends with months (Oct '06 – Dec '06) as a fixed effect; while seasonal differences in mean CPUE at the fishing grounds was compared using the non-parametric Mann-Whitney *U*-test.

Spatial variation in the species composition of catches

Various diversity measures were used to evaluate the species composition of aquarium fisher catches from each of the 11 fishing grounds (see Fig. 3.1 for locations). First, the relative percent abundance of each species was estimated for each fishing ground from the total number of fish collected. The species richness of the catches for each fishing ground was then described using the Shannon-Weiner's diversity index (*H'*), Margalef's species richness index (d), and Pielou's species evenness index (D). As detailed by Magurran (2004) the Shannon-Wiener diversity index (*H'*) was derived as:

$$H' = -\sum p_i (\log p_i)$$

where, p_i is the proportion of the total count arising from the *i*th species. Margalef's species richness index (d) was derived as:

$$d = (S - 1)/log_e N$$

where, S is the total number of species and N is the total number of individuals, and Pielou's species evenness index (J') was derived as:

$$J' = H'/log\ (S)$$

In interpreting *J'*, low values indicate that few species dominate, while high values indicate that the catch is relatively evenly represented in species composition. The association of fish species with fishing grounds was explored using Detrended Correspondence Analysis (DCA) based on relative abundance. DCA plots were based on species representing >1% of the total catches to allow for easy interpretation.

A combination of cluster analysis and non-metric Multidimensional Scaling (MDS) was performed to identify groupings of fishing grounds that were similar in species composition; and to assess the similarity in species catch composition between fishing modes of the aquarium fishers (snorkeling vs. SCUBA) based on the relative percent abundance of the species in the total catches. Combining cluster analysis with MDS ordination, as was done in this study, is the most effective way to check the consistency of patterns (Clarke & Warwick, 2001). The MDS ordination was based on a cut-off stress value of 0.1 and the output was superimposed with the clusters at 40 - 50% level of similarity. The dataset was pre-treated by square root transformation to down-weigh the importance of highly abundant species so that similarities could be more evenly distributed (Clarke & Warwick, 2001). Matrices of similarities were obtained using the Bray-Curtis coefficient (Bray & Curtis, 1957), which is the most commonly used index for comparing similarities in species composition and diversity (Chao *et al*., 2006).

The significance of differences in species composition between the identified groups was tested using the non-parametric analysis of similarities (ANOSIM). In ANOSIM, the significance level is given by an R statistic, which ranges between 0 and 1. Values close to 0 indicate significant similarities in species composition between groups, while values close to 1 indicate significant dissimilarities (Clarke & Warwick, 2001). Similarity percentages analysis (SIMPER) was then used to determine the percentage contribution of species to dissimilarities between groups assuming a cut off at 70%.

3.3.2. Vulnerability Risk Assessment of Target Species to Exploitation by the Marine Aquarium Fishery

An Excel worksheet developed by the Marine Stewardship Council (MSC, 2010) was used to assess the vulnerability risk of the selected species to exploitation by the marine aquarium fishery. The productivity and susceptibility attributes used in this study (described in section 3.2.2 and Appendix I) were adopted from Roelofs & Silcock (2008), Patrick *et al*. (2009) and Fishbase (Froese & Pauly, 2016) and the scoring bins were modified as shown in Table 3.1. The modification was done to increase contrast in scoring of the aquarium fish species. The attributes were scored as 1 (low risk), 2 (medium risk) or 3 (high risk) for each of the 102 species based on Hobday *et al*. (2007, 2011), and each attribute was assigned equal weighting (see Appendix III for the scoring of each species). The productivity risk value for each species was estimated by **averaging the scores** for productivity attributes, while the susceptibility risk value was estimated as the **multiplicative product** of the scores for the susceptibility attributes (Hobday *et al*., 2007, 2011).

A 'desirability/market value' score of 3 was assigned to a species if it ranked among the top 2 within its family based on the catch data. The ranking was based on the premise that species captured in high abundance face relatively intense collection pressure irrespective of their market value. The Pearson correlation coefficient (r) was used to examine the correlation between productivity and susceptibility attribute scores. A two-dimensional bivariate plot was then generated based on the euclidean distances of the risk values from the origin. Contour lines divided the plot area into equal thirds representing low, medium, and high-risk vulnerability categories (Fig. 3.3). Species having low productivity and high susceptibility scores (with overall risk scores > 3.18) were considered to have a **high vulnerability risk** to the aquarium fishery, whereas those with high productivity and low susceptibility scores (with overall risk scores < 2.64) were considered to have a **low vulnerability risk** (Hobday *et al*., 2007; see Fig. 3.3).

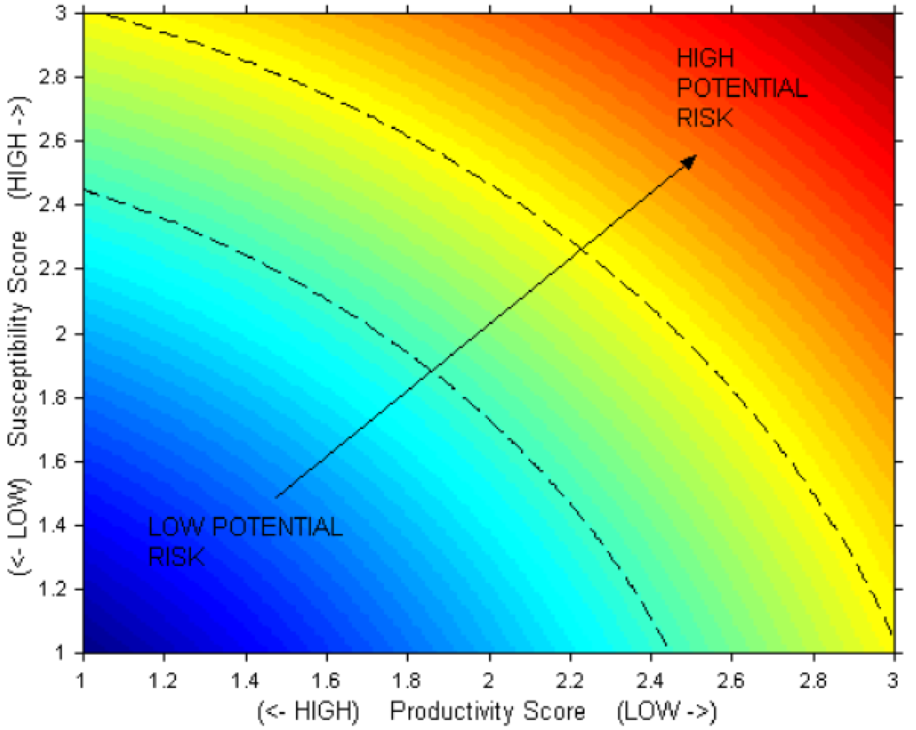


Figure 3.3. A model of a two-dimensional bi-plot of the productivity and susceptibility analysis (PSA). The *x*-axis represents productivity scores of attributes of a species, and the *y*-axis represents susceptibility scores of attributes of the species to impacts from fishing. Relative risk to a species is based on a combination of the productivity and susceptibility scores, i.e. species with high susceptibility and low productivity are at highest risk, while species with low susceptibility and high productivity are at lowest risk. The contour lines dividing the plot area into equal thirds representing low, medium and high risk vulnerability categories (Source: Hobday *et al*., 2007)

3.3.3. Gear-based overlaps in species selectivity and potential interactions between artisanal and aquarium fisheries at the southcoast of Kenya

Species composition of artisanal and aquarium fishery catches

Rank abundance histograms of the 40 most abundant species were generated from the pooled data of the artisanal and aquarium fisher landings sampled during January to December 2014 at the Shimoni area (see Fig. 3.2 for location). Histograms were also generated for the main artisanal gear types (handlines, basket traps, spearguns and reef seines) to compare the relative abundance of species landed per gear. Three community indices (species richness S, Shannon-Wiener *H’* and Pielou’s evenness *J’*) as described by Magurran (2004) were used to characterize the structure of the catches by fishery and gear type (see section 3.3.1 for formulae).

Overlaps in species selectivity and spatial distribution of fishing effort

Hierarchical agglomerative cluster analysis (Clarke & Warwick, 2001) was used to assess the degree of similarity in species composition among the artisanal gear types. Prior to the cluster analysis, Bray-Curtis similarity index was applied on square root transformed data in order to down-weigh the influence of rare and extremely abundant species. The Similarity Profile (SIMPROF) analysis test (Clarke *et al*., 2008) was then used to detect the presence of a statistically significant structure in the identified clusters. The fish species captured in the artisanal gears were further categorized by their commercial value as C (artisanal commercial) or A (Aquarium). Categorization of the fish species as aquarium target species was based on published lists of aquarium species (Okemwa *et al*., 2006) and data compiled by the State Department for Fisheries. Pianka’s index (Pianka, 1973), calculated as:

$$O_{kl} = \frac{\sum_i^n p_{il} p_{ik}}{\sqrt{\sum_i^n p_{il}^2 \sum_i^n p_{ik}^2}}$$

was then used to characterize the overlap in species selectivity among the artisanal fishing gears and between fisheries (artisanal vs. aquarium); where, O_{kl} = Pianka's index of niche overlap between gear k and gear l, p_{il} = the proportion of the ith species in gear 1, p_{ik} = the proportion of the *i*th species in gear k, and n = the total number of species caught by the gears. The index ranges from 0 (no species in common between gears and fisheries) to 1 (complete overlap among gears and fisheries). In using the index, a basic assumption was made that all species were equally accessible to all the gears.

K-dominance curves of the percentage cumulative rank abundances of the species captured were plotted against the log species (Clarke & Warwick, 2001) for the main artisanal gear types (handlines, basket traps, spearguns, reef seines, gillnets, monofilament nets) and aquarium fishing methods (SCUBA vs. snorkeling). Steeper curves indicate dominance of a few species and hence higher species selectivity of the gears and fishing methods. The spatial distribution of fishing effort in the Shimoni area fishing grounds was then estimated as a summation of number of fishers recorded daily (number of fisher days) for each gear type. Finally, Detrended Correspondence Analysis (DCA) was applied to test for gear-based species associations among the fisheries and fishing grounds.

3.3.4. Recruitment Dynamics of Juvenile Coral Reef Fishes

The species composition of recruits (refer to definition in section 3.2.4) within each study site was assessed at family and species level by calculating their relative abundance. The data for recruits of the family Scaridae (parrotfishes) was pooled and assessed at family level only due to uncertainties in identifying recruits some species which have very similar colouration. Moreover, the juveniles (refer to definition in section 3.2.4) were also observed to be highly mobile, moving in small groups of mixed species which made it difficult to reliably estimate their numbers to species level.

The assemblage structure of recruits at each site was assessed using three community indices on the pooled data: Margalef's species richness d, the Shannon-Wiener H' index, and Pielou's evenness J′ index (described in section 3.3.1.2). A *k*-dominance curve was generated for each study site for a graphical representation of the species relative abundance and evenness of the recruits. In Mwipwa and Sii Island (see Fig. 3.2 for the locations), recruits of pelagic species (Atherinidae and Caesionidae spp.) were encountered sporadically during the surveys in very large schools and were therefore excluded from the analysis.

Non-metric multidimensional scaling (MDS) was applied to compare differences in the species composition of newly settled recruits between sites. A Bray-Curtis similarity matrix was applied on square root transformed data to reduce the weighting of abundant species (Clark & Warwick, 2001). Group-average clustering was performed and the derived MDS plot was overlaid with the similarity contours from the cluster analysis to elucidate the spatial patterns. Analysis of Similarities (ANOSIM) was used to compare differences in species composition of recruits between sites, years and seasons, and a similarity percentage (SIMPER) analysis was applied to identify which species contributed to dissimilarities in species composition between sites. Finally, a checklist of the fish species recorded as recruits and juveniles in the study sites showing their presence and absence and ranked by occurrence was developed. Recruit density was estimated as the mean number of recruits counted per transect (± standard error).

For the analysis of seasonal trends in recruit densities and species composition between sites, the Kuruwitu data, where the most consistent sampling was undertaken, was limited to the 10 months when sampling was done at the other sites. Monthly estimates of mean recruit densities for abundant families and species in Kuruwitu were presented graphically to elucidate longer term temporal trends. The non-parametric Wilcoxon Rank Sum (Mann-Whitney U test) was used to test for significant patterns in recruit densities for key families between years (Kuruwitu only) and seasons (all study sites). A two-way ANOVA was further applied to the Kuruwitu data to check for significant patterns between years and seasons among 10 key species. The fish abundance data was $\log_{10}$ (x + 1) transformed to meet assumptions of normality and homoscedascity for the ANOVA model (Zar, 1999).

3.3.5. Habitat Associations of Recruit and Juvenile Coral Reef Fishes

A one-way ANOVA was applied used to assess for significant variations in benthic substrate cover between sites. Prior to the analysis, the percent cover data of the major substrata categories (defined in Table 3.2) was arc-sine transformed to meet assumptions of normality and homoscedasticity for the ANOVA model (Zar, 1999). Canonical Correspondence Analysis (CCA, Legendre & Legendre, 1998) was used to test for associations of ontogenic life phases and sites with habitat variables. Detrended Correspondence Analysis (DCA; Hill & Gauch, 1980) was then applied for a visual examination of species-specific habitat associations. Data analysis was conducted using various softwares: STATISTICA version 7 (StatSoft, Inc. 2007), PRIMER version 6.1.5 (Clarke & Gorley, 2006) and PAST version 3.14 (Hammer *et al*., 2001). EcoSim version 7.0 (Gotelli & Entsminger, 2001) was used to calculate niche overlaps between gears and fisheries.

CHAPTER FOUR

RESULTS

4.1. Spatio-temporal Patterns of Coral Reef Fish Exploitation by the Marine Aquarium Fishery

4.1.1. General Catch and Effort Trends

Analysis of the logbook catch data from the 11 fishing grounds (Fig. 3.1) showed that a total of 1.45 million aquarium fish were collected from October 2006 to December 2011, representing an annual average of 279,000 fish and ranging from 235,000 in 2007 to a peak of 327,000 in 2008 (Fig. 4.1a). Snorkel fishers landed 55.3% of the total number of fish (803,010 fish) compared to 44.5 % (656,033 fish) landed by SCUBA fishers. However, the mode of fishing for 4,295 fish (0.3%) obtained from independent fishers was not recorded, and thus unknown.

A total 60,052 fisher-days were recorded over the study period with snorkeling accounting for 65% of the total fishing effort (Fig. 4.1a). Approximately 80% of the fishing effort was concentrated in four of the eleven fishing grounds: Shimoni (28.5%), Kanamai (21.5%), Mtwapa (15.4%), and Kilifi (14.2%), while the lowest effort was observed in Lamu accounting for 0.03% of the total. Catches from six of the 11 fishing grounds constituted about 94% of the total fish landed and included Shimoni (33%), Kanamai (20%), Mtwapa (18.5 %), Kilifi (12.3%), Nyali (5.6%) and Diani (4.2%). The remaining 6% was collected from Shariani (3.5%), Shelly (1.7%), Msumarini (0.8%), Malindi (0.3) and Lamu (0.1%) (Refer to Fig. 3.1 for locations). The total number of fish peaked in 2008 after which there was a general decline (Fig. 4.1a).

The main fishing grounds for SCUBA fishers was in Shimoni and Mtwapa constituting 65% and 92% of the landed fish respectively; while snorkel fishers mainly fished in Diani, Kanamai, Msumarini, Shariani, Malindi and Lamu (Fig. 4.1b). A declining trend in total annual catches was observed from 2008 to 2010 in some fishing grounds such as Diani, Shelly, Nyali, and Kilifi, while an increasing trend was observed in Mtwapa and relatively stable or fluctuating trends in the other sites (Fig. 4.2). Shifts in fishing effort among the fishing grounds were observed to correspond with the trend in annual catches (Fig. 4.2).

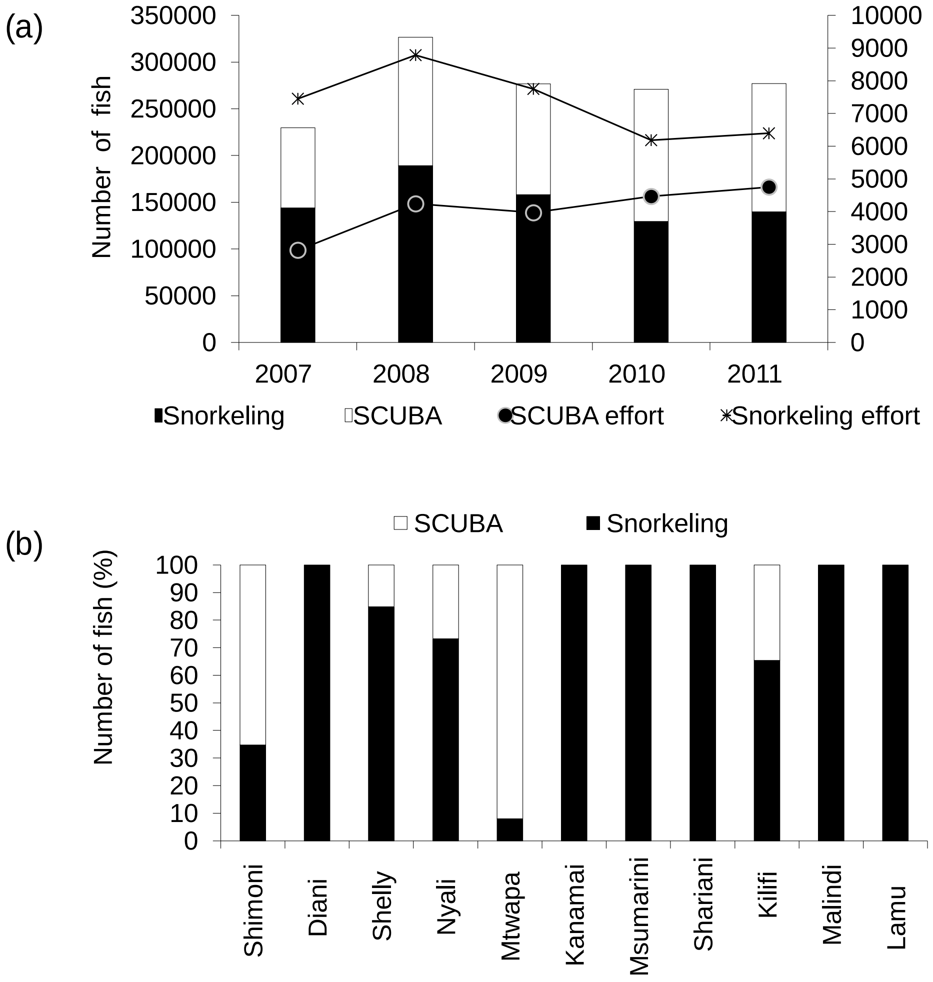


Figure 4.1(a) Trends in the total number of aquarium fish collected annually, and (b) the spatial variation in percentage quantity of fish catches grouped by fishing mode (SCUBA or Snorkeling) among the 11 studied fishing grounds in coastal Kenya

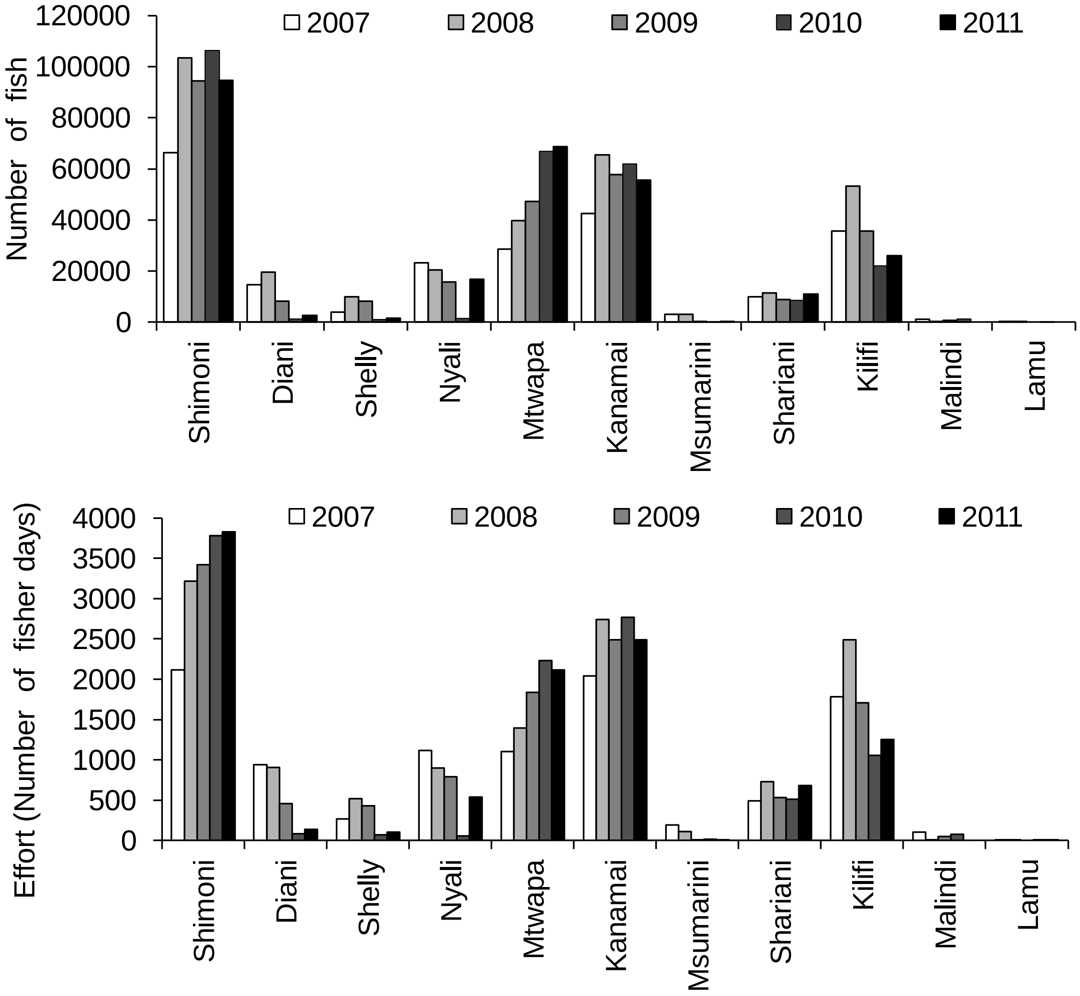


Figure 4.2. Variation in the annual total number of aquarium fish collected; and annual total fishing effort (number of fisher days) among 11 fishing grounds from January 2007 to December 2011

4.1.2. Catch per Unit Effort (CPUE) Trends

Over the six-year period from October 2006 to December 2011, the overall mean CPUE (number of fish/fisher/day ± SE) was 24 ± 0.5 and differed significantly among the 11 fishing grounds (Kruskal-Wallis H test, $p < 0.05$). SCUBA fishers had a significantly higher mean CPUE (31.9 ± 0.3) compared to snorkel fishers CPUE (20.5 ± 0.1) (Mann-Whitney *U*-test, $p < 0.05$). Among snorkel fishers, the mean CPUE was highest in Lamu at 48 ± 0.6 (double the overall average) and lowest in Malindi at 13 ± 0.3. The monthly trend for the pooled data showed a three-fold increase in fishing effort, which occurred in August 2007. The mean CPUE was highest in March 2007 at 34 ± 0.2 and lowest in September 2011 at 18 ± 0.3 (Fig. 4.3a). The mean CPUE was significantly different among the years, influenced by a significantly lower CPUE in 2007 as indicated by pair-wise *post hoc* comparisons (Kruskal-Wallis H test, $p < 0.05$).

In addition, the CPUE data showed strong seasonality demonstrated by a significantly higher mean CPUE (27 ± 0.2) during the NEM months from November to March compared to the SEM months of April to September (CPUE of 22 ± 0.1) (Mann-Whitney *U*-test, $p < 0.05$). Linear regression of CPUE with fishing effort showed a weak negative relationship ($R^2 = 0.011$; $p > 0.05$; Fig. 4.3b); while regression of CPUE with time (months) showed no significant change in CPUE over time for snorkel fishers ($R^2 = 0.0063$, $p > 0.05$) and SCUBA fishers ($R^2 = 0.0208$, $p > 0.05$; Fig. 4.3c).

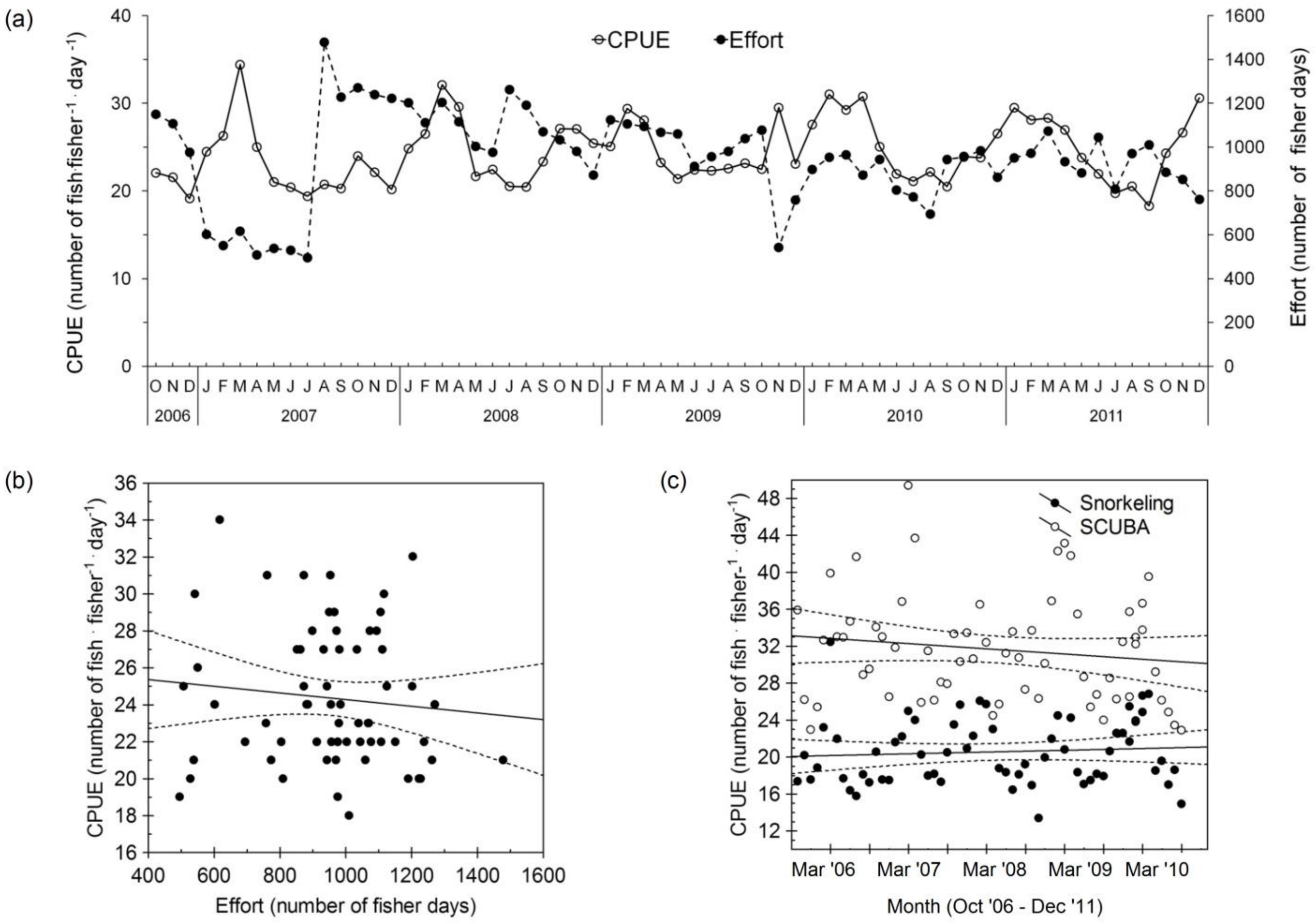
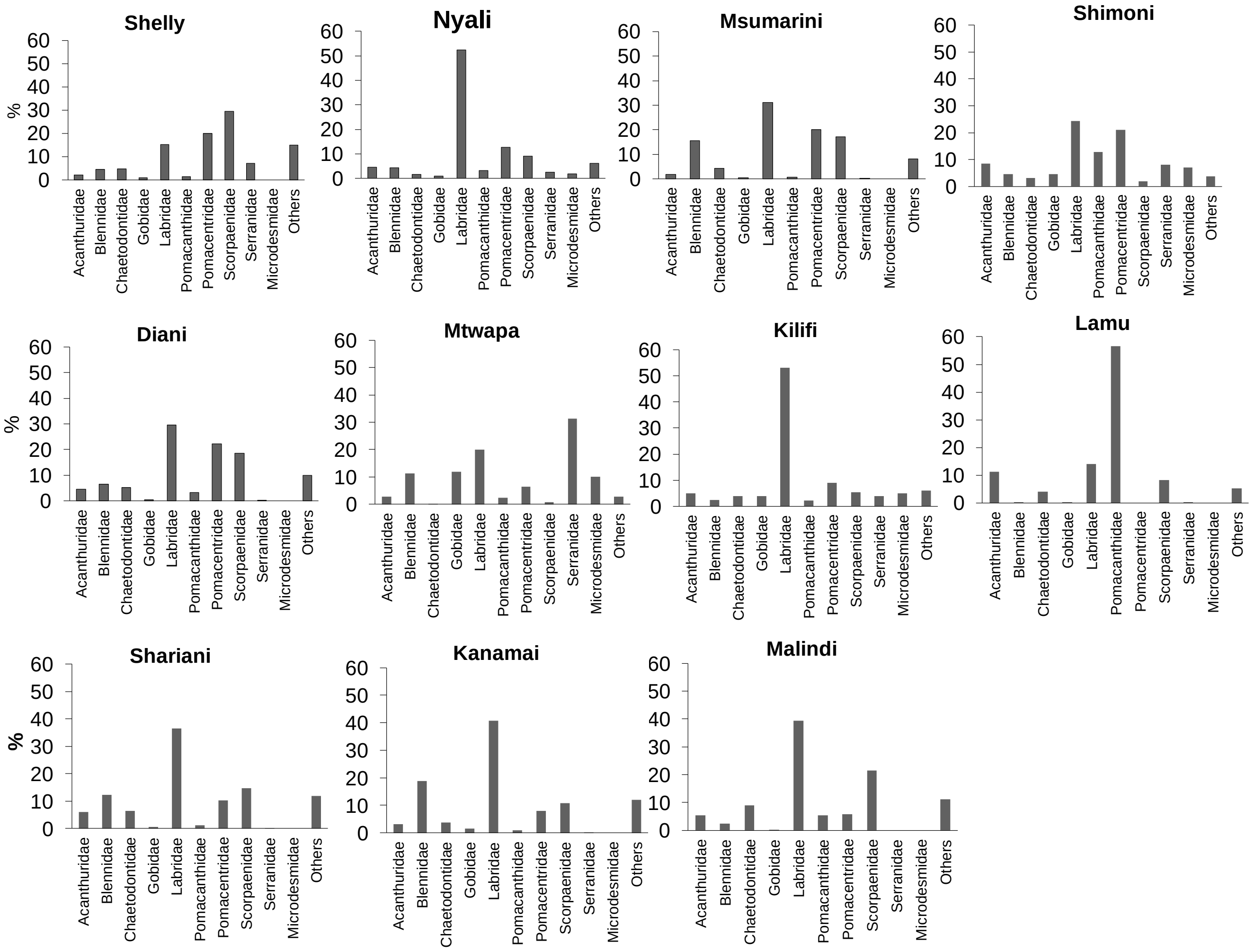


Figure 4.3(a) The monthly trend in the mean CPUE (fish fisher $^{-1}$ day $^{-1}$), (b) the linear relationship between mean CPUE and fishing effort: y = -0.0018x + 26.085, R^2 = 0.011; and (c) the linear trend in mean monthly CPUE for snorkel and SCUBA fishers over time. Snorkel fishers: y = 0.016x + 20.07, R^2 = 0.0063; SCUBA = y = -0.047x + 33.13, R^2 = 0.0208). Dotted boundaries indicate upper and lower 95% confidence limits

4.1.3. Species Composition of Aquarium Fish Catches

The aquarium fish catches collected from the 11 fishing grounds during October 2006 to December 2011 was comprised of 220 species belonging to 36 families (see Appendix IV for full list of species). Ten families accounted for 94% of the total catch: Labridae (32%, 42 species), Pomacentridae (14%, 14 species), Serranidae (9%, 8 species), Blenniidae (9%, 7 species), Scorpaenidae (7%, 8 species), Pomacanthidae (5%, 10 species), Acanthuridae (5%, 16 species), Microdesmidae (5%, 3 species), Gobiidae (5%, 8 species) and Chaetodontidae (3%, 23 species). Labridae represented the most collected aquarium fish family from all the fishing grounds apart from Lamu and Mtwapa (Fig. 4.4) and ranged from 24% (35 species) of the species collected from Shimoni to 53% of the species collected from Kilifi (35 species).

Thirty-two species constituted 80% of the total catch from all the fishing grounds, with the top ten species accounting for over 50% of the catch from all the fishing grounds (Fig. 4.5). The species richness and diversity of the aquarium fisher catches varied among the fishing grounds. The southernmost site of Shimoni (see Fig. 3.1 for locations) had the highest number of species collected (193 species). The highest diversity (H' = 3.59) was observed for Shimoni and Nyali, while the least number of species and lowest diversity of the fisher catches was from the northernmost site of Lamu (38 species, H' = 2.31).



Shelly

Nyali

Msumarini

Shimoni

Diani

Mtwapa

Kilifi

Lamu

Shariani

Kanamai

Malindi

Figure 4.4. Relative abundance (%) of the coral reef fish families collected by aquarium fishers from the 11 fishing grounds studied based on the pooled data recorded in fisher logbooks during October 2006 to December 2011

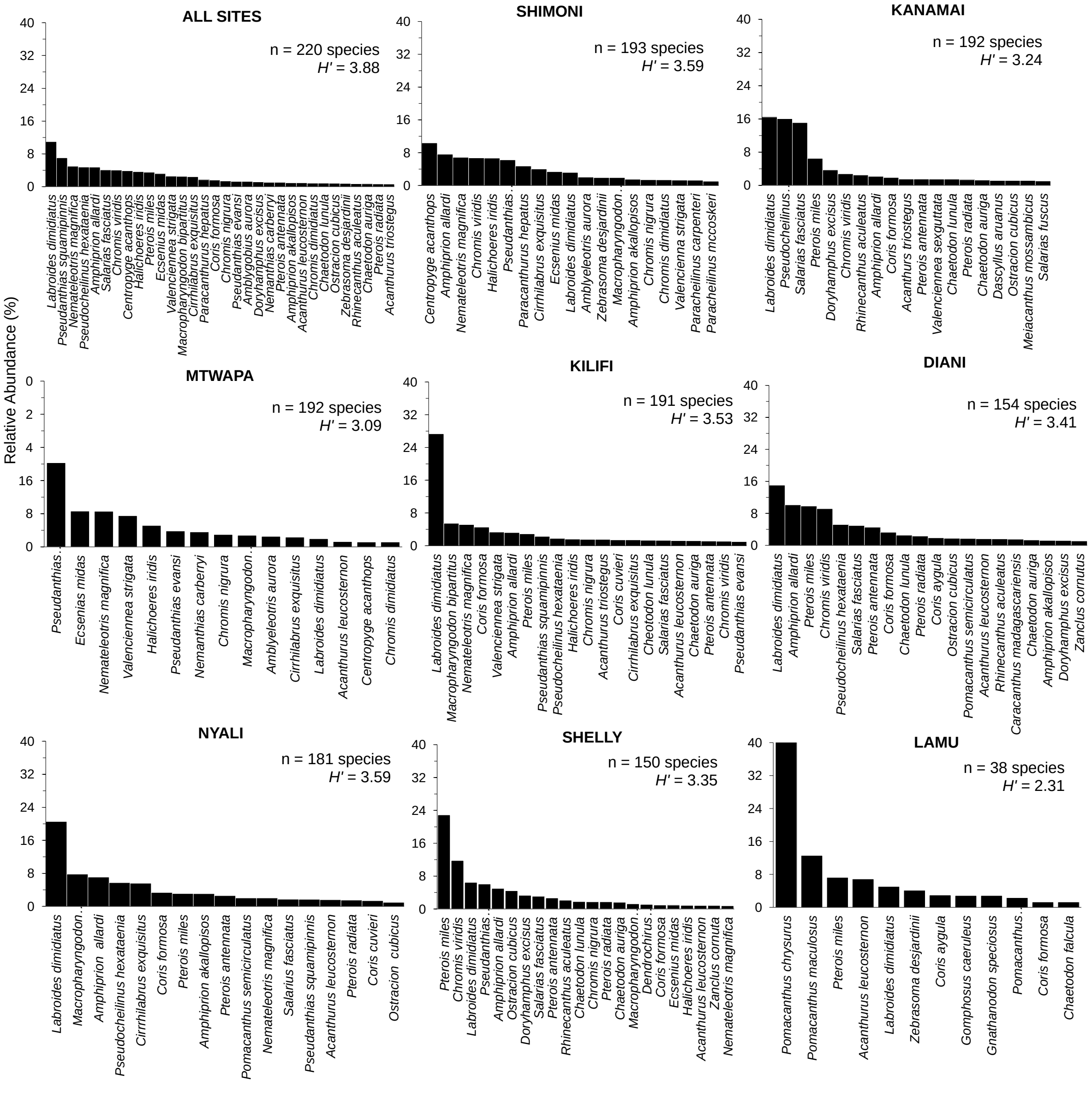


Figure 4.5. The composition of species comprising 1% or more of aquarium fisher catches from selected fishing grounds based on the total numbers of the pooled data recorded during October 2006 to December 2011

As shown in Fig. 4.5, the most commonly collected species at the study sites included the bluestreak cleaner wrasse, *Labroides dimidiatus* (11%), the sea goldie *Pseudanthias squamipinnis* (8%), the fire goby, *Nemateleotris magnifica* (5%), the sixline wrasse, *Pseudocheilinus hexataenia* (4.8%), and the two-bar anemonefish, *Amphiprion allardi* (4.8%). Among the Labridae, *L. dimidiatus* and *P. hexataenia* accounted for 34% and 15% of the total catches from all the fishing grounds, respectively; while the Pomacentridae species were dominated by *A. allardi* (36%) and *Chromis viridis* (30%). Anthiinae was dominated by *P. squamipinnis* constituting 75% of the family Serranidae. *Paracanthurus hepatus* and *Acanthurus leucosternon* constituted 31% and 16%, respectively of the Acanthuridae landed from all the fishing grounds. Pomacanthidae catches were dominated by *Centropyge acanthops* (71%), while the Blenniidae were dominated by *Salarias fasciatus (*47%) and *Ecsenius midas* (36%). Scorpaenidae catches were dominated by *Pterois miles (*60%) and *P. antennata* (17%).

Results of the Analysis of Similarity (ANOSIM) test applied to determine the difference in species catch composition between the fishing grounds showed significance ($P < 0.05$); however, the R value was low ($R = 0.34$) suggesting that the differences were not strong. Pair-wise tests between fishing grounds further revealed that strongest differences in species composition were between Lamu - Shelly, and Lamu - Kanamai both pairs showing a high R value of 0.907, while non-metric multidimensional scaling (MDS) ordination revealed three distinct groups (I, II, III) at 50% similarity having a reliable stress value of 0.1 (Fig 4.6a).

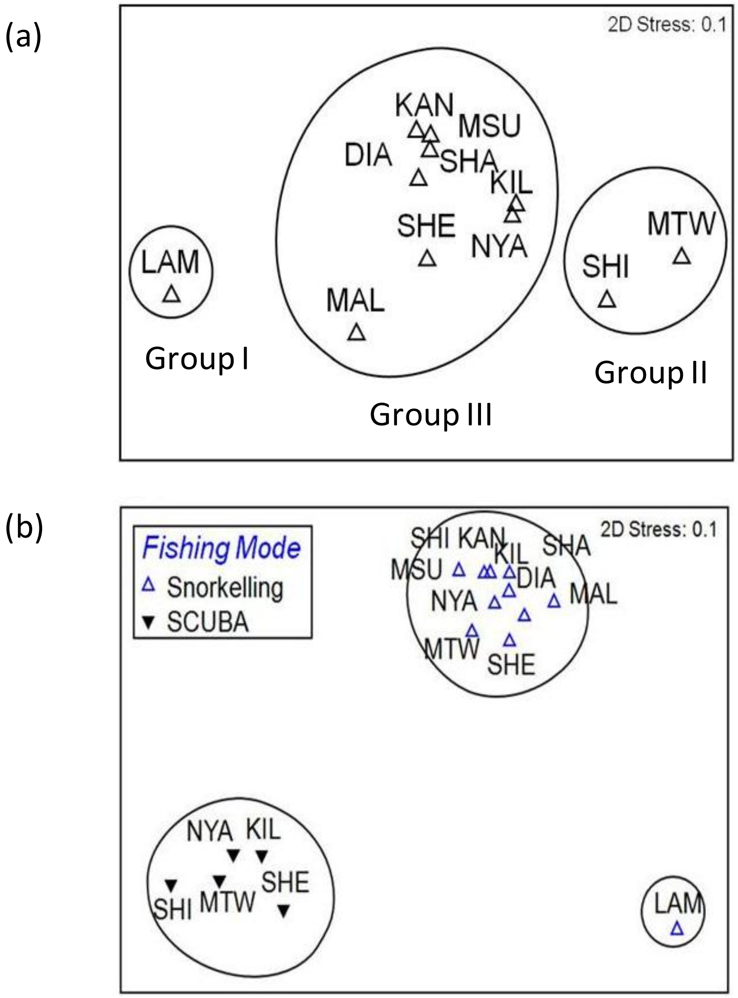


Figure 4.6. Two dimensional non-metric Multidimensional Scaling (MDS) ordination plots based on Bray-Curtis similarity of standardised square root transformed species frequency data for (a) pooled catches, and (b) mode of fishing. The contours indicate clusters identified at 50% (SHI = Shimoni, DIA = Diani, SHE=Shelly, NYA = Nyali, MTW=Mtwapa, KAN=Kanamai, MSU = Msumarini, SHA = Shariani, KIL = Kilifi, MAL= Malindi, LAM=Lamu)

Lamu (Group I) was distinctly separated from the other grounds, while Shimoni and Mtwapa (Group II) were relatively similar in composition, as were sites that formed Group III (Diani, Shelly, Nyali, Kanamai, Msumarini, Shariani, Malindi, Kilifi) (Fig. 4.6a). A second MDS ordination of the aquarium fisher catches by mode of fishing (SCUBA or snorkeling) further showed dissimilarity in the species composition of snorkel and SCUBA fisher catches in all the fishing grounds. In addition, the species composition of snorkel fisher catches from Lamu grouped as dissimilar from snorkel catches in the other fishing grounds (Fig. 4.6b).

Application of the similarities percentage (SIMPER) analysis to determine which species contributed to dissimilarities between the fishing grounds indicated that Group I and Group II were most dissimilar by 92.6%. The angelfishes *Pomacanthus chrysurus* and *P. maculosus* contributed most (about 35%) to the dissimilarities between the two groups. Dissimilarities between Group I and Group III was also due to the catches of *P. chyrusurus*, which contributed about 30% to the dissimalirity, while the cleaner wrasse *L. dimidiatus* contributed most to dissimilarities between group II and III (Table 4.1).

Exploration of the species composition of catches among fishing grounds using Detrended Correspondence Analysis (DCA) showed a spatial segregation of some species to specific fishing grounds (Fig. 4.7). Notably, the orangeback angelfish, *C. acanthops*, the surgeonfishes, *P. hepatus* and *Zebrasoma desjardinii* and the radiant wrasse *H. iridis*, were associated with Shimoni. The exquisite wrasse, *Cirrhilabrus exquisitus* and the midas blenny, *Ecsenius midas*, were associated with Shimoni and Mtwapa; *P. hexataenia* was associated with Kanamai and Msumarini, and the damselfish, *Chromis viridis*, was associated with Mtwapa, while the bluebanded goby, *Valenciennea strigata*, with Kilifi and Mtwapa (Fig 4.7).

Table 4.1.One-way SIMPER analysis of aquarium fish catches from 11 fishing grounds along the Kenya coast, showing species contributing to dissimilarity between the three groups identified by MDS (in Fig. 4.6a) based on a cumulative percentage of 70%. Group I= (Lamu), Group II = (Shimoni, Mtwapa) and Group III = (Diani, Shelly, Nyali, Kanamai, Msumarini, Shariani, Malindi, Kilifi)

Species	**Mean Abundance**		**Average Dissimilarity**	**Ratio**	**Contrib. %**
Group I vs. Group II	**Group I**	**Group II**	**Average dissimilarity = 92.59**		
Pomacanthus chrysurus	60.08	0.28	29.9	2.05	32.29
Pomacanthus maculosus	11.19	0.09	5.58	1.23	6.02
Labroides dimidiatus	3.11	11.12	5.44	0.92	5.88
Amphiprion allardi	0	8.25	4.13	0.79	4.46
Nemateleotris magnifica	0	7.49	3.75	0.91	4.05
Chromis viridis	0	6.91	3.46	0.76	3.73
Centropyge acanthops	0	6.76	3.38	0.78	3.65
Ecsenius midas	0	6.55	3.27	1.01	3.54
Zebrasoma desjardinii	6.48	2.34	3.2	1.07	3.46
Halichoeres iridis	0	5.74	2.87	0.93	3.1
Group I vs. Group III	**Group I**	**Group III**	**Average dissimilarity = 89.03**		
Pomacanthus chrysurus	60.08	0.69	29.7	2.07	33.36
Labroides dimidiatus	3.11	21.3	9.39	1.38	10.54
Pomacanthus maculosus	11.19	0.01	5.59	1.25	6.28
Pterois miles	3.99	11.35	4.8	1.28	5.39
Zebrasoma desjardinii	6.48	0.42	3.18	0.94	3.57
Chromis viridis	0	5.72	2.86	0.73	3.21
Salarias fasciatus	0.16	5.68	2.8	0.87	3.14
Amphiprion allardi	0	5.39	2.69	1.26	3.03
Acanthurus leucosternon	4.66	1.19	2.17	1.14	2.44

Table 4.1 continued

Species	**Mean Abundance**		**Average Dissimilarity**	**Ratio**	**Contrib. %**
Group II vs. Group III	**Group II**	**Group III**	**Average dissimilarity = 71.36**		
Labroides dimidiatus	11.12	21.3	8.68	1.4	12.17
Pterois miles	2.26	11.35	4.82	1.27	6.75
Chromis viridis	6.91	5.72	4.24	1.02	5.95
Nemateleotris magnifica	7.49	3.59	4.21	1.04	5.9
Amphiprion allardi	8.25	5.39	4.17	1.07	5.85
Ecsenius midas	6.55	0.81	3.26	1.04	4.57
Centropyge acanthops	6.76	0.47	3.26	0.78	4.56
Macropharyngodon bipartitus	3.68	4.21	3.03	0.99	4.24
Halichoeres iridis	5.74	1.86	2.96	1.05	4.15
Salarias fasciatus	1.23	5.68	2.74	0.93	3.83
Valenciennea strigata	4.78	1.91	2.52	0.95	3.53
Pseudocheilinus hexataenia	1.52	4.23	2.08	0.88	2.92
Paracanthurus hepatus	4.06	0.19	2.02	0.71	2.82
Cirrhilabrus exquisitus	2.2	1.65	1.58	0.85	2.22
Pseudanthias squamipinnis	2.78	0.54	1.45	0.79	2.03

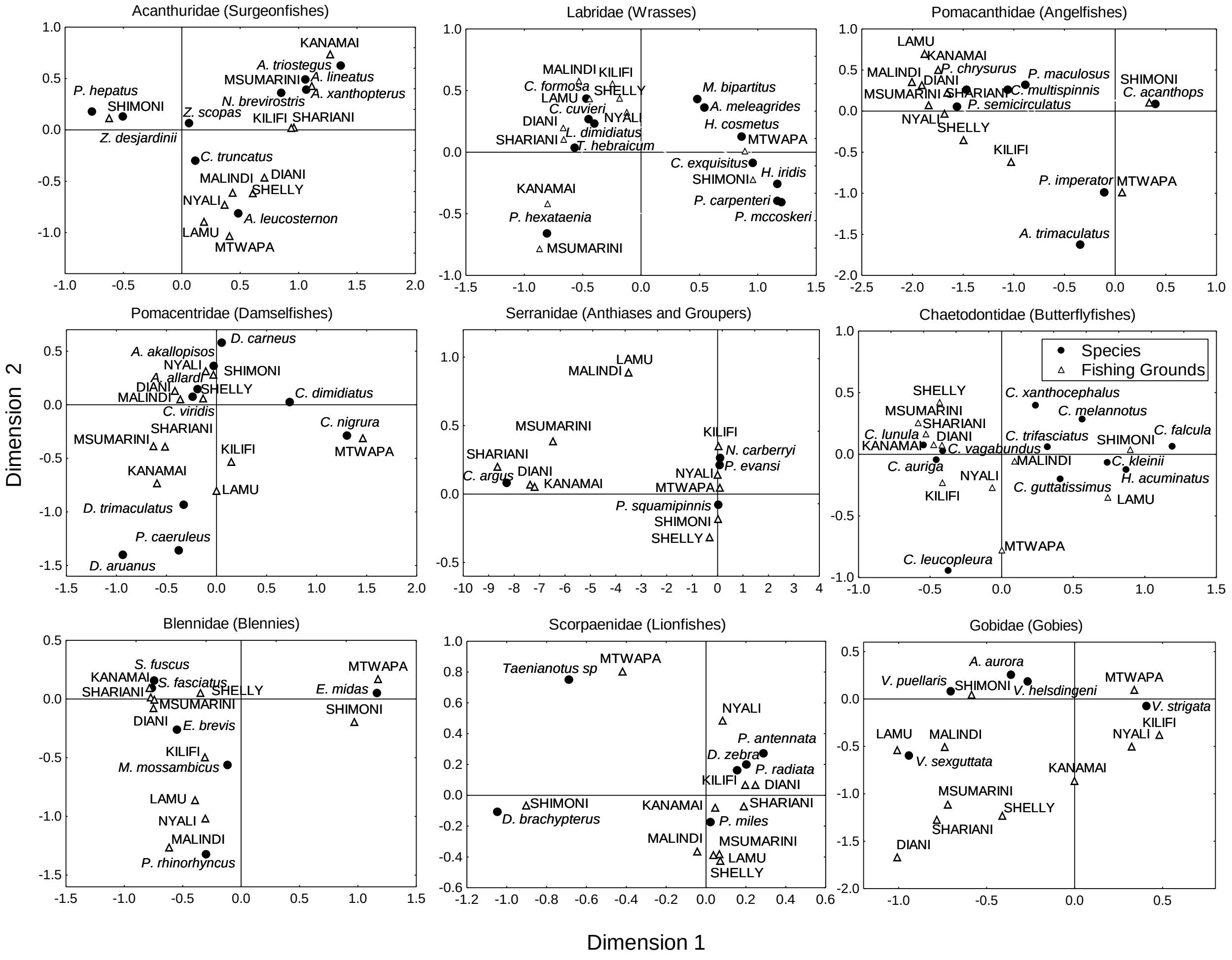


Figure 4.7. Detrended Correspondence Analysis (DCA) plot showing the association of key species (representing >1% of the total catch) with fishing grounds. Black circles = species, open triangles = fishing grounds

4.2. Vulnerability Risk Assessment of Target Species to Exploitation by the Marine Aquarium Fishery

The scoring results for productivity and susceptibility for each of the 102 species assessed in the study are presented in Appendix III. There was a strong correlation between 'average size at maturity and 'average maximum age' (r = 0.77) (Table 4.2). The strongest correlation among susceptibility attributes was observed between 'post capture mortality' and 'habitat niche' (*r* = 0.59). Hobday *et al*. (2011) recommend dropping either of two strongly correlated attributes from the analysis if the *r*-values are above 0.9 due to redundancy. All the selected attributes were therefore included in the risk assessment since the r-values for all paired correlations were below 0.9 (See Fig. 4.8 and in Appendix III).

The risk scores for the productivity attributes ranged from 1.13 to 2.50 with an average score of 1.62, while the risk scores for the susceptibility attributes ranged from 1.02 to 3.00 with an average of 1.32. The derived vulnerability risk values ranged from a low risk value of 1.57 to a high-risk value of 3.68 (Appendix III), with an average low risk value of 2.12. Pomacanthidae had the highest vulnerability risk at family level, having a mean value of 2.68 ± 0.73SD (n = 8), followed by Microdesmidae (represented by one species, *N. magnifica*, species #10 in Fig. 4.8) with a value of 2.66. The fish families that ranked least vulnerable to overexploitation included Syngnathidae, represented by one species *Doryhamphus excises*, which had a vulnerability risk ranking of 58 and a risk value of 1.70; and the Blenniidae which had a mean vulnerability risk value of 1.75 (n = 6).

Table 4.2. A Pearson correlation matrix of the productivity and susceptibility scores for 102 aquarium fish species assessed. The correlation (r) values shown in bold were significant (p<0.05).

Productivity attributes:	Overall mean score	Std. Dev	Av. max. age	Min. pop. doubling time	Fecundity	Av. max. size	Av. size at maturity	von Bertalanffy (K)	Reproductive strategy	Trophic level
Av. max. age	1.86	0.51	-	0.06	0.18	**0.34**	**0.42**	**0.51**	-0.10	0.10
Min. pop. doubling time	2.70	10.05	0.06	-	0.02	-0.03	-0.04	-0.02	0.14	0.02
Fecundity	1.91	0.73	0.18	0.02	-	0.00	0.07	-0.06	-0.05	-0.15
Av. max. size	1.43	0.64	**0.34**	-0.03	0.00	-	**0.77**	**0.45**	**-0.30**	-0.06
Av size at maturity	1.42	0.55	**0.42**	-0.04	0.07	**0.77**	-	**0.55**	**-0.34**	0.03
von Bertalanffy (K)	1.35	0.61	**0.51**	-0.02	-0.06	**0.45**	**0.55**	-	**-0.24**	**0.35**
Reproductive strategy	1.26	0.44	-0.10	0.14	-0.05	**-0.30**	**-0.34**	**-0.24**	-	-0.10
Trophic level	1.98	0.54	0.10	0.02	-0.15	-0.06	0.03	**0.35**	-0.10	-

Susceptibility attributes:	Overall mean score	Std. Dev	Availability	Encounterability : depth	Encounterability: habitat niche	Desirability / market value	Post capture mortality
Availability	1.41	0.65	-	0.11	**0.29**	**0.37**	**0.19**
Encounterability: depth	2.94	0.34	0.11	-	-0.05	-0.04	-0.12
Encounterability: habitat niche	1.81	0.67	**0.29**	-0.05	-	0.11	**0.59**
Desirability/market value	2.16	0.81	**0.37**	-0.04	0.11	-	0.11
Post capture mortality	**0.19**	-0.12	**0.59**	0.11	1.00	**0.19**	-0.12

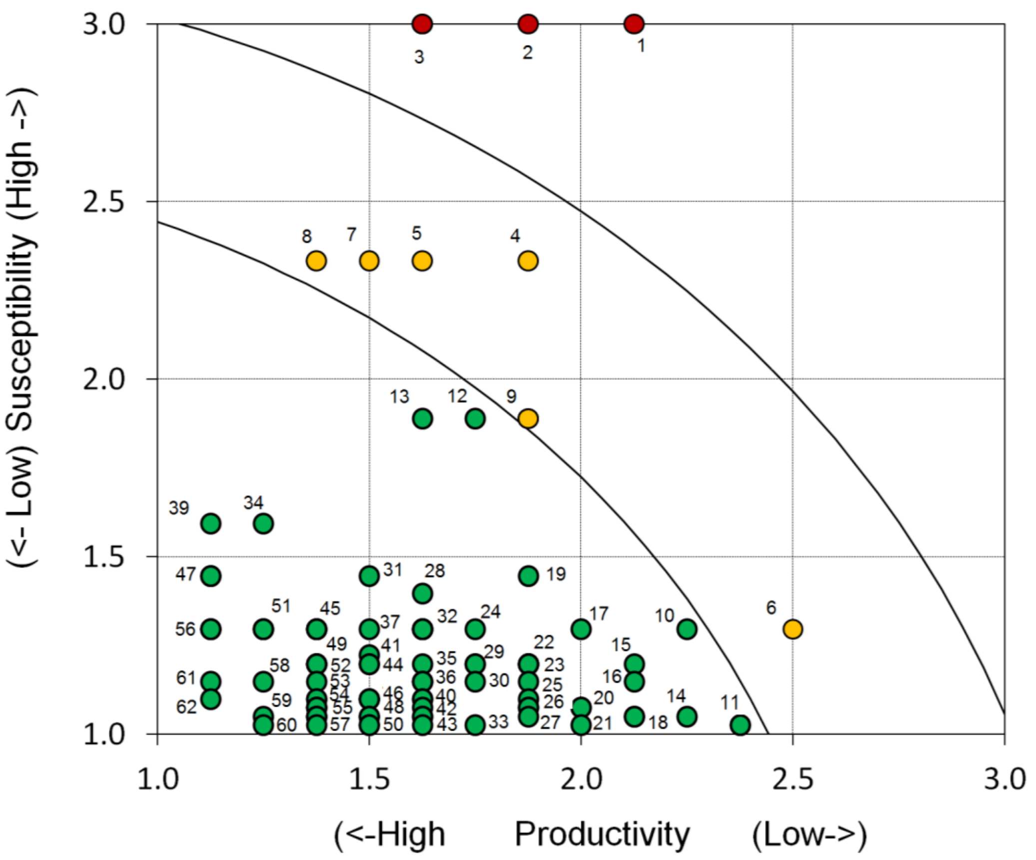


Figure 4.8. A Productivity Susceptibility Analysis (PSA) bi-plot showing the risk scores of 102 fish species targeted by the marine aquarium fishery in Kenya. Curved lines indicate divisions into equal thirds of the plot area showing species at low risk (<2.64), medium risk (2.64 – 3.18) and high risk (> 3.18). The colours indicate the vulnerability risk represented as green (low), yellow (medium) and red (high risk). The top 15 species with the highest vulnerability risk to overexploitation include *Pomacanthus maculosus*[1], *Pomacanthus chrysurus*[2], *Amphiprion akallopisos*[3], *Amphiprion allardi*[3], *Pomacanthus imperator*[4], *Pygoplites diacanthus*[5], *Coris aygula*[6], *Paracanthurus hepatus*[7], *Halichoeres iridis*[8], *Nemateleotris magnifica*[9], *Pomacanthus semicirculatus*[9], *Pterois miles*[10], *Cephalopholis miniata*[11], *Gnathanodon speciosus*[11], *Zebrasoma desjardinii*[12]

The vulnerability risk rankings of the top 15 species from highest to lowest risk are presented in Table 4.3. Four species with vulnerability risk values ranging from 3.41 and above ranked as **highly vulnerable** to overexploitation included the Yellowbar angelfish, *P. maculosus* (vulnerability risk ranking = 1), the Goldtail angelfish, *P. chrysurus* (vulnerability risk ranking = 2), the anemonefish, *A. allardi* and the Skunk clownfish, *Amphiprion akallopisos* (both having a vulnerability risk ranking = 3). Seven species ranked as **medium risk** to overfishing by the aquarium fishery. This included the angelfishes; *Pomacanthus imperator*, *Pygoplites diacanthus* and *Pomacanthus semicirculatus* (vulnerability risk ranking = 4, 5, and 9, respectively) (see Fig. 4.8), the wrasses *Coris aygula* and *H. iridis* (vulnerability risk ranking = 6 and 8, respectively), the surgeonfish *P. hepatus* (vulnerability risk ranking = 7), and goby *N. magnifica* (vulnerability risk ranking = 9) (see Fig. 4.8). **Low risk** species that were at the borderline with vulnerability risk values below 2.64 included the scorpionfish, *P. miles* (vulnerability risk ranking = 10), the grouper, *Cephalopholis miniata* and the trevally, *Gnathanodon speciosus* (both with a risk ranking = 11) and the surgeonfish, *Zebrasoma desjardinii* (vulnerability risk ranking = 12).

Table 4.3. Results of Productivity and Susceptibility Analysis (PSA) showing the risk score and vulnerability risk ranking of the top 15 species. The full list and scores for 102 species assessed is shown in Appendix III. The scoring criteria used to score each attribute were: 1=low risk, 2= medium risk, and 3 = high risk, NB: Species that tied with similar overall vulnerability risk values received the same risk ranking

Latin Name	Common Name	Productivity risk score	Susceptibility Risk score	Overall vulnerability risk value	Overall risk category	Vulnerability risk ranking
Pomacanthus maculosus	Yellowbar angelfish	2.13	3.00	3.68	High	1
Pomacanthus chrysurus	Goldtail angelfish	1.88	3.00	3.54	High	2
Amphiprion akallopisos	Skunk clownfish	1.63	3.00	3.41	High	3
Amphiprion allardi	Twobar anemonefish	1.63	3.00	3.41	High	3
Pomacanthus imperator	Emperor angelfish	1.88	2.33	2.99	Medium	4
Pygoplites diacanthus	Regal angelfish	1.63	2.33	2.84	Medium	5
Coris aygula	Clown coris	2.50	1.30	2.82	Medium	6
Paracanthurus hepatus	Palette surgeonfish	1.50	2.33	2.77	Medium	7
Halichoeres iridis	Rainbow wrasse	1.38	2.33	2.71	Medium	8
Nemateleotris magnifica	Fire dartfish	1.88	1.89	2.66	Medium	9
Pomacanthus semicirculatus	Semicircle angelfish	1.88	1.89	2.66	Medium	9
Pterois miles	Devil firefish	2.25	1.30	2.60	Low	10
Cephalopholis miniata	Coral hind	2.38	1.02	2.59	Low	11
Gnathanodon speciosus	Golden trevally	2.38	1.02	2.59	Low	11
Zebrasoma desjardinii	Desjardin's sailfin tang	1.75	1.89	2.57	Low	12

4.3. Gear-based Overlaps in Species Selectivity and Potential Interactions betweenArtisanal and Aquarium Fisheries at the Southcoast of Kenya

4.3.1. Species Composition and Diversity of Fish Catches

During January to December 2014, 7,786 fish were sampled from the artisanal landings in the Shimoni area at the southcoast of Kenya. The sampled artisanal landings constituted 52 families and 230 species, dominated by; Lethrinidae (20%), Atherinidae (10.3%), Siganidae (9%), Scaridae (9%), Lutjanidae (8.2%) and Labridae (6%) by weight; and the most abundant species by landed weight included: *Lethrinus lentjan* (7.6%), *Siganus sutor* (7.1%), *Lutjanus fulviflamma* (6.5%), *Leptoscarus vaigiensis* (5.5%), *Lethrinus borbonius* (5.3%) and *Lethrinus harak* (4.2%) (Fig. 4.9a).

A total of 2,033 aquarium fish constituting 183 species were recorded during monitoring of aquarium fisher landings at Shimoni from September 2010 to March 2013. Twenty three species composed 90% of the landings by number (Fig. 4.9b), dominated by the angelfish *Centropyge acanthops* (21%). Seven other species; the anthias *P. squamipinnis,* the anemonefish *A. allardi,* the damselfish *C. viridis,* the rainbow wrasse *H. iridis,* the surgeonfish *P. hepatus,* the dartfish *N. magnifica,* and the blenny, *Ecsenius midas,* made up about 6 - 8% each of the total catches or collectively about 50% (Fig. 4.9b).

Handlines captured the highest total number of species (145 species, n = 2539), and also had the highest species diversity (*H'* = 3.62), and highest average number of species per day (13 species/day, n = 33) (Table 4.4). This was followed by basket traps (104 species, 11 species/day, *H'= 3.25*) and spearguns (88 species, 8 species/day, *H'=3.07*); while cast nets and ringnets had the lowest number of species. Pielou's evenness (J') index averaged at about 0.71 for all the gears, and ranged from 0.46 for cast nets to 0.94 for ringnets (Table 4.4).

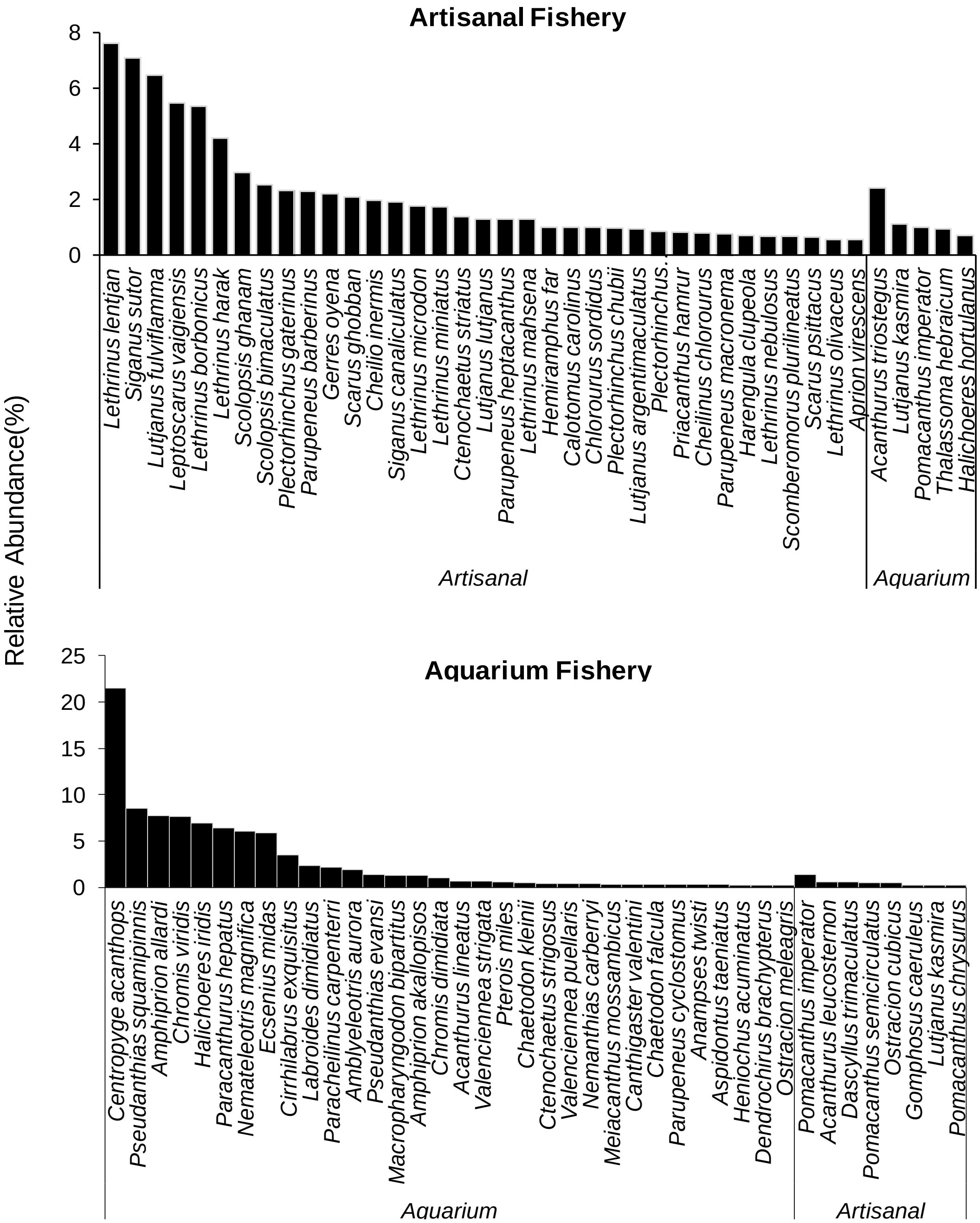


Figure 4.9. The relative abundance (by number) of the 40 most abundant reef fish species landed in Shimoni, southcoast of Kenya by (a) artisanal fishers and (b) aquarium fishers showing species that overlapped in both fisheries.

Generally, aquarium snorkel fishers captured more species compared to SCUBA fishers, and also captured more species daily on average (10 species/day compared to 8 species/day for SCUBA fishers) (see Table 4.4). However, the SCUBA fishers captured a slightly higher diversity of species (*H’* = 2.71) compared to snorkel fishers (*H’*=2.67). The diversity index for both the aquarium fishing methods was generally comparable to that of artisanal reef seines (*H’* = 2.60) and gillnets (*H’*=2.59).

Table 4.4. The diversity of artisanal and aquarium fisher catches in Shimoni Kenya, during January to December 2014 based on community indices: number of species (S), Margalef’s species richness (D), Shannon-Weiner diversity index (*H’*) and Pielou’s evenness (*J’*)

Fishery	Gears/ Methods	Number of fish sampled	Average length of fish (cm)	S	(D)	(*J*')	(*H*')	Average number of species
Artisanal fishery	Handlines	2539	22	145	18.37	0.73	3.62	13, n =
	Basket traps	1732	20	104	13.81	0.70	3.25	11, n =
	Spearguns	904	23	88	12.78	0.68	3.07	8, n =
	Monofilament	229	23	45	8.10	0.77	2.93	18, n =
	Reef seines	687	20	47	7.04	0.68	2.60	6, n =
	Gillnets	391	27	38	6.20	0.71	2.59	4, n =
	Cast nets	678	11	3	0.31	0.46	0.51	2, n = 3
	Ringnets	58	58	2	0.25	0.94	0.65	1, n = 2
Aquarium fishery	SCUBA		-	106	10.65	0.58	2.71	8, n =
	Snorkeling		-	122	12.4	0.55	2.67	10, n =

n = number of individuals

4.3.2. Overlaps in Species Selectivity between Gears and Fisheries

A cluster analysis of the species composition of artisanal catches for the main gear types used in Shimoni identified three distinct clusters of gear types at 20% similarity: basket traps, handlines, gillnets, spearguns, monofilament gillnets and reef seines (Group I), ringnets (Group II), and castnets (Group III) (Fig. 4.10). However, the SIMPROF test revealed that the sub-structure grouping of handlines with basket traps and spearguns with monofilament nets in Group I was not statistically significant ($p < 0.05$) as separate groups.

Pair-wise comparisons among the Group I artisanal gear types using Pianka's niche overlap index showed partial overlaps in species selectivity among all the gear types (Table 4.5). Basket traps and monofilament nets had the strongest overlap in species composition ($O = 0.722$), followed by basket traps and gillnets ($O = 0.549$), and basket traps and handlines ($O = 0.545$). The lowest overlap in species selectivity was between spearguns and gillnets ($O = 0.176$).

Pair-wise comparisons between the two fisheries showed that handlines and spearguns of the artisanal fishery had the highest overlap in species selectivity with the aquarium fishery, and that snorkel fishers had the highest overlap with artisanal gears (Table 4.5). Of the 7,786 fish sampled in the artisanal catches, 660 (8%) constituted species targeted by aquarium fishers, with a total of 57 species and 17 families overlapping between the two fisheries (see Appendix V for the full list of species). Aquarium species captured in artisanal gears were dominated by Labridae (31%, 19 species), followed by Acanthuridae (28%, 9 species), Pomacanthidae (12%, 3 species), Lutjanidae (11%, 2 species), and Pomacentridae (5%, 7 species) (Table 4.6).

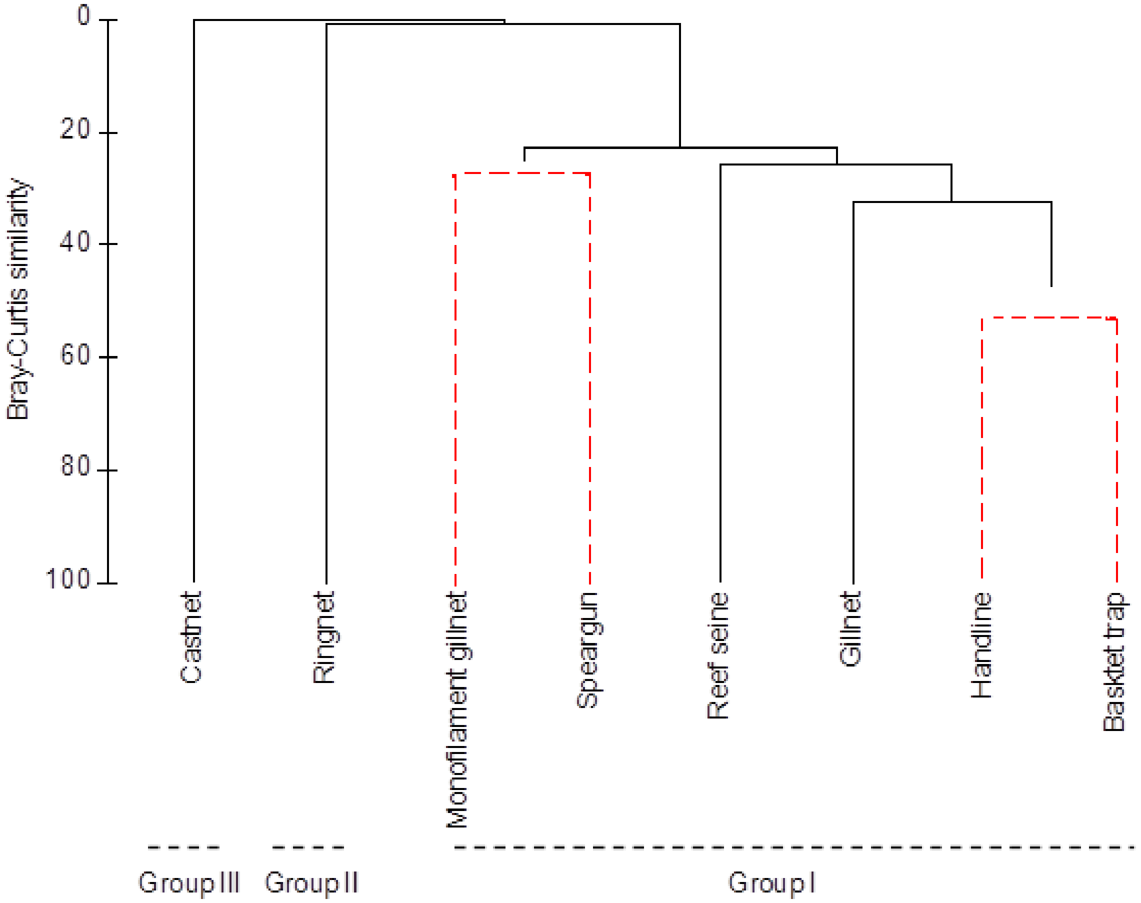


Figure 4.10. A cluster analysis dendrogram showing the similarity in species composition of 8 commonly used artisanal gear types used in Shimoni, Kenya. Dashed lines indicate sub-clusters that were not detected as significant by the similarity profile (SIMPROF) test ($p < 0.05$)

Table 4.5. A pair-wise matrix showing overlaps in species selectivity among the main artisanal fishing gear types and aquarium fishing methods in Shimoni, Kenya, based on Pianka's niche overlap (*Oi*) index which ranges between 0 (total separation) and 1 (total overlap)

	Handline	Basket trap	Speargun	Reefseine	Gillnet	Monofilament gillnet	Aquarium SCUBA fishing	Aquarium snorkel fishing
Handline		0.545	0.233	0.392	0.453	0.334	0.002	0.039
Basket trap			0.415	0.469	0.549	0.722	0.0001	0.005
Speargun				0.326	0.176	0.418	0.012	0.017
Reefseine					0.368	0.351	0.001	0.009
Gillnet						0.403	0.0001	0.002
Monofilament gillnet							0.0003	0.003
Aquarium SCUBA fishing								0.016

Table 4.6. The relative abundance and number of aquarium species captured by artisanal gears among 17 fish families in Shimoni area, Kenya

Family (Number of species)	Total number	%
Labridae (19)	206	31
Acanthuridae (9)	188	28
Pomacanthidae (3)	78	12
Lutjanidae (2)	70	11
Pomacentridae (7)	32	5
Siganidae (1)	29	4
Balistidae (3)	20	3
Zanclidae (1)	10	2
Chaetodontidae (2)	8	1
Mullidae (1)	4	1
Dasyatidae (1)	4	1
Carangidae (1)	3	0
Ostraciidae (1)	3	0
Cirrhitidae (1)	2	0
Malacanthidae (1)	1	0
Ephippidae (1)	1	0
Plotosidae (1)	1	0

The most abundant aquarium species captured in the artisanal gears included *Acanthurus triostegus* (reef seines), *Lutjanus kasmira* (handlines), *Pomacanthus imperator* (spearguns) and *Thalassoma hebraicum* (handlines and reef seines) (Fig. 4.11).

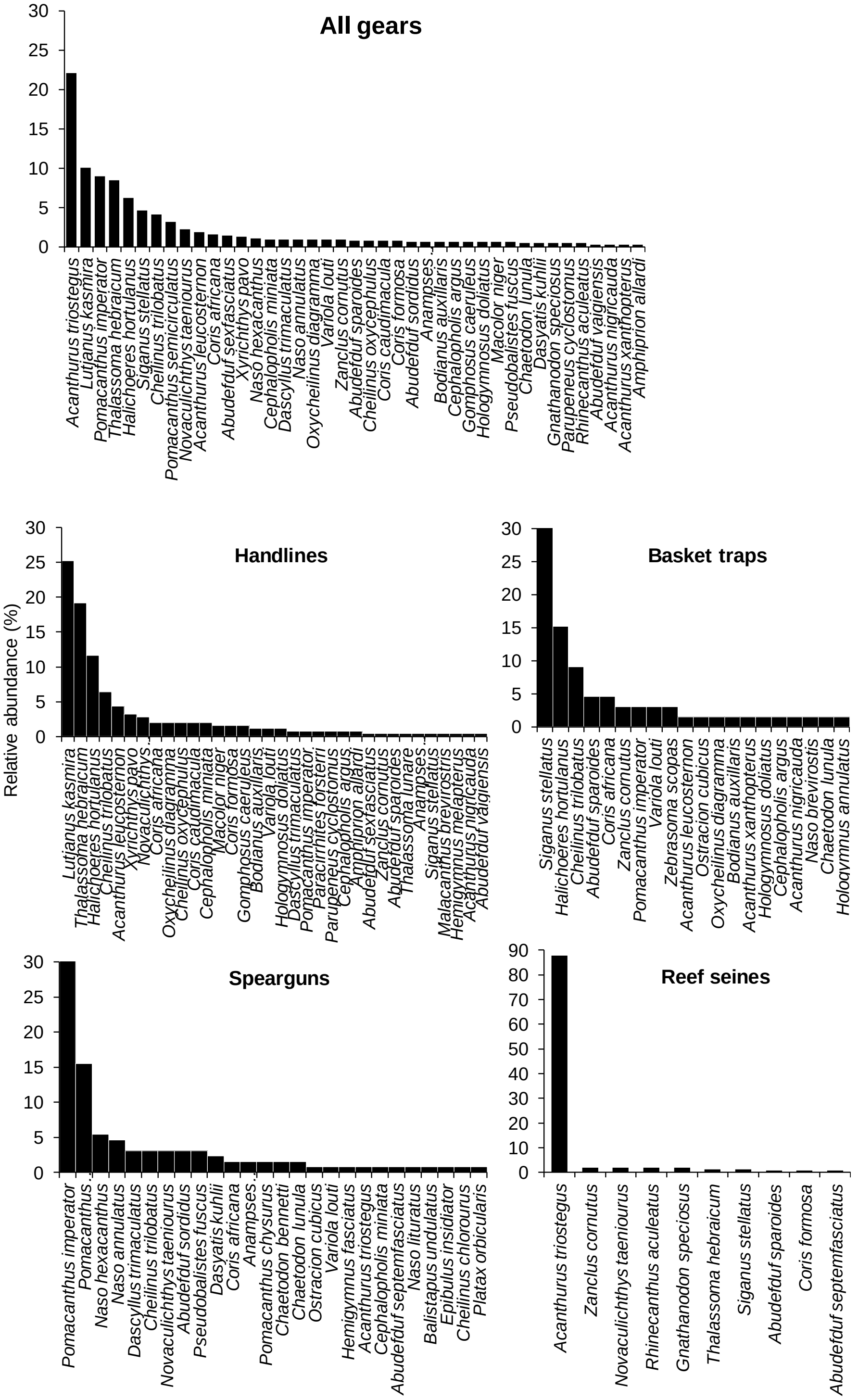


Figure 4.11.The relative abundance by number of aquarium species captured by the four main artisanal gear types used in Shimoni area, Kenya

K-dominance curves revealed that a higher dominance of aquarium species were captured in artisanal gears, particularly among reef seines, gillnets and monofilament nets (Fig. 4.12). Similarly, aquarium SCUBA catches had a higher species dominance compared to the catches of aquarium snorkel fishes. Detrended correspondence analysis (DCA) associating the aquarium species with artisanal gear types distinctly separated the species composition of reef seines from all the other gear types (Fig. 4.13).

The composition of aquarium species captured by handlines was also distinct from spearguns; while aquarium species captured by gillnets, monofilament gillnets and basket traps grouped together indicating that the three gear types had high overlaps in selectivity for aquarium species (Fig. 4.13). DCA Ordination also showed the angelfishes, *Pomacanthus imperator* and *Pomacanthus semicirculatus* to be strongly associated with spearguns, while the wrasses *Halichoeres hortulanus* and *Thalassoma hebraicum,* and the surgeonfish, *Acanthurus leucosternon* were strongly associated with handlines. Reef seines were strongly associated with the surgeonfish *Acanthurus triostegus*, while gillnets, monofilament nets and basket traps were associated with diverse species (Fig. 4.13).

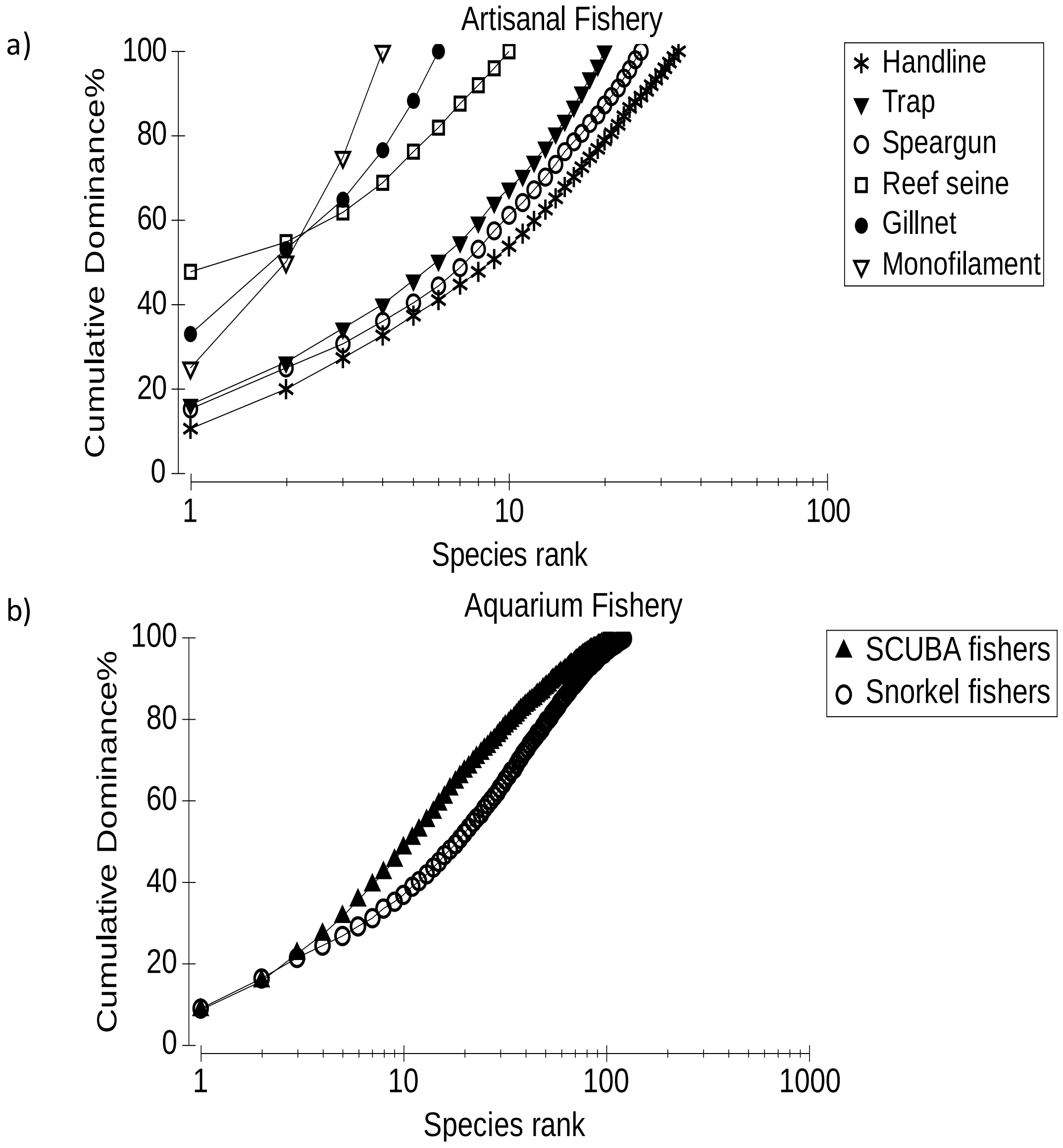
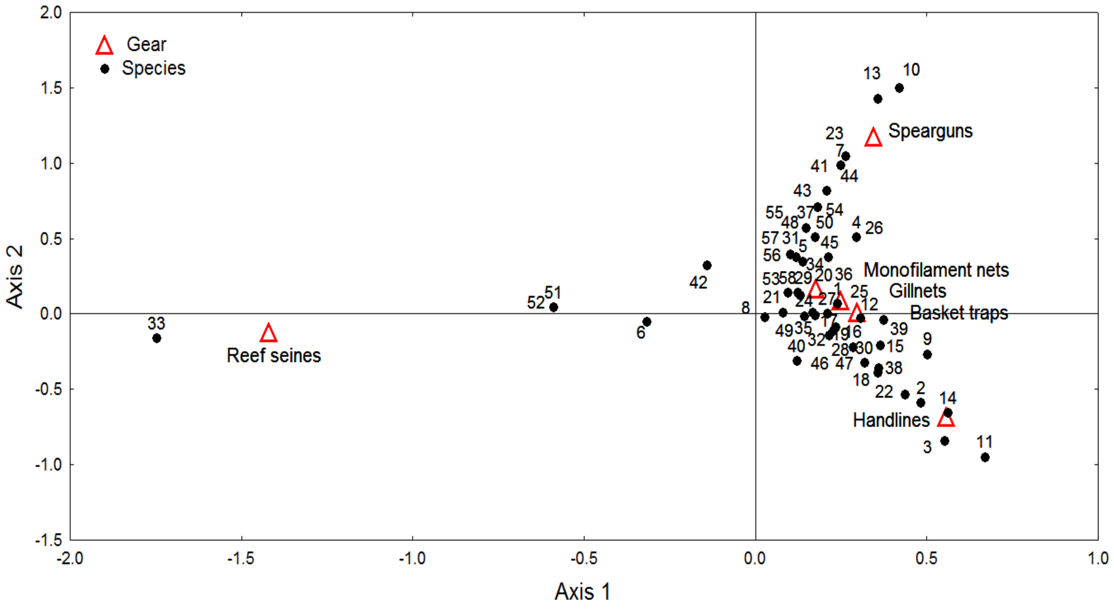


Figure 4.12. K-Dominance curves of (a) artisanal fishing gears based on the composition of aquarium species captured and (b) aquarium fishing methods in Shimoni area, Kenya



1 *Abudefduf sexfasciatus*
2 *Acanthurus leucosternon*
3 *Thalassoma hebraicum*
4 *Dascyllus trimaculatus*
5 *Ostracion cubicus*
6 *Zanclus cornutus*
7 *Naso annulatus*
8 *Abudefduf sparoides*
9 *Cheilinus trilobatus*
10 *Pomacanthus imperator*
11 *Lutjanus kasmira*
12 *Coris africana*
13 *Pomacanthus semicirculatus*
14 *Halichoeres hortulanus*
15 *Oxycheilinus diagramma*
16 *Bodianus auxillaris*
17 *Paracirrhites forsterri*
18 *Cheilinus oxycephulus*
19 *Parupeneus cyclostomus*
20 *Acanthurus xanthopterus*
21 *Novaculichthys taeniourus*
22 *Xyrichthys pavo*
23 *Naso hexacanthus*
24 *Thalassoma lunare*
25 *Variola louti*
26 *Anampses caeruleopunctatus*
27 *Siganus stellatus*
28 *Hologymnosus doliatus*
29 *Malacanthus brevirostris*
30 *Macolor niger*
31 *Hemigymnus fasciatus*
32 *Cephalopholis argus*
33 *Acanthurus triostegus*
34 *Hemigymnus melapterus*
35 *Acanthurus nigricauda*
36 *Zebrasoma scopas*
37 *Pomacanthus chysurus*
38 *Coris caudimacula*
39 *Cephalopholis miniata*
40 *Coris formosa*
41 *Abudefduf sordidus*
42 *Abudefduf septemfasciatus*
43 *Dasyatis kuhlii*
44 *Pseudobalistes fuscus*
45 *Naso lituratus*
46 *Amphiprion allardi*
47 *Gomphosus caeruleus*
48 *Balistapus undulatus*
49 *Abudefduf vaigiensis*
50 *Epibulus insidiator*
51 *Rhinecanthus aculeatus*
52 *Gnathanodon speciosus*
53 *Naso brevirostis*
54 *Chaetodon bennetti*
55 *Chaetodon lunula*
56 *Cheilinus chlorourus*
57 *Platax orbicularis*
58 *Hologymnus annulatus*

Figure 4.13. Detrended Correspondence Analysis (DCA) plot of artisanal fishery catches indicating association with aquarium species captured in the main artisanal gear types used in Shimoni area, Kenya

4.3.3. Spatial Distribution of Fishing Effort among Fishing Grounds

Ninety three percent (93%) of the 660 aquarium fish captured by artisanal gears were fished from 6 fishing grounds: Mpunguti (30%), Mkwiro (26%), Kitugamwe (11%), Nyuli (11%), Waga (7%) and Mwamba mkuu (7%), respectively (Table 4.6, see Fig. 3.2 for locations). In terms of fishing effort, artisanal fishers mainly fished in two fishing grounds: Nyuli (125 fisher days, 26% of fishing effort) and Mpunguti (121 fisher days, 25% of fishing effort); while the fishing grounds having the least fishing effort included Mijira, Nyuma ya maji and Mnarani (see Fig. 3.2 for locations). The fishers captured the highest number of aquarium species from Mpunguti (39 species) and the lowest in Jiwe jahazi (3 species).

DCA ordination associated use of handlines, basket traps, and spearguns with Mpunguti (including the reserve area), Mkwiro, Waga, and Jiwe jahazi; while use of reef seines and cast nets were mainly associated with Mwamba mkuu, Sii Island and Chumani fishing grounds (Fig. 4.14). Among the aquarium fishers, the ordination showed a clear separation in the use of fishing grounds between SCUBA and snorkel fishers. SCUBA fishers concentrated 92% (1443 fisher days) of their fishing effort in Nyuli, collecting 95% of the total number of fish and 84 species (Table 4.7).

On the other hand, aquarium snorkel fishers utilized more diverse fishing grounds, with the five most frequented grounds including Chumani, Sii Island, Mwamba mkuu, Mkwiro and Mwipwa; and they collected the highest number of aquarium species from three fishing grounds: Mwamba mkuu (65 species), Sii Island (63 species) and Mkwiro (60 species) collectively constituting 52% of the total number of fish collected.

Table 4.7. The proportion of aquarium fish species captured by artisanal fishers within fishing grounds in Shimoni area Kenya, during January to December 2014

Fishery	Fishing grounds	Fisher Days (Effort)	No. of aquarium species in catches	Total no. of aquarium fish in sampled catches	Proportional abundance of aquarium fish (%)
Artisanal fishers	Mpunguti	121	39	194	30.1
	Mkwiro	40	17	170	26.4
	Kitugamwe	53	11	73	11.3
	Nyuli	125	20	72	11.2
	Waga	59	19	47	7.3
	Mwamba mkuu	37	15	43	6.7
	Mwipwa	2	7	12	1.9
	Sii Island	12	2	3	0.5
	Mijira	4	1	2	0.3
	Mnarani	4	2	9	1.4
	Kibuyuni	6	5	7	1.1
	Nyuma ya maji	4	5	9	1.4
	Jiwe jahazi	12	3	4	0.6
Aquarium snorkel fishers	Chumani	191	59	343	21.8
	Sii Island	163	63	328	20.8
	Mwamba mkuu	143	65	273	17.3
	Mwipwa	139	55	246	15.6
	Mkwiro	42	60	219	13.9
	Mundini	27	29	45	2.9
	Kibuyuni	12	24	39	2.5
	Jiwe Jahazi	52	25	40	2.5
	Funzi	11	18	22	1.4
	Nyuma ya maji	12	11	11	0.7
	Nyuli	24	9	10	0.6
Aquarium SCUBA fishers	Nyuli	1443	84	2741	94.7
	Mpunguti	12	5	5	0.2
	Mwamba mkuu	10	19	19	0.7
	Waga	59	26	89	3.1
	Funzi	39	18	40	1.4

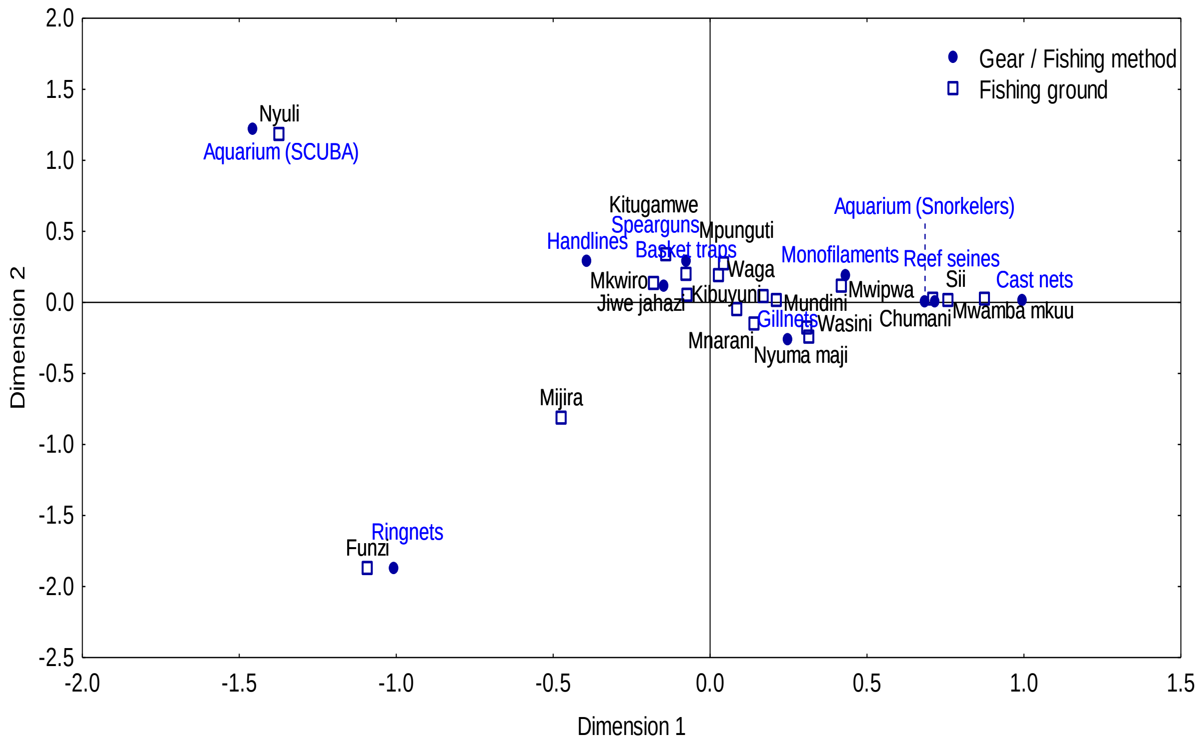


Figure 4.14. **Detrended Correspondence Analysis (DCA) plot showing the spatial association of artisanal gear types and aquarium fishing methods with fishing grounds in Shimoni area, Kenya**

4.4. Recruitment of Juvenile Coral Reef Fishes in Coastal Kenya

4.4.1. Spatial Patterns of Recruitment

A total of 24,946 recruits (as defined in section 3.3.4) were recorded, comprising 15 families and 112 species were recorded during the underwater visual census surveys conducted for 10 months between February 2013 and February 2015 in Kilifi, Sii, Mwipwa and Wasini, and for 30 months in Kuruwitu between June 2012 and March 2016. A checklist of the species recorded as recruits and juveniles is provided in Appendix VI. Families with the highest number of species recruiting included the Pomacentridae with 23 species, followed by Labridae (20 species), Chaetodontidae (10 species), Scaridae (7 species) and Acanthuridae (7 species).

Collectively, 25 species constituted 1% or more of the total number of recruits. The most abundant species recruiting overall were the damselfishes, *Chromis viridis* and *Neopomacentrus azysron,* the wrasses *T. hebraicum* and *Gomposus caeruleus*, and the cardinalfish *Ostorhinchus cookii*, which altogether comprised 60% of the total number of recruits recorded (Table 4.8). The highest number of species recruiting was recorded in Kuruwitu (67 species), and the lowest number was in Mwipwa (46 species) (Fig. 4.15). The damselfish, *C. viridis*, was the most abundant species recruiting in Kuruwitu (25%), Kilifi (27%) and Wasini (63%) (Table 4.8).

Table 4.8. Relative abundance (%) of reef fish recruits at the five study sites for the 25 most abundant species and the associated community diversity indices

Species	Relative Abundance (%)				
	Kilifi	Kuruwitu	Mwipwa	Sii Island	Wasini
Chromis viridis	27	25	0	7	63
Neopomacentrus azysron	0	0	0	59	0
Thalassoma hebraicum	7	16	5	0	3
Apogon cookii	2	12	0	0	0
Gomphosus caeruleus	2	10	4	1	2
Scarus mixed sp	1	5	13	1	1
Neopomacentrus cyanomos	0	0	0	13	0
Ptereleortris evides	0	0	24	9	0
Chrysiptera unimaculata	1	5	0	0	0
Dascyllus aruanus	0	4	0	0	3
Thalassoma amblycephalus	10	3	0	0	1
Cheilodipterus quinquilineatus	6	0	2	0	9
Abudefduf vaigiensis	0	3	3	0	0
Siganus sutor	11	0	0	3	0
Halichoeres scapularis	0	2	0	0	0
Ctenochaetus striatus	4	1	5	0	3
Stethojulis albovittata	2	2	0	0	0
Thalassoma hardwicke	0	2	2	0	0
Stegastes nigricans	0	1	3	0	1
Plectroglyphidodon lacrymatus	2	1	3	1	0
Scarus psittacus	0	1	1	0	0
Zebrassoma scopas	0	0	12	0	0
Chaetodon trifasciatus	0	0	1	1	2
Labroides dimidiatus	2	1	0	0	0
Dascyllus trimaculatus	1	0	0	0	2
Number of species (S)	57	67	45	49	54
Margalef's species richness D	7.56	7.08	5.86	5.69	6.59
Pielou's evenness *J'*	0.69	0.61	0.48	0.40	0.43
Shannon-Wiener Diversity *H'*	2.82	2.56	1.85	1.58	1.72

Recruits of the damselfishes *N. azysron* and *Neopomacentrus cyanomos* were most abundant in Sii Island, representing (59%) and (13%) of the total respectively (Table 4.8). In Mwipwa, the most abundant species recruiting was the dartfish *Ptereleotris evides* Scaridae species and the surgeonfish *Z. scopas*. Pomacentridae species *N. azysron* and *C. viridis*, and *P. evides* recruits were in high abundance at the two sties likely due to the tendency to aggregate in very large numbers.

In terms of the community structure of the recruits, the highest species richness and diversity was at Kilifi, while the lowest was at Sii Island (Table 4.8). The highest species evenness was at Mwipwa while the lowest was at Wasini and Sii Island (Table 4.8). The results of a Kruskal-Wallis multiple (post-hoc) test comparing the species richness of recruits between the study sites showed no significant differences (*H'* = 6.55; p = 0.16). However, significant differences in species diversity were observed between Sii Island and Kuruwitu (*H'* = 14.8, p = 0.005). The test further showed significant differences in the mean species evenness between study sites (*H*' =13.1, p = 0.011) with pair-wise comparisons between Wasini which had the highest species evenness (*J'* = 0.71) and Kilifi which had the lowest (*J'* = 0.46) revealing boardline statistical significance (p = 0.047).

The *K*-dominance curves showed slightly elevated curves for the southcoast sites i.e. Sii Island, Wasini and Mwipwa, compared to the northcoast sites (Kuruwitu and Kilifi) indicating higher species dominance of recruits in the offshore fringing reef sites (Fig. 4.15). Further exploration of spatial patterns using non-metric multidimensional scaling (MDS) grouped Kuruwitu and Kilifi together as most similar in species composition at a 40% level of similarity, while Wasini slightly overlapped with Kuruwitu and Kilifi (Fig. 4.16a). However, Sii Island and Mwipwa separated distinctly from the rest of the sites. The stress loading for the pooled data was low (close to 0) indicating that the ordination adequately explained the spatial variations. Although a higher stress loading of 0.19 was observed for the monthly-disaggregated data, the ordination patterns closely matched those of the pooled data (4.16b).

Analysis of similarities (ANOSIM) test, applied to check for significant differences in the species composition of recruits among sites, seasons and years indicated that sites and seasons contributed the greatest to the variations in species composition (Global R = 0.79 and R = 0.75, respectively) (Table 4.9). Pair-wise tests further showed that the strongest differences were between Wasini and Kilifi (R = 0.99), Wasini and Mwipwa (R = 0.96), Mwipwa and Kilifi (R = 0.94), Sii and Kilifi (R = 0.92) and Kuruwitu and Mwipwa (R = 0.91). The pairing of Wasini and Sii sites had the lowest difference in species composition (R = 0.54).

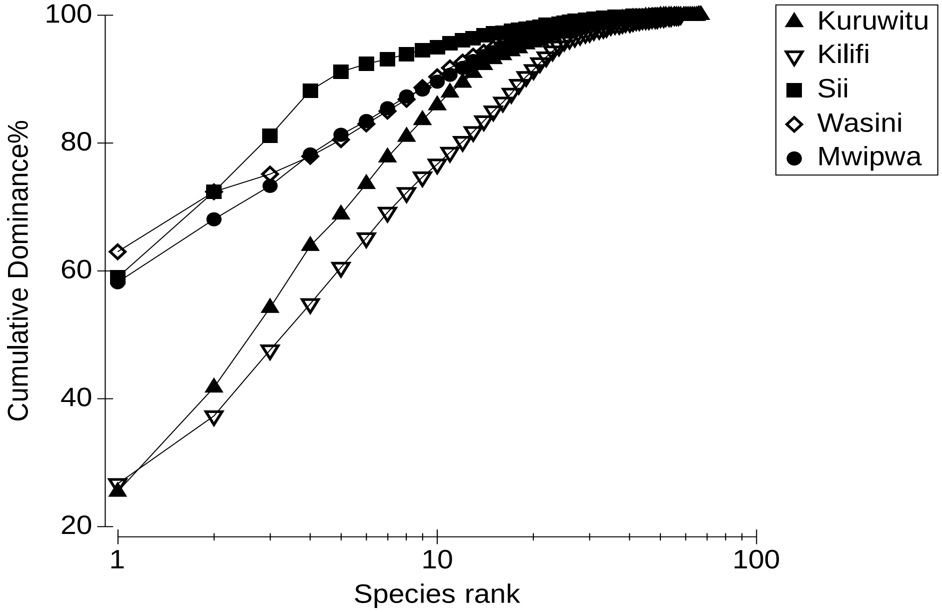


Figure 4.15. ***K*-dominance curves of the species composition of recruits at the five study sites**

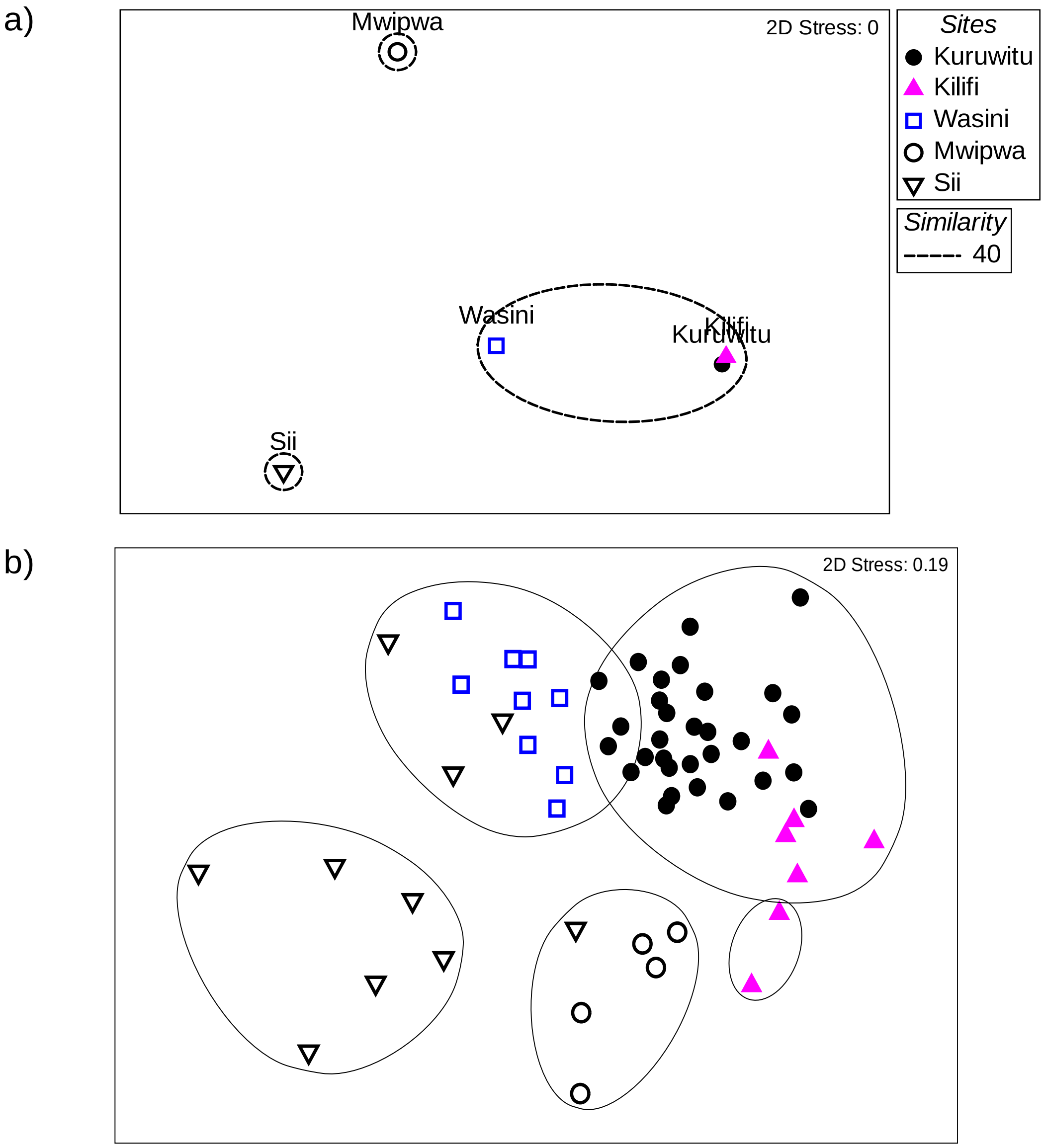


Figure 4.16. A non-metric multidimensional scaling (MDS) ordination plot using Bray–Curtis similarities of square root transformed standardized data showing the similarities in the species composition of reef fish recruits among the five study sites. Figure (a) is based on the pooled data for each site and (b) is based on the monthly data

Table 4.9. Summary of Analysis of Similarities (ANOSIM) results comparing differences in species composition of recruits among sites, years and seasons

Component	Factor	*R*-statistic	Significance
Spatial	Sites	0.794	P< 0.01
Temporal	Seasons (NEM vs. SEM)	0.751	P< 0.01
	Years	0.23	P< 0.01

DCA ordination of the 40 most abundant species further confirmed the variation in the species composition of recruits between the sites (Fig 4.17). Wasini, Kilifi and Kuruwitu grouped as distinctly different from Mwipwa and Sii Island, similar to the findings of the MDS, although Kilifi and Wasini were grouped as more similar in species composition. The observed spatial patterns suggest an increasing similarity in the species composition of recruits among the mainland fringing lagoon reefs compared to the offshore island fringing reefs. The results of SIMPER (similarity percentages) applied to identify the species that contributed most to dissimilarities between sites (Table 4.10), showed that the separation of Sii Island and Mwipwa from the other sites was mainly influenced by a high abundance of *N. azysron* and *P. evides* recruits. *Neopomacentrus azysron* also contributed most to dissimilarities between Kilifi and Wasini, Mwipwa and Sii Island, and Kuruwitu and Sii Island, while *C. viridis* contributed most to the dissimilarities between Wasini and four sites (Kilifi, Sii Island, Mwipwa, and Kuruwitu) (Table 4.10). Dissimilarities in recruit species composition between Kilifi and Sii was influenced by the abundance of *N. azysron*, *T. hebraicum* and *C. viridis* which altogether contributed about 20% to the dissimilarity, respectively (Table 4.10). Kuruwitu and Kilifi clustered as most similar in species composition by the MDS ordination (see Fig. 4.16) influenced by the abundance of *C. viridis, T. hebraicum* and *O. taeniophorus*, contributing about 19% to the dissimilarities.

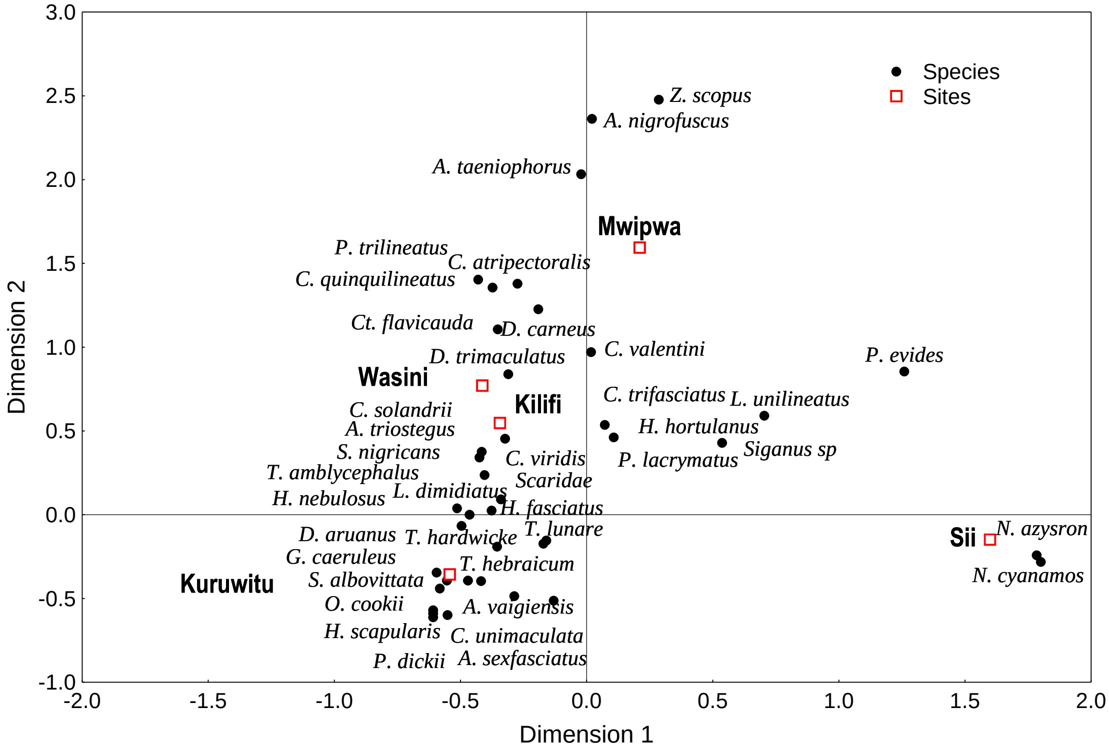


Figure 4.17. **Detrended Correspondence Analysis (DCA) of the 40 most abundant reef fish species recruiting at the five study sites along the Kenyan coast**

Table 4.10. Results of SIMPER analysis showing the top 3 species contributing to differences in the recruit species composition between the study sites

Species	Mean Abundance		Average Dissimilarity	Contribution %
Kilifi vs. Sii Island	Kilifi	Sii	**Av. diss = 89.3**	
Neopomacentrus azysron	0	4.77	8.88	9.95
Thalassoma hebraicum	3.61	0.56	5.87	6.58
Chromis viridis	0.82	2.57	5.02	5.62
Kilifi vs. Wasini	Kilifi	Wasini	**Av. diss. = 78.7**	
Chromis viridis	0.82	7.64	12.16	15.42
Cheilodipterus quinquilineatus	1.85	1.56	4.73	6
Thalassoma hebraicum	3.61	1.41	4.26	5.41
Sii Island vs. Wasini	Sii	Wasini	**Av. diss. = 76.2**	
Chromis viridis	2.57	7.64	11.16	14.64
Neopomacentrus azysron	4.77	0.13	9.68	12.7
Neopomacentrus cyanomos	2.69	0.24	5.28	6.92
Mwipwa vs. Kilifi	Kilifi	Mwipwa	**Av. diss. = 77.2**	
Ptereleotris evides	0	4.5	7.35	9.53
Cheilodipterus quinquilineatus	1.85	1.01	3.93	5.1
Thalassoma hebraicum	3.61	1.56	3.82	4.96
Mwipwa vs. Sii Island	Sii	Mwipwa	**Av. diss. = 83.4**	
Neopomacentrus azysron	4.77	0	8.76	10.51
Ptereleotris evides	1.23	4.50	7.8	9.36
Neopomacentrus cyanomos	2.69	0	4.71	5.65
Mwipwa vs. Wasini	Wasini	Mwipwa	**Av. diss. = 80.2**	
Chromis viridis	7.64	0	13.08	16.3
Ptereleotris evides	0.11	4.5	7.92	9.87
Cheilodipterus quinquilineatus	1.56	1.01	2.99	3.72
Mwipwa vs. Kuruwitu	Mwipwa	Kuruwitu	**Av. diss. = 76.9**	
Ptereleotris evides	4.5	0	7.4	9.62
Chromis viridis	0	3.07	4.76	6.19
Thalassoma hebraicum	1.56	4.24	4.72	6.13
Kuruwitu vs. Kilifi	Kilifi	Kuruwitu	**Av. diss. = 67.6**	
Chromis viridis	0.82	3.07	4.96	7.35
Thalassoma hebraicum	3.61	4.24	3.83	5.67
Ostorhinchus cookii	1.69	2.21	3.83	5.66
Kuruwitu vs. Sii Island	Sii	Kuruwitu	**Av. diss. = 83.4**	
Neopomacentrus azysron	4.77	0.21	8.73	10.46
Thalassoma hebraicum	0.56	4.24	7.10	8.52
Chromis viridis	2.57	3.07	5.73	6.87

Table 4.10 continued

Species	**Mean Abundance**		**Average Dissimilarity**	**Contribution %**
Kuruwitu vs. Wasini	Wasini	Kuruwitu	**Av. diss. = 68.8**	
Chromis viridis	7.64	3.07	8.58	12.47
Thalassoma hebraicum	1.41	4.24	5.27	7.67
Gomphosus caeruleus	1.07	3.17	4.23	6.15

4.4.2. Temporal Patterns of Recruitment

Recruitment of juvenile reef fish at Kuruwitu was observed throughout the year (Fig. 4.18). Correlation of the mean monthly temperature values with average monthly recruit densities as well as the total number of species recruiting monthly using Pearson's correlation coefficient (r) was positive and significant for both variables (r = 0.55, p = 0.002, Fig. 4.18a). Recruitment patterns also varied annually, as indicated by higher recruitment strength in 2013 among the four most abundant families (Labridae, Pomacentridae, Apogonidae and Scaridae) when compared to the other years (Table 4.11, Fig. 4.18b).

The Mann-Whitney U test results showed significant seasonal differences (z = -7.05, p = 0.00), in recruitment among the four fish families in some years, with the exception of the Labridae (Table 4.11). A two-way ANOVA further detected significant effects of Year (F = 12.06, *p* = 0.001) and season (F = 79.29, *p* = 0.001) on recruit densities, as well as significant interactions of the two factors (F = 143.9, *p* = 0.001).

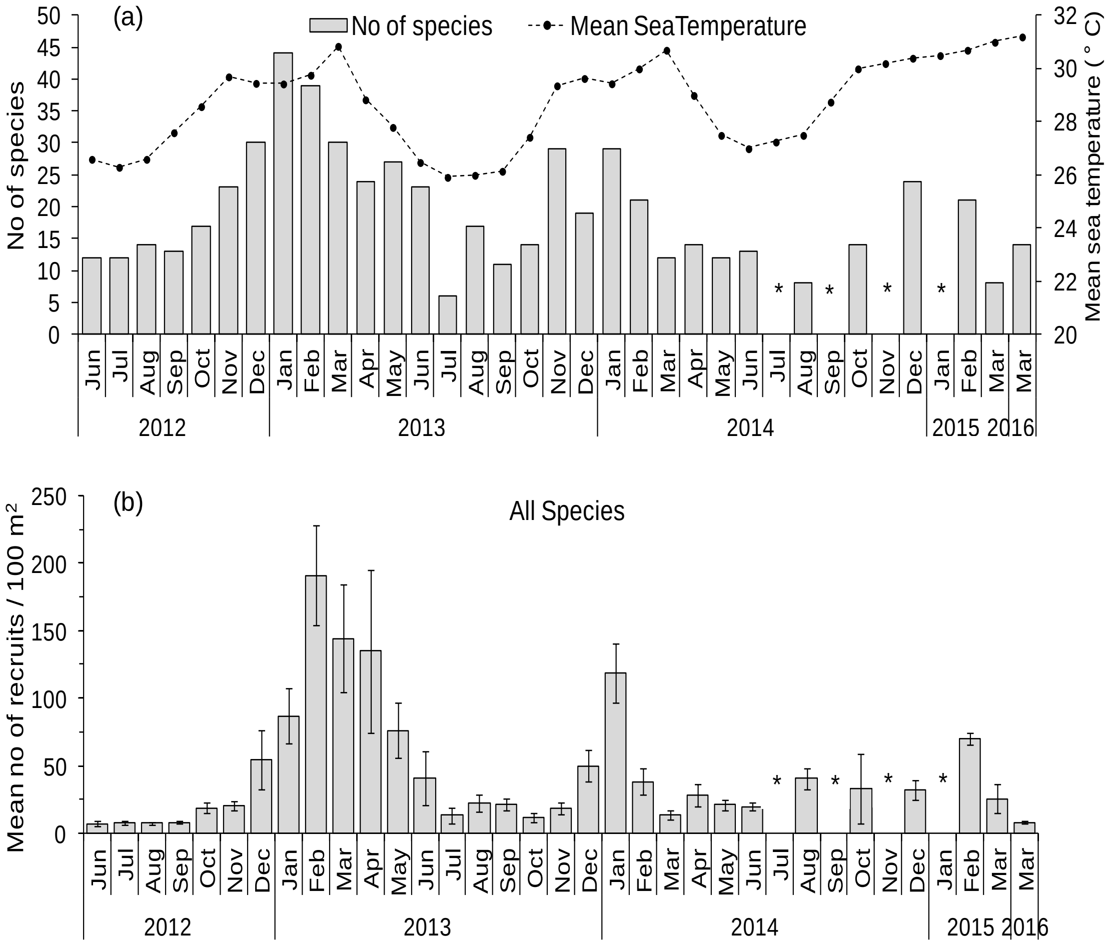


Figure 4.18.(a) Monthly patterns in the abundance of newly settled recruits in Kuruwitu presented as the total number of species recruiting monthly; and (b) the mean density of recruits per transect based on under water visual census surveys conducted from June 2012 to March 2016. Error bars indicate SE. * indicates no data collected.

Table 4.11. Mann-Whitney U-test results comparing annual seasonal variations in mean densities (number of fish / 100 m^2) of newly settled recruits for the 4 most abundant fish families at Kuruwitu from June 2012 to December 2014, and from February to March 2015 (Significant effects are shown in bold)

Family	Year	NEM	SEM	Mann-Whitney U test	
				z	p-level
Labridae	2012	9.6 ± 1.5	6.8 ± 1	-1.69	0.09
	2013	23.0 ± 3	15.4 ± 1.9	-1.91	0.06
	2014	28.8 ± 7.8	12.3 ± 1.8	-0.93	0.35
	2015	3.9 ± 1.6	-		
Pomacentridae	2012	27.3 ± 13.8	2.5 ± 0.7	-4.10	**0.001**
	2013	44.0 ± 12.2	22.4 ± 9.6	-5.68	**0.001**
	2014	10.7 ± 2.2	9.8 ± 3.6	-1.75	0.08
	2015	3.8 ± 2	-		
Apogonidae	2012	0.4 ± 0.2	0.2 ± 0.2	-1.23	0.22
	2013	29.2 ± 12.4	10.4 ± 5.7	-1.36	0.18
	2014	13.4 ± 6.3	7.5 ± 4.1	-2.85	**0.001**
	2015	12.4 ± 5.8	-		
Scaridae	2012	1.9 ± 0.8	0.1 ± 0.1	-1.62	0.10
	2013	8.3 ± 1.9	1.3 ± 0.5	-3.22	**0.001**
	2014	5.0 ± 1.3	0.9 ± 0.3	-3.28	**0.001**
	2015	2.3 ± 0.8	-		

The timing of the seasonal peaks in recruitment during 2012/2013 was generally consistent with the patterns observed in 2013/2014 among the four families (Fig. 4.19), coinciding with the peaks in water temperature recorded during November to March in 2012/2013 and again during 2013/2014 period. Among the four most abundant species recruiting at Kuruwitu, the Labridae species *T. hebraicum* and *G. ceruleans* recruited year-round; however, the monthly timing of recruitment peaks was not consistent between years (Fig. 4.20), as compared to the Pomacentridae species *C. unimaculata* and *D. aruanus*, which exhibited more consistent timing of recruitment peaks suggesting annual variation in factors that drive recruitment between species.

A two-way ANOVA to test for effects of years (2012-2014) and season (NEM vs. SEM) on the recruitment strength of the 10 most abundant species is shown in Table 4.12. Among the Labridae species, *T. hebraicum* showed significant differences in recruit densities between years but not between seasons indicating a pattern of extended recruitment. On the other hand, *G. caeruleus*, *T. hardwicke* and *O. cookii* showed significant differences in recruit densities between years and seasons indicating a pattern of periodic or highly sporadic recruitment pulses.

Among the Pomacentridae species, *C. viridis* only showed significant variations between years, while *S. nigricans*, *C. unimaculata* and *D. aruanus* showed significant differences between years and seasons (Table 4.12). However, there was no significant effect of year and season for *Z. scopas*, *C. valentini* likely due to low recruitment numbers. A significant interaction effect of year and season was also observed for all the 10 species except for *C. valentini* and *Z. scopas.*

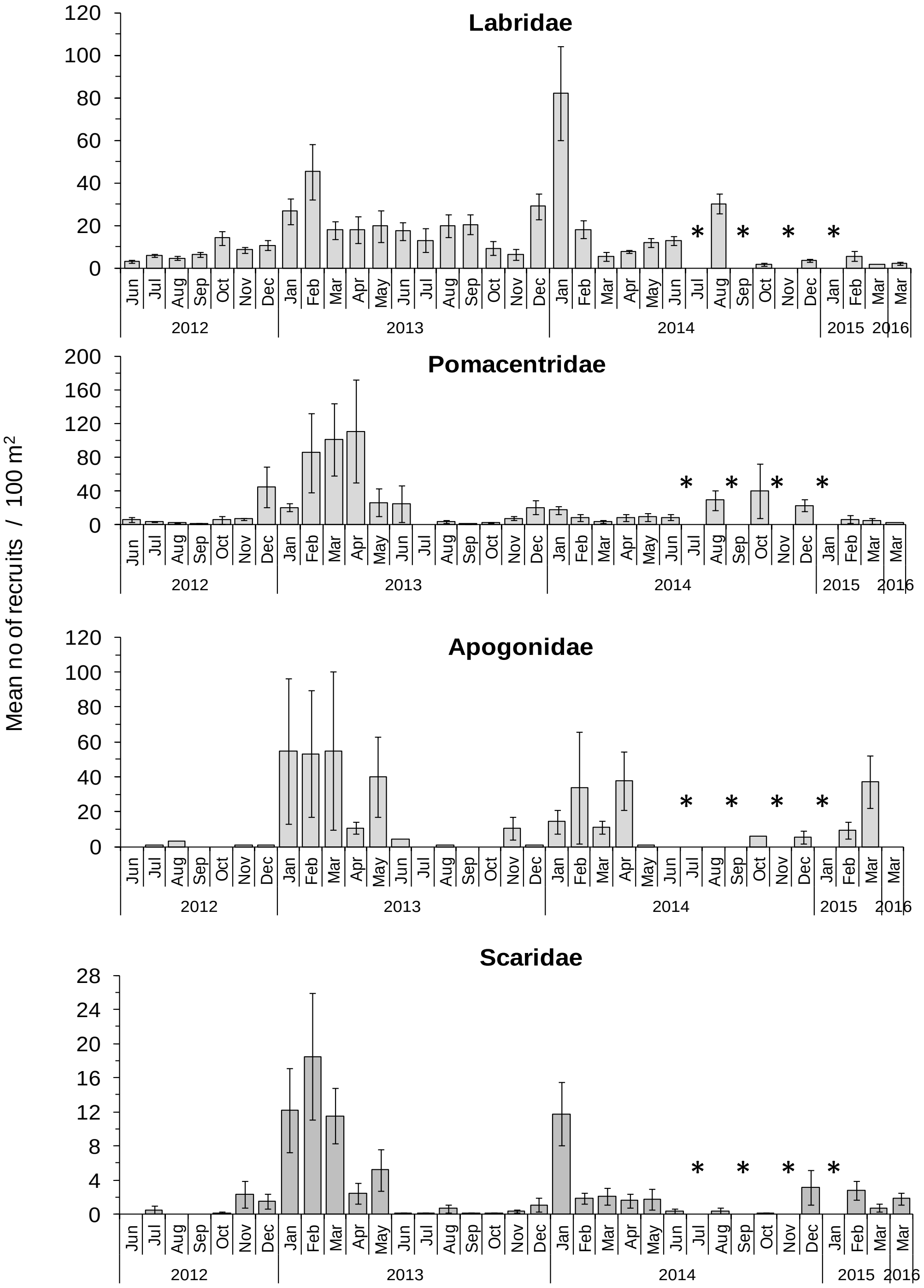


Figure 4.19. **Monthly trends in the mean number of newly settled recruits (± SE) recorded monthly in Kuruwitu during under water visual census surveys conducted from June 2012 to March 2016 for the 4 most abundant fish families recruiting. * indicates no data collected**

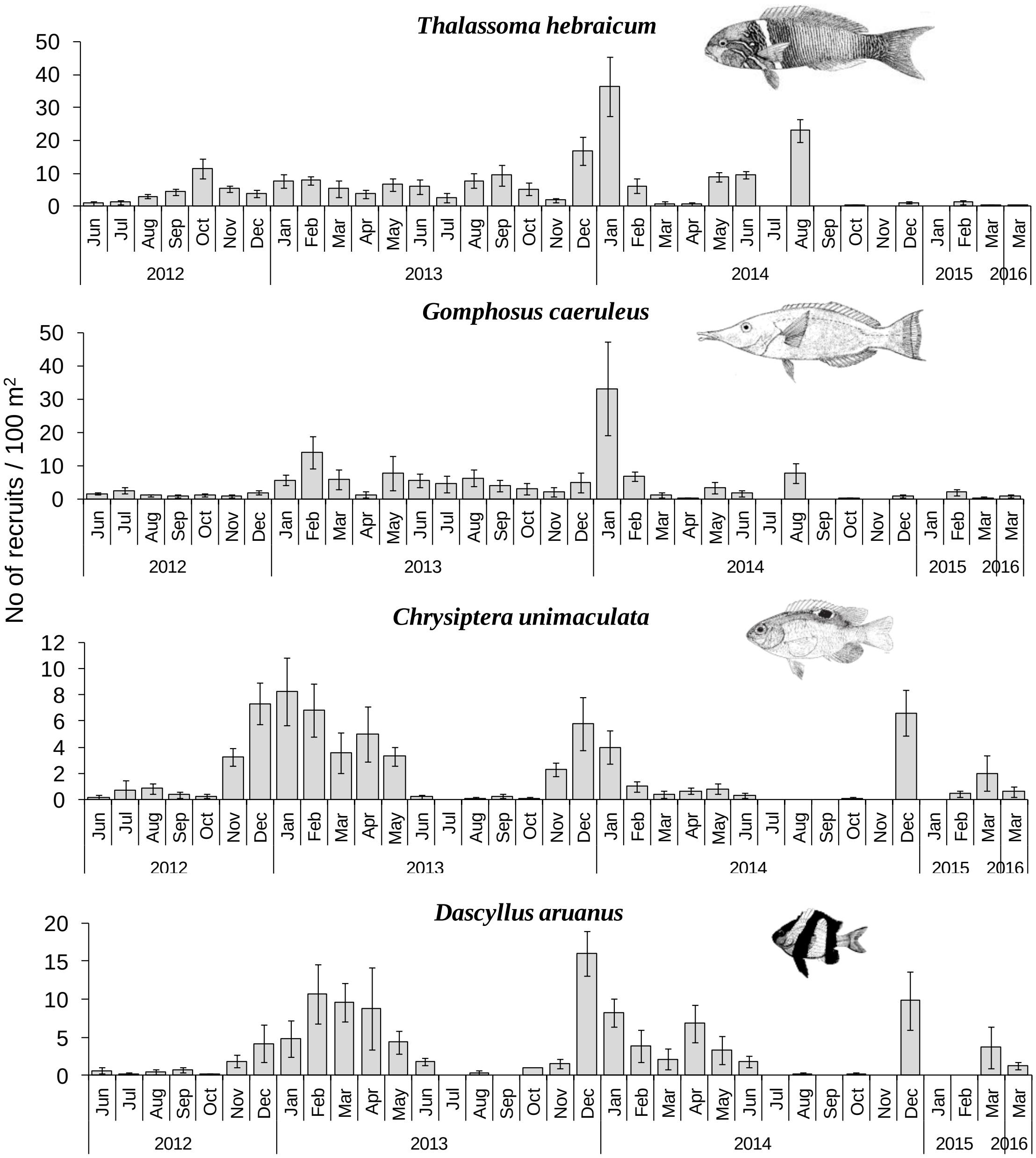


Figure 4.20. Monthly trends in the mean number of newly settled recruits (±SE) for the most abundant species (*Thalassoma hebraicum*, *Gomphosus caeruleus*, *Chrysiptera unimaculata*, and *Dascyllus aruanus*) recorded during the study period in Kuruwitu

Table 4.12. Results of two-way ANOVA testing for effects of years (2012-2014) and season (NEM vs. SEM) on recruit densities of the 10 most abundant species at Kuruwitu. Significant effects (p < 0.05) are shown in bold.

	Thalassoma hebraicum		*Gomphosus caeruleus*		*Thalassoma hardwicke*		*Ostorhincus cookii*		*Canthigaster valentini*	
Effect	F	*p*	F	*p*	F	*p*	F	*p*	F	*p*
Year	**8.15**	**0.001**	**4.35**	**0.001**	**2.73**	**0.03**	4.02	**0.001**	0.73	0.57
Season	2.60	0.11	**8.64**	**0.001**	**25.40**	**0.001**	4.47	**0.04**	0.02	0.90
Year x Season	**117.03**	**0.001**	**56.64**	**0.001**	**8.19**	**0.001**	6.31	**0.001**	1.64	0.20
	Chromis viridis		*Stegastes nigricans*		*Chrysiptera unimaculata*		*Dascyllus aruanus*		*Zebrassoma scopas*	
Effect	F	*p*	F	*p*	F	*p*	F	p	F	p
Year	**2.65**	**0.04**	**9.57**	**0.001**	**33.45**	**0.001**	**9.45**	**0.001**	0.72	0.58
Season	0.25	0.62	**80.97**	**0.001**	**142.66**	**0.001**	**19.15**	**0.001**	0.00	1.00
Year x Season	**15.84**	**0.001**	**8.18**	**0.001**	**46.33**	**0.001**	**89.35**	**0.001**	0.25	0.62

4.5. Habitat Associations of Recruit and Juvenile Coral Reef Fishes

The main substrate types at the study sites included live coral, dead coral, rubble and rock substrate (Fig. 4.21). The five study sites exhibited significant differences in substrate cover (One-way ANOVA; F = 11.21, p = 0.034). Live coral was the dominant substrate type in Kuruwitu and Wasini, while coral rubble was dominant in Kilifi, Mwipwa and Sii Island (Fig. 4.21). A total of 5,204 recruits and juveniles belonging to 19 families and 81 species were recorded (see Appendix VI for a check-list of the species). Live coral was associated with 63% (3,268) of the recruits and juveniles recorded. Dead coral was associated with 11% (559) of the total number of recruits recorded, while about 18% (945) were associated with seagrass and the remaining 8% (432) were associated with rubble mixed with sand, rocky substrate, turf algae, macroalgae, sponges and anemones.

Results of Canonical Correspondence Analyses (CCA) applied to assess general habitat associations among the three life phases (recruits, juveniles and adults showed strong ontogenic preferences (Fig. 4.22). The Eigenvalues for Axis 1 and 2 in the CCA bi-plot, accounted for 75.2% and 24.8% of the variance, respectively. Live coral and rugosity (or habitat complexity) were the two main predictors of recruit abundance, pointing towards a pattern of increasing recruit abundance with increasing hard coral cover and rugosity (Fig. 4.22). Rugosity had the most acute angle against Axis 1, indicating a stronger relationship with recruits compared to coral cover (Fig. 4.22). The results also showed a pattern of decreasing recruit abundance with increasing seagrass cover, algal cover and dead coral.

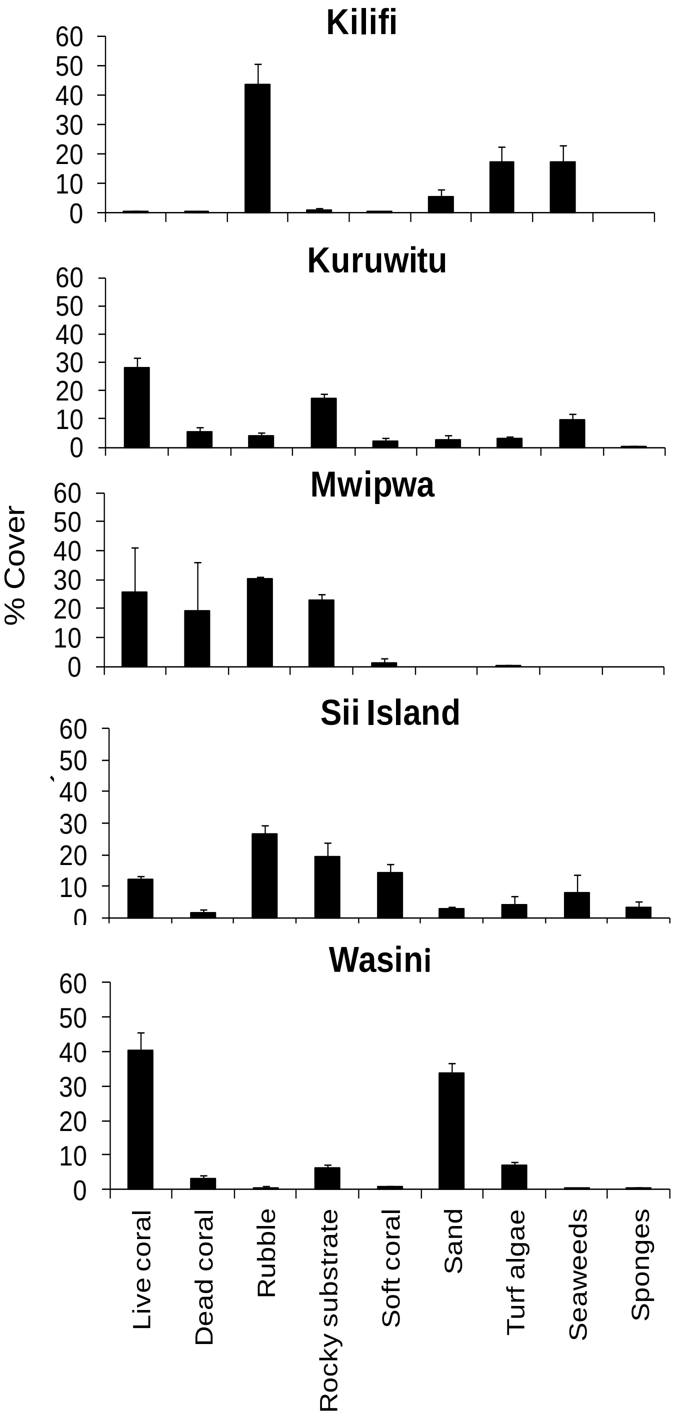


Figure 4.21. The composition of the benthic substrates (mean percentage ±SE) along 50 m^2 belt transects at the five study sites

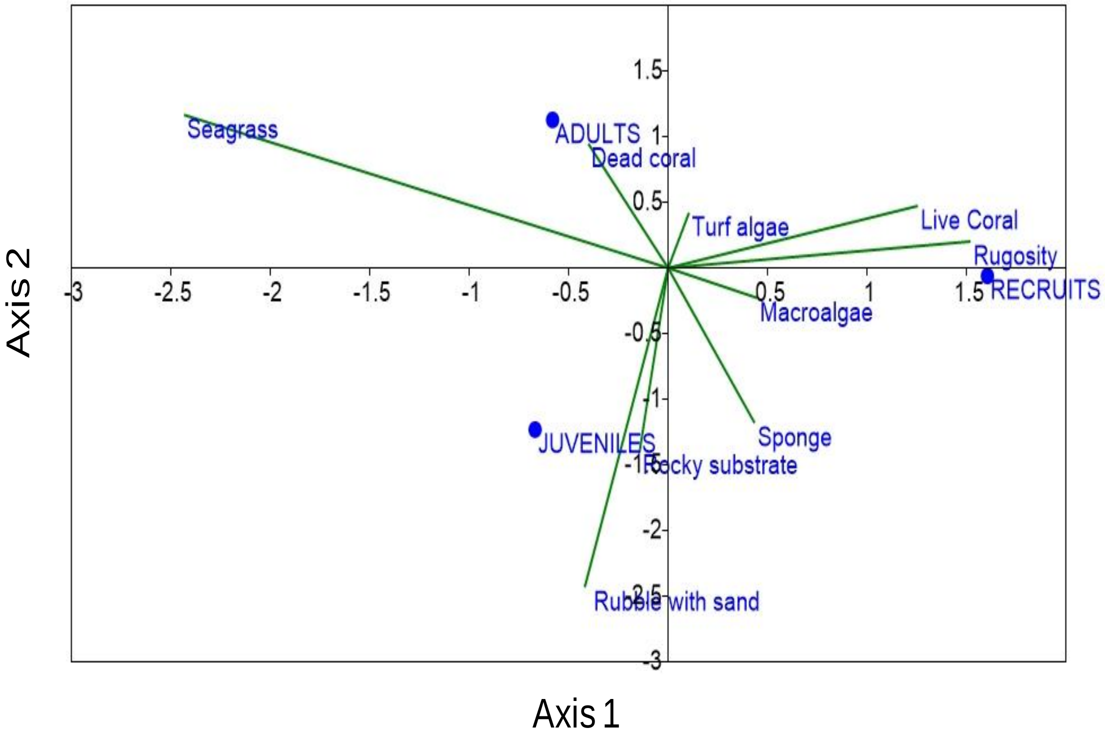


Figure 4.22. A Canonical Correspondence Analysis (CCA) biplot of the first two axis showing the general habitat associations of recruits, juvenile and adult coral reef fishes for all species combined

On the other hand, the main habitat types that predicted the abundance of adult life phases included seagrass, followed by algal turf and dead coral (Fig. 4.22), likely due to the high abundance of herbivores like Acanthuridae and Labridae (mostly *Thalassoma* species) at the study sites. The extended length of the seagrass and rubble vectors indicated the influence of the two substrate types in predicting the abundance of juvenile and adult life phases of the reef fish species at the study sites, whether positively or negatively. Notably, juvenile life phases were negatively associated with rubble (see Fig. 4.22). Further, results of DCA showed varying habitat associations at the family level (Fig. 4.23). The families Pomacentridae, Chaetodontidae, Microdesmidae and Apogonidae were strongly associated with live coral. On the other hand, Acanthuridae were associated with turf algae and macroalgae, while the Scaridae, Siganidae, Mullidae and Sphyraenidae were strongly associated with seagrass habitats (Fig.4.23). The Labridae were associated with diverse substrates including rocky substrate, dead coral with algae and dead coral, while Tetraodontidae, Gobiidae and Blennidae were associated with rubble mixed with sand.

Among the Pomacentridae, recruits and juveniles of *C. viridis*, *D. aruanus* and *D. carneus* were relatively site attached and strongly associated with live coral (Fig. 4.24). This pattern was consistent between sites irrespective of coral cover (Fig. 4.24), whereas *Stegastes nigricans* and *Plectroglyphidodon lacrymatus* were strongly associated with dead coral and rocky substrates. On the other hand, the Labridae species *Halichoeres hortulanus* and *H. scapularis* were strongly associated with sandy habitats mixed with rubble, especially under massive corals and rocks. Recruits and juveniles of the cleaner wrasse *L. dimidiatu*s and the wrasses *T. hebraicum* and *Thalassoma lunare* were however associated with diverse habitats (Fig. 4.24). Juveniles of the surgeonfish *Acanthurus nigrofuscus* had strong associations with seagrass cover with algal turf, while recruits and juveniles of *Zebrassoma veliferum* and *Zebrassoma scopas* were strongly associated with live coral.

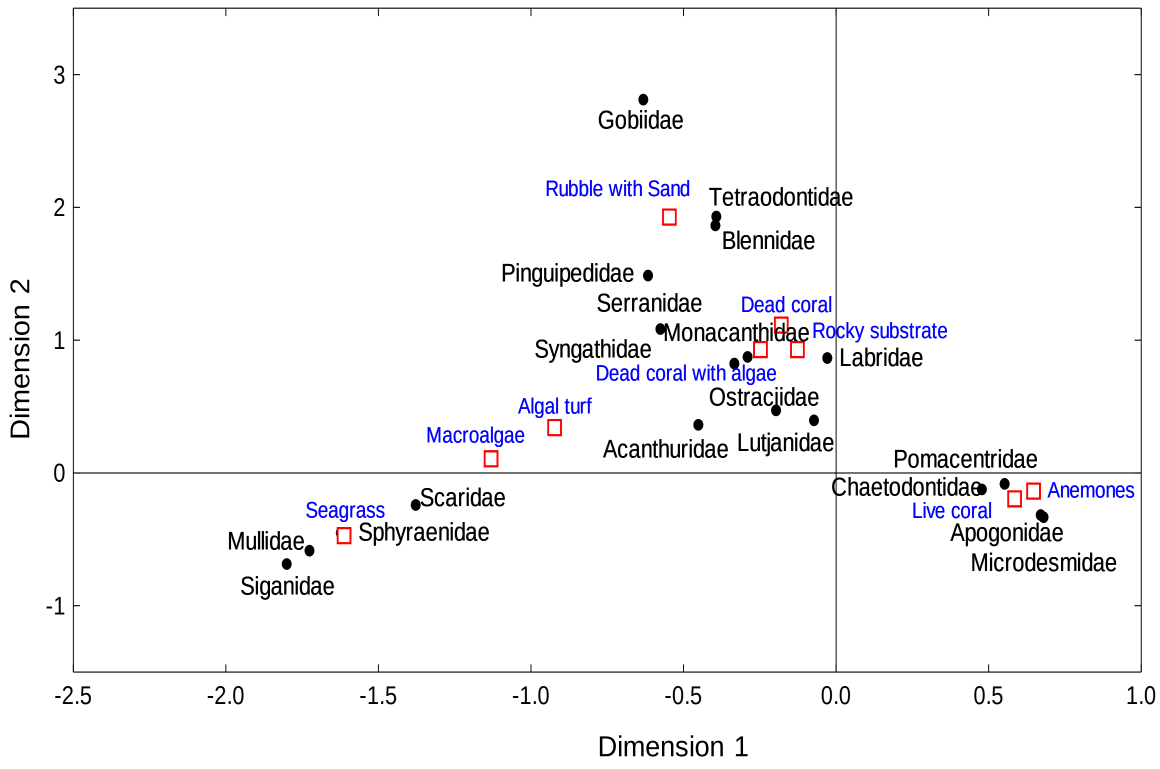


Figure 4.23. Results of Detrended Correspondence Analysis (DCA) showing the association of reef fish recruits and juveniles with benthic substrate types for the key fish families recorded during visual census surveys conducted in January 2014 at four study sites (Kuruwitu, Wasini, Mwipwa and Sii Island)

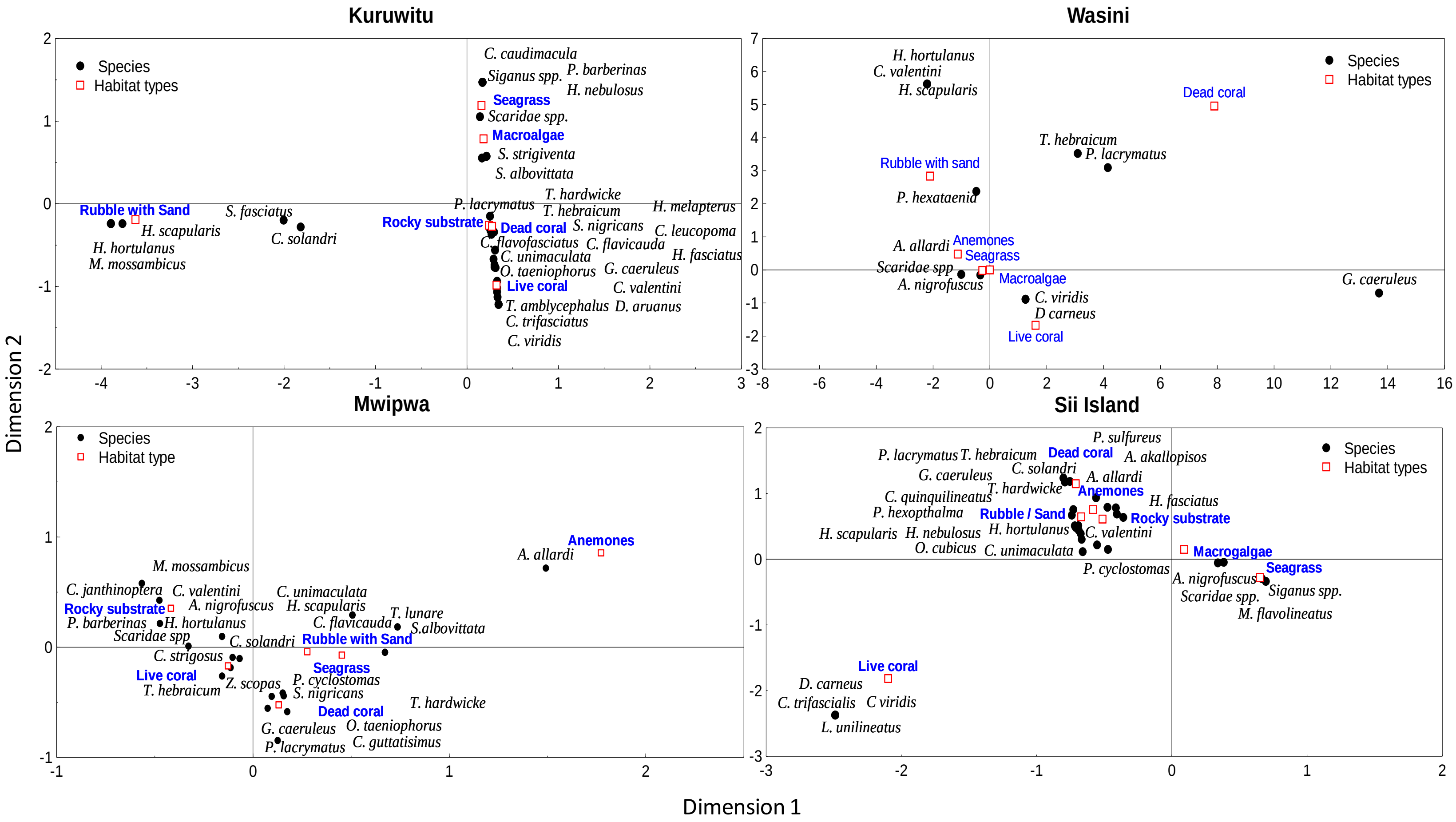


Figure 4.24. Results of Detrended Correspondence Analysis (DCA) showing habitat associations of recruits and juveniles of the more abundant species recorded during visual census surveys conducted in January 2014 at four study sites along the Kenya coast

CHAPTER FIVE

DISCUSSION

5.1. Spatio-temporal Patterns of Coral Reef Fish Exploitation by the Marine Aquarium Fishery

This study represents the first comprehensive assessment of the marine aquarium fishery in Kenya and the WIO region. The study assessed spatio-temporal patterns in the fishery over a period of six years. Based on the results, an estimated 240,000 to 341,000 fish are collected annually in Kenya by aquarium fishers. This estimated figures take into consideration an estimated post-capture mortality rate of approximately 5% (Okemwa *et al.*, 2009), and the premise that the data represent about 70% of total landings. The estimate constitutes a two-fold increase in annual catches of aquarium fishes in Kenya from that reported by Wood (2001a) during the 1990s. The trend is likely associated with increasing demand for marine aquarium resources on the global market (Thornhill, 2012).

The temporal shifts in fishing effort between fishing grounds observed in the study (Fig 4.2) could be due to fishers trying to optimize fishing effort and catches of the target species based on their knowledge of species distributions. Furthermore, the significant correlation of fishing effort with total catches (Fig. 4.3), and the observed temporal patterns in fishing effort depicts a trend of increasing fishing pressure that is a likely response to a reduction in the abundance and availability of some target species. Notably, there was an apparent shift in fishing effort northwards to Lamu, a relatively pristine area, and specific targeting of high-value angelfishes, *P. maculosus* and *P. chrysurus,* could be in response to a reduction in the abundance and availability of these highly valued species in other fishing grounds and the need to maximize economic returns.

Based on the perceptions of aquarium fishers (Okemwa, unpublished data 2012), angelfishes (Pomacanthidae) have become more difficult to catch over time. As a result, more remote and relatively pristine source areas such as Lamu are being exploited, explaining the selective targeting of angelfishes from Lamu. Furthermore, importation of *P. maculosus* from Tanzania has been reported (State Department of Fisheries, 2016), providing more supportive evidence of possible localized depletion of species on most fishing grounds. Shifts in fishing depth may also be typical to the fishery as documented in Hawaii where aquarium fishers were observed to dive deeper and increase their fishing effort in response to weak recruitment of their target species in shallower areas (Stevenson *et al*., 2011).

The estimated mean CPUE for Kenya's aquarium fishers of 24 ± 0.5 fish $\text{fisher}^{-1}\text{day}^{-1}$ in this study is within previously reported ranges for Australia (20 - 45 fish $\text{fisher}^{1}\text{day}^{-1}$ and the Cook Islands (24 - 36 fish/man/day (Wood, 2001a), but lower than that reported by Shuman *et al*. (2004) for the Philippines (37.5 - 48 fish $\text{fisher}^{-1}\text{day}^{-1}$). However, the CPUE estimate for Kenya is likely underestimated taking into account unreported mortalities that may have occurred during fishing because of poor handling. The use of nominal CPUE as an index of relative stock abundance is robust to violation of key assumptions on fishing effort (see Maunder and Punt, 2004; Maunder *et al*., 2006).

Key factors that may influence the fishing efficiency of aquarium fishers include the target species, variability in their population dynamics including recruitment, as well as local environmental variability. For purposes of this study, an assumption was made that the efficiency of aquarium fishers did not differ between individual fishers. However, the target species and number of individuals collected is strongly dictated by the fish dealers (Okemwa *et al*., 2006). Some species are routinely collected in large numbers as "filler species"; others are collected opportunistically when encountered due to their rarity or high value, while others are only collected on specific request by a client (Okemwa personal observation). Despite these dynamics, the CPUE index derived in this study provides a useful indicator of catch trends, which can be used for monitoring the future performance of the fishery over time.

The five-fold increase in the number of aquarium fish species collected from 48 in the 1980s (Samoilys, 1988) to approximately 220 in this study clearly indicates increasing fishing pressure on Kenyan reefs. The increase in species targeted in Kenya’s aquarium fishery is in tandem with the global pattern, which is fuelled by an increasing demand for new species (Rhyne & Tlusty, 2012). Globally, only 10 fish families account for 83% of the international trade dominated by the Pomacentridae (damselfishes) which account for 42% of the total volume (Green, 2003; Wabnitz *et al*., 2003). Seven fish families accounted for 81% of Kenya’s aquarium fishery catches, dominated by the Labridae (wrasses, 42 species) which made up 32% of the catches. The dominance of Labridae in marine aquarium catches is similar to other countries i.e Sri Lanka (44 wrasse species, Ekaratne, 2000). This indicates that Kenya is a key source for wrasse species in the global aquarium fish market.

Although the cleaner wrasse, *L. dimidiatus* was the most collected species in most of the fishing grounds (Fig. 4.5), it was ranked as having a low vulnerability risk to depletion due to the low scoring of its productivity attributes (Appendix III, No. 45). This implies that the species could be generally more resilient to heavy fishing pressure. *Labroides dimidiatus* is a popular species in the aquarium trade due to its mutualistic cleaning behavior which controls the ectoparasite load of other fish in aquarium tanks (Grutter, 1996; Wood, 2001a). Studies have documented an association of the presence of cleaner wrasses with the abundance and diversity of fish communities, and the size of individual fish. For example, Bshary (2003) observed a reduction in the species richness of resident fish when *L. dimidiatus* was experimentally removed from reefs in the Red Sea after 4 to 20 months.

A longer-term experiment conducted for over 8.5 years further observed a reduction in the individual size and growth of site-attached damselfishes (*Pomecentrus. moluccensis* and *P. amboinensis*) in reefs where all *L. dimidiatus* were removed compared to control reefs (Clague *et al*., 2011; Waldie *et al*., 2011). Clague *et al*. (2011) reported that individuals cleaned by *L. dimidiatus* were 27% larger. *Labroides dimidiatus* can also influence the settlement patterns of coral reef fish by acting as a positive cue during microhabitat selection of some damselfish species (Sun *et al*., 2016). Consequently, heavy collection of *L. dimidiatus* in high numbers is perceived to likely have significant ecological implications (Wood, 2001a), but the impacts have not been establish in the WIO region including Kenya.

The relative composition of catches differed among the 11fishing grounds studied with results of the non-metric Mutlidimensional Scaling (MDS) separating the grounds into three distinct groups strongly influenced by fishing modes (Snorkeling vs. SCUBA fishing). The MDS analysis showed a distinct segregation in the species composition of catches from Lamu (on the northern coast), likely due to selective targeting of the Yellowbar angelfish, *P. maculosus* and *P. chrysurus* (Goldtail angelfish) which were the top species collected from the area. Results of Detrended Correspondence Analysis further showed that some species were more associated with specific fishing grounds, indicating potential differential depletion of vulnerable species, due to variable fishing effort. These results indicate the need for site-specific management plans and models that may prevent spatial depletion of species.

5.2. Vulnerability Risk Assessment and Sustainability of Target Species to Exploitation by the Marine Aquarium Fishery

Overall, most species targeted by the marine aquarium fishery fell in the high productivity and low susceptibility categories (Fig. 4.8), placing them at a relatively low vulnerability risk to localized depletion. Pomacanthidae had the highest overall mean vulnerability risk score of 2.6 ± 0.71SD, with *P. maculosus* and *P. chrysurus* ranking as highly vulnerable to fishing pressure. Angelfish of the genus *Pomacanthus* have life history characteristics that make them more vulnerable to overexploitation including being relatively long-lived, delayed maturity and low rates of recruitment (Tebua, 2005). The anemonefishes, *A. allardi* and *A. akallopisos* also ranked at high vulnerability risk.

Anemonefishes are heavily targeted by Kenya's aquarium fishery. They have a mutualistic relationship with specific species of anemones, which provide protection from potential predators (Fautin, 1986, 1991). Anemonefish also guard their nests, which are attached at the base of the anemones (Bender *et al*., 2013). Such characteristics make anemonefishes highly vulnerable to overfishing and other anthropogenic pressures that may affect their habitats. Studies in Philippines (Shuman *et al*., 2005) and the Great Barrier Reef (Jones *et al*., 2008) confirmed declines in both anemone and anemonefish densities in areas exploited by aquarium fishers.

The high vulnerability ranking of *P. maculosus, P. chrysurus, A. allardi* and *A. akallopisos* in this study is in agreement with very early concerns of Lubbock & Polunin (1975) and Samoilys (1988) on their potential for overexploitation. Angelfish (*Pomacanthus* spp.) and anemonefishes (*Amphiprion* Spp.) are highly desired on the global market (Sadovy & Vincent, 2002; Shuman *et al*., 2004), which provides a strong incentive for continued intense collection despite overall abundances being low. This places them at an even higher risk of depletion compared to other target species which is sustainability concern. Conversely, since these species still provide an important component of Kenya's aquarium fishery almost 30 years later, it is likely that the populations and catch levels may be sustainable with appropriate management interventions. Nonetheless, there is need for more studies on the life-history strategies and population dynamics to guide the formulation of appropriate management controls on extraction rates.

The PSA analysis showed seven species to have moderate vulnerability to overexploitation by the fishery including three angelfish species *P. imperator, P. diacanthus* and *P. semicirculatus*, the wrasses, *Coris aygula* and *H. iridis,* the surgeonfish *P. hepatus* and the dartfish *N. magnifica*. Evidence of declines due to heavy collection by the aquarium fishery have been reported for *P. imperator* and *P. hepatus* populations in Philippines and Indonesia (Rubec, 1987) which supports the need to monitor the Kenyan stocks. The risk ranking of *N. magnifica* as medium concurred with the findings of Fujita *et al*. (2013) for Indonesian stocks. This study also showed that the lionfish, *P. miles* is also highly targeted in Kenya, but the species was ranked among the borderline low-risk species. Darling *et al*. (2011) reported that *P. miles* populations are generally in low densities and are smaller in Kenya compared to stocks in the Caribbean, warranting further investigation to verify the status of the stocks in Kenya.

Studies have documented the contribution of Kenya's marine parks in replenishing reef fish populations in fished areas through spillover of adults (McClanahan & Kaunda-Arara, 1996; McClanahan & Mangi, 2000; Kaunda-Arara & Rose, 2004) and larval supply (Kaunda-Arara *et al*., 2009; Mwaluma *et al*., 2011). However, the abundance of the mostly lower trophic level aquarium species may decrease in MPAs due to higher abundance of predators (Watson *et al*., 2007). To balance such effects, smaller spatial closures (e.g. community-managed areas) may be beneficial, especially for species that have site-fidelity and a tendency to self-recruit such as anemonefishes (Madduppa, 2012). A number of small community managed areas have been established in Kenya (Rockliffe *et al*., 2014), which will likely play an important role in sustaining juvenile reef fish populations. In addition, large spatial closures such as the Kisite Marine National Park within the Shimoni area provide an important replenishment zone for the affected populations, and are complemented with the smaller Community Conservation Areas (CCAs) which have increasingly gained local support by resource managers and fisher communities (Rockliffe *et al*., 2014).

5.3. Gear-based Overlaps in Species Selectivity and Potential Interactions between Artisanal and Aquarium Fisheries in Shimoni

The artisanal fishery in Shimoni on the south coast of Kenya was dominated by the use of handlines, basket traps and spearguns. A major finding of this study was that these gears had the highest potential to interact with the aquarium fishery. The assessments of both fisheries showed that the fishers shift between fishing grounds and target different species associated with specific fishing grounds. Certain fishing grounds were preferred by both fisheries, and aquarium snorkel fishers were more likely to interact with artisanal fishing gears. Various studies have demonstrated that allocation of fishing effort is essentially not random, as fishers will tend to concentrate in areas where they are likely to experience higher catch rates to maximize on returns (Johannes *et al*., 2001; Pet-Soede *et al*., 2001; Wiyono *et al*., 2006; Daw, 2008). Thus, the roving behaviour increases the likelihood of interactions between fisheries in shared fishing grounds.

Areas where multiple fisheries occur are more likely to experience depletion of stocks and require management interventions that are ecosystem based (FAO, 2003; Micheli *et al*., 2014). The fishing grounds where interactions between artisanal and aquarium fishers were highly likely to occur in this study included Mwamba mkuu and Mkwiro on the south coast. The study estimated that approximately 8% of artisanal catches consisted of species of value to the aquarium fishery. In comparison, Cinner *et al*. (2009) estimated that <6% of artisanal fish catches constituted species strongly associated with corals, many of which are most likely targeted by aquarium fishers.

Selective targeting of the angelfishes, *P. imperator* and *P. semicirculatus,* by artisanal speargun fishers was documented in this study. Such selective targeting of angelfishes by speargun fishers has also been observed elsewhere in Belize (Babcock *et al*., 2013) and is an issue of concern as these species are highly valued, heavily fished and highly vulnerable to localized population declines due to their life history traits (Okemwa *et al*., 2016). The effects of cumulative fishing mortality on a species from multiple gears and fisheries is more likely to lead to a higher risk of localized depletion, relative to the impacts of an individual fishery (Micheli *et al*., 2014).

Thus, some precautionary management measures are needed to control such effects, especially where multiple fisheries impact reef fish populations as in Kenya. However, gear-based management interventions targeting the artisanal fishery are also crucial and should include improving enforcement of the ban on spearguns and adoption of gear modifications that minimize the capture of juveniles and low-value species targeted by the aquarium fishery. Trials on basket traps modified with escape gaps have yielded promising results in Kenya (see Mbaru & McClanahan, 2013; Gomes *et al*., 2014). Similar trials are also needed to establish optimum mesh and hook sizes for gillnets and handlines in order to avoid indiscriminate captures of reef fishes.

5.4. Recruitment Dynamics of Coral Reef Fishes in Coastal Kenya

Studies on the recruitment dynamics of juvenile reef fishes are scanty in the WIO region. This study represented the first effort in Kenya to understand the recruitment dynamics of the early post-settlement phase of reef fishes. Pomacentridae and Labridae were the most abundant species recruiting at the study sites, similar to the findings of Abesamis & Russ (2010) and Garpe & Öhman (2003) in Mafia, Tanzanian reefs. Ordination of the data using MDS (Fig. 4.17) showed that the species composition of recruits differed between sites. The MDS grouped study sites in mainland fringing lagoon reef sites (Kuruwitu, Kilifi and Wasini) as relatively similar in the species composition of recruits compared to offshore island fringing reef sites (Sii Island and Mwipwa). The spatial segregation reflects differences in habitat types and oceanographic factors between the nearshore and offshore sites.

Recruitment of juvenile reef fishes to shallow lagoon reefs along the Kenya coast was observed year-round, with a general unimodal peak during the warmer northeast monsoon season between the months of December and March. Similar unimodal peaks have been reported for the Great Barrier Reef in Australia (Russell *et al*., 1977), Barbados (Tupper & Hunte, 1994) and the Phillipines (Abesamis & Russ, 2010). The species composition of recruits signficiantly differed between seasons, demonstrating that seasonality has a strong influence on the recruitment dynamics f coral reef fish along the Kenya coast. The study showed a correlation of monthly variations in recruit densities and species richness with changes in sea temperature, which were observed to increase with increasing temperature similar to studies in the Great Barrier Reef (Russell *et al*., 1977), US Virgin Islands (Miller *et al*., 2000), and the Philippines (Abesamis & Russ, 2010).

Seasonal changes in environmental conditions can trigger spawning patterns and hence larval settlement when conditions become suitable. Some reef fish species are known to delay metamorphosis from the larval phase until triggered by certain chemical or environment cues corresponding with temperature or increased food availability (Lecchini *et al*., 2007). Moreover, seasonal changes in environmental conditions related to wave action, lunar and tidal cycles may differ between sites and this could have contributed to some of the spatial variations in recruitment strengths observed between the mainland (Kilifi and Kuruwitu) and offshore island fringing reef sites (Mwipa, Sii Island and Wasini) as observed in other similar studies (see Aburto-Oropeza & Balart, 2001; Nemeth & Appeldoorn, 2009; Tyler *et al*., 2009).

5.5. Habitat Associations of Recruit and Juvenile Coral Reef Fishes

The study demonstrated the importance of reef habitat types in structuring the recruitment of juvenile reef fish populations along the Kenya coast. Although diverse microhabitats were utilized, results of Canonical Correspondence Analysis (CCA) indicated live coral, rocky substrates and rugosity (or structural complexity) as most important habitat variables influencing the abundance of recruits and juveniles at the study sites (Fig. 4.23). Reef areas with high structural complexity provide a refuge to recruits from predators; which minimizes early post-settlement mortality (Gillanders *et al*., 2003).

Detrended Correspondence Analysis (DCA) further demonstrated species-specific habitat associations among recruits and juveniles (Figs. 4.24 and 4.25). Studies have confirmed that recruitment of juvenile coral reef fish is strongly associated with particular habitats (Sale *et al*., 1984b; Holbrook *et al*., 2000; Sponaugle *et al*., 2012). The study observed that juveniles of the Pomacentridae species *C. viridis*, and *D. aruanus* were strongly associated with live coral habitats. The Pomacentridae species *Stegastes nigricans* and *P. lacrymatus* were strongly associated with dead coral and rocky substrates. This observation concurs with studies elsewhere (Lecchini *et al*., 2007; Deocadez *et al*., 2008; Ticzon *et al*., 2012).

As observed in this study, clear associations among recruits and juveniles of Pomacentridae species with specific growth forms of live hard coral cover have also been documented in a number of studies elsewhere (see Tolimieri, 1998; Sale *et al*., 2005; Wilson *et al*., 2008a, 2010; DeMartini *et al*., 2010). Because many Pomacentridae species have strong microhabitat associations, they may exhibit consistent patterns of habitat use; however, such consistency may result in interspecific competition for space shortly after settlement as observed for the coral-dwelling damselfishes *Dascylus malenurus* and *Chrysiptera parasema* at Kimbe Bay, New Guinea (Bonin *et al*., 2009). Habitat characteristics at reef sites are therefore important variables to be considered in modeling recruitment patterns to coral reefs (Shulman, 1984).

On the other hand, some species exhibit variable patterns of habitat use (Tolimieri, 1998). In this study, recruits and juveniles of the labrid species *T. hebraicum* and *G. caeruleus* were observed to be associated with diverse habitats indicating generalist behavior, which may enhance resilience to loss of coral cover (Jones *et al*., 2004; Bonin *et al*., 2009). Thus, understanding species-specific habitat associations may be useful in modelling species distributions at different spatial scales and in predicting the likely effects of habitat degradation along different gradients of anthropogenic pressure. The conclusions and recommendations derived from the discussion of these results are summarized in the next chapter.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The results on spatio-temporal patterns of the marine aquarium fishery demonstrate that species composition of marine aquarium fisher catches along the Kenya coast is variable in time and space, and is influenced by the mode of fishing (snorkel vs. SCUBA). Although the temporal-scale of the datasets was relatively short, the findings address important information gaps and provide a benchmark for prioritizing future quantitative assessments. The vulnerability risk assessment of 102 target species based on their productivity and susceptibility attributes predicted four fish species *Pomacanthus maculosus*, *Pomacanthus chrysurus*, *Amphiprion allardi* and *Amphiprion akallopisos* as having a high risk to overfishing by the marine aquarium fishery. These species are among the most valued and traded by the marine aquarium fishery.

The findings further confirm the existence of gear-based overlaps in species selectivity between artisanal and aquarium in coastal Kenya and indicate that some species targeted by aquarium fishers are experiencing added fishing mortality. A major finding of the study was that handlines, basket traps, and spearguns had the highest potential to interact with the aquarium fishery, particularly with aquarium snorkel fishers who fish in relatively shallow areas. There was also evidence of selective targeting of angelfish species (*P. imperator and P. semicirculatus*) by speargun fishers, which further increase the risk to overfishing. Thus, there is a need to develop species-specific harvest controls, as well as area and temporal closures for the vulnerable species.

Understanding the recruitment dynamics of coral reef fish to natural reefs, especially for fish species that are highly targeted, can be particularly useful in predicting the sustainability of harvestable stocks. The study demonstrates the importance of understanding the influence of recruitment patterns on the assemblage structure of local fish communities. The variations in recruitment between study sites observed were most likely influenced by species-specific dynamics associated with benthic habitat preferences as well as seasonal changes in environmental variables such as sea temperature and wave action. A general recruitment peak was observed to occur between December and March. This temporal pattern was consistent between years, although the recruitment strengths varied annually between sites for different species. This finding supports the hypothesis of spatio-temporal variation in recruitment of coral reef fishes on the Kenyan coast.

The results of this study further support the hypothesis that some target species are highly vulnerable to over-exploitation and cumulative gear interactions with artisanal and aquarium fisheries. The study has also provided new insights on the importance of shallow fringing lagoon reefs along the Kenya coast as recruitment hotspots and nursery grounds for juvenile reef fishes. The study provides a scientific baseline that models spatio-temporal variability in fishery dynamics with ecological processes associated with target species. Overall, the results bridge critical information gaps on the marine aquarium fishery in Kenya, which will be useful for the development of precautionary management measures to enhance sustainability.

6.2. Recommendations

Based on the results of this study, the following recommendations are made:

1. **Institute management measures** to enhance sustainable harvesting of vulnerable aquarium species identified in this study such as the anemonefishes and angelfishes. The measures should include setting catch limits and/or species bans to control harvest rates. Given that enforcement of species bans may be met with some resistance by the industry, it will be important to ensure that the decision-making process is consultative involving key stakeholders including the industry players to enhance compliance. Taking into consideration existing uncertainties on the biology and stock status of target species, precautionary management measures should focus on regulating fishing effort in the aquarium fishery by limiting entry, and by implementing spatial or seasonal closures during peak periods for recruitment. An adaptive management approach with full participation of all stakeholders will also be needed.

2. In-light of the cumulative risks faced by some aquarium species from multiple gear types, application of a modified PSA risk assessment is recommended, such as that undertaken by Micheli *et al*., (2014).

3. **Promotion of gear-based management approaches** is recommended to reduce the effects of cumulative interactions with artisanal fisheries should focus on improving the selectivity of artisanal fishing gears to minimize the capture of juvenile reef fish. Apart from this, there is a need to improve enforcement of gear restrictions on the illegal use of spearguns because these were found to selectively target vulnerable angelfish species.

4. **Raising local awareness on the importance of protecting shallow fringing reef areas** should be paramount as these were found to be important recruitment grounds

for post-larval stages of many species. This should be coupled with the promotion of well managed marine protected areas and community conservation areas to help in replenishing exploited reef fish populations and restoring degraded habitats.

5. **Future research** should focus on collection of basic information on the biology and ecology of primary species targeted by the marine aquarium fishery to support the development of appropriate management measures to conserve the fish stocks. Establish a long-term recruitment-monitoring programme will also provide useful biological signals of environmental change especially those associated with climate change and habitat degradation. Closer monitoring of the species identified as vulnerable to overexploitation by the aquarium fishery should be prioritized. An assessment of the impacts of collecting high numbers of the cleaner wrasse, *Labroides dimidiatus* is also recommended.

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APPENDICES

APPENDIX I. Definitions of productivity and susceptibility attributes used in the PSA of species targeted in Kenya's aquarium fishery (adapted from Hobday *et al*., 2007, Roelofs & Silcock (2008), and Patrick *et al*. (2009).

Productivity Attributes	**Definition**
Minimum population doubling time	Defined as the time required to double a population size and used as a proxy for recruitment rate. Approximations were obtained from Fishbase.
Average maximum age	Maximum age is a direct indication of the natural mortality rate (M), where low levels of M are negatively correlated with high maximum ages. Approximations of maximum age were obtained from Fishbase.
Fecundity	Defined as the number of eggs produced at each spawning event or period. The more eggs that are produced, the better the chances of recovery success (Values used are approximations obtained from Fishbase or empirical studies from published literature at the species level or generalized at the family level (see list of references used in the analysis below).
Average maximum size	Defined as the maximum length in centimeters (cm) attained by each of the species. Maximum size is correlated with productivity, with large fish tending to have lower levels of productivity. Approximations of maximum size were obtained from Fishbase. The length measurements are generally taken from the end of the snout to the tip of the tail.
Average size at maturity	Defined as the mean size at which 50% of a cohort spawns for the first time. Low mean size at maturity would suggest higher growth rates and therefore higher productivity. Approximations of average size at maturity were obtained from Fishbase.
von Bertalanffy (K)	The von Bertalanffy growth coefficient measures how rapidly a fish reaches its maximum size, where long-lived, low-productivity stocks tend to have low values of *k*.

APPENDIX 1. Continued

Susceptibility attributes	**Definition**
Reproductive strategy	The breeding strategy of a stock provides an indication of the level of mortality that might be expected for the offspring in the first stages of life.
Trophic level	The position of a stock within the larger fish community can be used to infer stock productivity, with lower trophic-level stocks generally being more productive and having higher growth rates than higher trophic-level stocks.
Availability	This attribute considers the overlap of fishing effort with a species distribution. For species without distribution maps as in this case, availability is scored based on broad geographic distribution categories (Global: Indo-Pacific, Regional: Western Indian Ocean, and endemic to East Africa or Kenya).
Habitat niche	This is termed as "ecological niche" by Roelofs and Silcock (2008). The attribute emphasizes the critical interconnections between fish species and habitats. The more specific an ecological connection and the more restricted that species is, the more likely it is to be vulnerable to heavy collection leading to localized depletion. This also emphasizes the health of critical habitats in ensuring species survival e.g. climate change and coral bleaching are likely to have a greater impact on obligate corallivores and coral dwellers.
Selectivity:Desirability/market value	This attribute assumes that highly valued fish stocks are more susceptible to overfishing or becoming overfished and represents an interaction between the demand of a species by the trade (desirability) and the market value, which may not always reflect demand, but simply a reflection of the costs associated with collecting a species. Low value species are generally easy to collect and plentiful and are considered a low vulnerability risk, whereas a higher market value may be related to the rarity of a species or reflect costs associated with its collection and handling.

APPENDIX I. continued

Susceptibility attributes	**Definition**
Encounterability	Encounterability is determined by the depth zone(s) that a species occurs, and is correlated with the level of fishing effort that can be applied. Higher risk corresponds to fishing within the core depth range of a species. Shallow water species found from 0 to 5m have increased vulnerability/exposure to collection due to high encounterability by snorkel fishers compared to species found in deeper depths, which can only be readily accessed by SCUBA from 5m and beyond 15m. This restricts the time spent fishing and hence fishing effort (the number of dives that can be safely made), as may be affected by seasonal climatic conditions. General depth approximations for scoring the species were obtained from Fishbase and corroborated with aquarium fishers.
Post capture mortality	This attribute measures the survival probability of the species after capture, which may vary by species. Data for scoring was based on percentage composition estimates of mortalities at family level at handling facilities (Okemwa *et al*., 2006 see below)

APPENDIX II. List of references used in the PSA for scoring productivity attributes

Species	References
Pomacentridae (Anemonefishes): *A. allardi* *A. akallopisos*	Expert opinion on similar taxa in: • Buechler, K. (2005). An evaluation of geographic variation in the life history and behaviour of anemonefishes: a common-garden approach. PhD thesis James Cook University, Australia. 175pp • Mangi, S. C., Roberts, C. M. (2006). Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. *Marine Pollution Bulletin* 52, 1646-1660. • Fishbase for other parameters
Other Pomacentridae: *A. sexfasciatus* *C. dimidiata* *C. nigrura* *C. viridis* *D. aruanus* *D. carneus* *D. trimaculatus*	Expert opinion on similar taxa in: • Vijay Anand P.E., Pillai, N. G. K. (2002). Reproductive biology of some common coral reef fishes of the Indian EEZ1. *Marine Journal of the Biological Association of India*, 44, 122-135. • Madan, M. Pillai, G., & Kunhi, Koya K. K (1985). Biology of the bluepuller, *Chromis caeruleus* (Cuvier) from Minicoy Atoll. Central Marine Fisheries Research Institute, Cochin. • Pillai, C. S. G., Mohan, M., & Kunhi, Koya K. K (1985). Ecology and biology of the White tailed humbug *Dascyllus aruanus* (Pomacentridae, Pisces) from Minicoy Atoll. *Journal of marine biological association of India* 27 (1&2), 113-123. • Mangi, S. C., & Roberts, C. M. (2006). Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. *Marine Pollution Bulletin* 52, 1646-1660.

Species	References
	• Fishbase for other parameters
Acanthuridae: *A. leucosternon, A. lineatus* *A.tennentii, A. triostegus* *C. truncatus, P. hepatus* *N. brevirostris, N. lituratus* *N. unicornis, N. vlamingi* *Z. desjardinii, Z. scopas* *Z. velifer*	• Mangi, S. C., & Roberts, C. M. (2006). Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. *Marine Pollution Bulletin* 52, 1646-1660. • Expert opinion based on similar taxa • Fishbase for other parameters
Chaetodontidae: *C. auriga, C. dolosus,* *C. falcula, C. guttatisimus* *C. kleinii, C. leucopleura* *C. lunula, C. melannotus* *C. unimaculatus,* *C. xanthocephalus* *C. zanzibarensis, H. acuminatus*	Expert opinion on similar taxa in: • Vijay, A., Pillai, P. E., N. G. K. (2002). Reproductive biology of some common coral reef fishes of the Indian EEZ1. Marine Journal of the Biological Association of India, 44, 122-135. • Fishbase for other parameters
Tetraodontidae: *A. hispidus, A. mappa* *A. nigropunctatus, A. stellatus* *C. janthinoptera, C. solandri* *C. valentini*	• Yu, C. F., 2003. A Comprehensive study of the Hong Kong pufferfishes and their toxicity. PhD Thesis The Hong Kong Polytechnic University. 275 pp. • Gladstone, W., Westoby, M. (1988). Growth and reproduction in *Canthigaster valentini* (Pisces, Tetradontidae): a comparison of a toxic reef fish with other reef fishes. Environmental biology of Fishes 21, 201-221. • Expert opinion on similar taxa • Fishbase for other parameters
Pomacanthide: *C. acanthops, C. multispinnis* *A. trimaculatus, P. chrysurus* *P. imperator , P. maculosus* *P. semicirculatus,*	Expert opinion on similar taxa in: • Arellano-Martínez, M., B. P. Ceballos-Vázquez, L. Hernández-Olalde & F. Galván-Maga ña. 2006. Fecundity of Cortez angelfish *Pomacanthus zonipectus* (Gill, 1863) (Teleostei: Pomacanthidae) off Espiritu Santo Island, Gulf of California, Mexico. *Ciencias Marinas* 32, 1-7.

Species	**References**
P. diacanthus	• Tebua, S., (2005). Age-based demography and reproductive ontogeny of angelfishes belonging to the family Pomacanthidae. MSc thesis, James Cook University. 128pp. • Sakai, Y., (1996). Fecundity of female angelfish, *Centropyge ferrugatus* independent of body size: field collection of spawned eggs. *Ichthyological Research* 43, 186-189. • Fishbase for other parameters
Blennidae: *E. brevis, S. fasciatus* *A. fuscus, A. taeniatus* *M. mossambicus, E. midas*	• No fecundity information available (expert opinion used based on reproductive strategy) • Fishbase for other parameters
Labridae: *C. exquisitus, C. aygula* *C. cuvieri, C. Formosa,* *C. trilobatus, G. caeruleus,* *H. hortulanus, H. iridis,* *H. fasciatus, H. melapterus,* *L. bicolor, L. dimidiatus,* *M. bipartitus, P. carpenterri,* *P. hexataenia, T. hardwicke,* *T. hebraicum,* *A. caeruleopuncatatus* *A. meleagrides, A. twistii,*	Expert opinion on similar taxa in: • Vijay, A., Pillai, P. E., N. G. K. (2002). Reproductive biology of some common coral reef fishes of the Indian EEZ1. Marine *Journal of the Biological Association of India*, 44 (1&2), 122 – 135. • Expert opinion on fecundity for *Labroides sp* due to haremic nature • Fishbase for other parameters
Scorpaenidae: *P. antennata, P. miles* *P. radiata, D. brachypterus,* *D. zebra*	• Morris J.D., 2009. Biology and ecology of the invasive Indo-Pacific Lionfish. PhD Thesis, North Carolina State University 183pp. • Mangi, S.C., & Roberts, C.M. (2006). Quantifying the environmental impacts of artisanal fishing gear on Kenya’s coral reef ecosystems. Marine Pollution Bulletin 52, 1646-1660. • Expert opinion on similar taxa • Fishbase for other parameters

Species	References
Serranidae (Anthiases): *N. carberryi* *P. squamipinnis*	- No fecundity information (Expert opinion on fecundity for *Labroides sp* due to haremic nature - Mangi, S. C., & Roberts, C. M (2006). Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. *Marine Pollution Bulletin* 52, 1646-1660. - Fishbase for other parameters
Other Serranidae: *C. argus* *C. miniata*	- No fecundity information available (expert opinion used based on reproductive strategy) - Mangi, S.C.,& Roberts, C.M (2006). Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. *Marine Pollution Bulletin* 52, 1646-1660. - Fishbase for other parameters
Monacanthidae: *O. longirostris*	- No fecundity information available (expert opinion used based on reproductive strategy) - Fishbase for other parameters
Ostraciidae *Ostracion cubicus* *Ostracion meleagris*	- No fecundity information available (expert opinion used based on reproductive strategy) - Fishbase for other parameters
Balistidae: *B. conspicillum, R. aculeatus, P. fuscus*	- No fecundity information available (expert opinion used based on reproductive strategy) - Fishbase for other parameters
Gobiidae: *V. helsdingenii, C. aurora* *V. puellaris, V. sexguttata* *V. strigata*	- No fecundity information available (expert opinion used based on reproductive strategy) - Fishbase for other parameters
Lutjanidae: *M. niger*	- No fecundity information available (expert opinion used based on reproductive strategy) - Fishbase for other parameters
Carangidae: *G. speciosus*	- No fecundity information available (expert opinion used based on reproductive strategy) - Fishbase for other parameters
Microdesmidae: *N. magnifica*	- No fecundity information available (high risk score used due to no data) - Fishbase for other parameters

Species	References
Mullidae: *P. cyclostomus*	• No fecundity information available (expert opinion used based on reproductive strategy) • Fishbase for other parameters
Syngnathidae: *D. excisus*	• No fecundity information available (expert opinion used based on reproductive strategy) • Fishbase for other parameters
Zanclidae: *Z. cornutus*	• No fecundity information available (expert opinion used based on reproductive strategy); Fishbase for other parameters

APPENDIX III. Summary of scoring of the productivity and susceptibility attributes given and the resulting overall risk values for 102 fish species targeted by the aquarium fishery in Kenya. The cut-off threshold values set as: high (> 3.18), moderate (2.64 – 3.18) and low (< 2.64) based on Hobday *et al*., 2007.

No.	Family	Latin Name	Common Name	Average maximum age	Minimum population doubling time	Fecundity	Average maximum size	Av size at maturity	Von Bertalanffy (K)	Reproductive strategy	Trophic level	Productivity	Availability	Habitat niche	Desirability / market value	Encounterability	Post capture mortality	Susceptibility	Overall Risk Values	Overall Risk Category	Vulnerability Risk Ranking
1	Pomacanthidae	*Pomacanthus maculosus*	Yellowbar angelfish	3	2	2	2	2	3	1	2	2.13	3	3	3	3	3	3.00	3.68	High	1
2	Pomacanthidae	*Pomacanthus chrysurus*	Goldtail angelfish	2	2	2	2	2	2	1	2	1.88	3	3	3	3	3	3.00	3.54	High	2
4	Pomacentridae	*Amphiprion allardi*	Twobar anemonefish	2	1	3	1	1	1	2	2	1.63	3	3	3	3	3	3.00	3.41	High	3
3	Pomacentridae	*Amphiprion akallopisos*	Skunk clownfish	2	1	3	1	1	1	2	2	1.63	3	3	3	3	3	3.00	3.41	High	3
5	Pomacanthidae	*Pomacanthus imperator*	Emperor angelfish	2	2	2	2	2	2	1	2	1.88	2	3	3	3	3	2.33	2.99	Med	4
6	Pomacanthidae	*Pygoplites diacanthus*	Regal angelfish	2	2	2	1	2	1	1	2	1.63	2	3	3	3	3	2.33	2.84	Med	5
7	Labridae	*Coris aygula*	Clown coris	3	3	2	3	3	3	1	2	2.50	2	1	3	3	2	1.30	2.82	Med	6
8	Acanthuridae	*Paracanthurus hepatus*	Palette surgeonfish	2	1	1	2	2	1	1	2	1.50	3	3	3	3	2	2.33	2.77	Med	7
9	Labridae	*Halichoeres iridis*	Radiant wrasse	2	1	2	1	1	1	1	2	1.38	3	2	3	3	3	2.33	2.71	Med	8
10	Microdesmidae	*Nemateleotris magnifica*	Fire goby	2	3	3	1	1	1	2	2	1.88	2	2	3	3	3	1.89	2.66	Med	9
11	Pomacanthidae	*Pomacanthus semicirculatus*	Semicircle angelfish	2	2	2	2	2	2	1	2	1.88	2	2	3	3	3	1.89	2.66	Med	9
12	Scorpaenidae	*Pterois miles*	Devil firefish	3	3	1	2	2	3	1	3	2.25	2	2	3	3	1	1.30	2.60	Low	10
13	Serranidae	*Cephalopholis miniata*	Coral hind	3	3	2	2	2	3	1	3	2.38	1	1	1	3	1	1.02	2.59	Low	11
14	Carangidae	*Gnathanodon speciosus*	Golden trevally	2	3	2	3	2	3	1	3	2.38	1	1	1	3	1	1.02	2.59	Low	11
15	Acanthuridae	*Zebrasoma desjardinii*	Desjardin's sailfin tang	2	2	3	2	2	1	1	1	1.75	3	2	3	3	2	1.89	2.57	Low	12
16	Acanthuridae	*Zebrasoma velifer*	Sailfin tang	2	2	3	2	1	1	1	1	1.63	3	2	3	3	2	1.89	2.49	Low	13
17	Lutjanidae	*Macolor niger*	Black and white snapper	2	2	2	3	3	2	1	3	2.25	1	1	2	3	1	1.05	2.48	Low	14
18	Labridae	*Hemigymnus melapterus*	Blackeye thicklip	2	3	2	3	2	2	1	2	2.13	1	2	2	3	2	1.20	2.44	Low	15
19	Labridae	*Coris formosa*	Queen coris	3	3	2	2	2	2	1	2	2.13	2	1	3	3	1	1.15	2.42	Low	16
20	Chaetodontidae	*Chaetodon melannotus*	Blackback butterflyfish	3	3	1	1	1	3	1	3	2.00	1	2	2	3	3	1.30	2.38	Low	17
21	Serranidae	*Cephalopholis argus*	Peacock hind	2	3	2	2	2	2	1	3	2.13	1	2	1	3	1	1.05	2.37	Low	18
22	Scorpaenidae	*Dendrochirus zebra*	Zebra turkeyfish	3	3	2	1	2	2	1	3	2.13	1	2	1	3	1	1.05	2.37	Low	18
23	Balistidae	*Balistoides conspicillum*	Clown triggerfish	2	2	1	2	2	2	2	2	1.88	3	2	3	3	1	1.44	2.37	Low	19
24	Tetraodontidae	*Arothron stellatus*	Stellate puffer	2	2	1	3	3	2	1	2	2.00	1	1	3	3	1	1.07	2.27	Low	20
25	Gobiidae	*Valenciennea helsdingenii*	Twostripe goby	2	2	3	1	2	2	2	2	2.00	1	1	3	3	1	1.07	2.27	Low	20

Appendix III. continued

No.	Family	Latin Name	Common Name	Average maximum age	Minimum population doubling time	Fecundity	Average maximum size	Av size at maturity	Von Bertalanffy (K)	Reproductive strategy	Trophic level	Productivity	Availability	Habitat niche	Desirability / market value	Encounterability	Post capture mortality	Susceptibility	Overall Risk Values	Overall Risk Category	Vulnerability Risk Ranking
26	Balistidae	*Pseudobalistes fuscus*	Yellow spotted triggerfish	2	2	2	2	2	2	2	2	2.00	1	1	3	1	1	1.02	2.25	Low	21
27	Labridae	*Anampses caeruleopuncatatus*	Blue spotted wrasse	2	2	2	2	2	2	1	2	1.88	1	2	2	3	2	1.20	2.22	Low	22
28	Labridae	*Hemigymnus fasciatus*	Barred thicklip	2	3	2	2	2	1	1	2	1.88	1	2	2	3	2	1.20	2.22	Low	22
29	Acanthuridae	*Naso brevirostris*	Spotted unicornfish	2	2	3	3	2	1	1	1	1.88	1	2	2	3	2	1.20	2.22	Low	22
30	Acanthuridae	*Naso unicornis*	Bluespine unicornfish	2	2	3	3	2	1	1	1	1.88	1	2	2	3	2	1.20	2.22	Low	22
31	Acanthuridae	*Zebrasoma scopas*	Twotone tang	2	2	3	1	2	3	1	1	1.88	2	2	1	3	2	1.20	2.22	Low	22
32	Tetraodontidae	*Arothron mappa*	Map puffer	2	2	1	3	2	2	1	2	1.88	2	1	3	3	1	1.15	2.20	Low	23
33	Pomacanthidae	*Apolemichthys trimaculatus*	Threespot angelfish	2	2	3	1	2	1	1	2	1.75	1	2	2	3	3	1.30	2.18	Low	24
34	Labridae	*Labroides bicolor*	Bicolor cleaner	2	3	3	1	1	1	1	3	1.88	1	2	1	3	2	1.10	2.17	Low	25
35	Tetraodontidae	*Arothron hispidus*	White-spotted puffer	2	2	2	2	2	2	1	2	1.88	1	1	3	3	1	1.07	2.16	Low	26
36	Mullidae	*Parupeneus cyclostomus*	Goldsaddle goatfish	2	2	2	2	2	1	1	3	1.88	1	1	3	3	1	1.07	2.16	Low	26
37	Labridae	*Coris cuvieri*	African coris	2	2	2	2	2	2	1	2	1.88	1	1	1	3	2	1.05	2.15	Low	27
38	Labridae	*Bodianus anthioides*	Lyretail hogfish	2	2	2	1	2	1	1	2	1.63	2	2	2	3	2	1.40	2.14	Low	28
39	Acanthuridae	*Naso lituratus*	Orangespine unicornfish	2	2	3	2	2	1	1	1	1.75	1	2	2	3	2	1.20	2.12	Low	29
40	Acanthuridae	*Naso vlamingii*	Vlamingi tang	2	2	3	2	2	1	1	1	1.75	1	2	2	3	2	1.20	2.12	Low	29
41	Ostraciidae	*Ostracion cubicus*	yellowbox fish	2	1	2	2	2	2	1	2	1.75	2	1	3	3	1	1.15	2.09	Low	30
42	Pomacentridae	*Chromis viridis*	Blue green damselfish	2	1	2	1	1	1	2	2	1.50	1	3	3	3	2	1.44	2.08	Low	31
43	Labridae	*Anampses twistii*	Yellowbreasted wrasse	2	2	3	1	1	1	1	2	1.63	1	2	3	3	2	1.30	2.08	Low	32
47	Gobiidae	*Amblyeleotris aurora*	Pinkbar goby	2	2	2	1	1	1	2	2	1.63	2	2	3	3	1	1.30	2.08	Low	32
44	Pomacentridae	*Dascyllus aruanus*	Whitetail dascyllus	2	2	2	1	1	1	2	2	1.63	2	3	1	3	2	1.30	2.08	Low	32
45	Labridae	*Labroides dimidiatus*	Bluestreak cleaner Wrasse	2	2	3	1	1	1	1	2	1.63	1	2	3	3	2	1.30	2.08	Low	32
46	Zanclidae	*Zanclus cornutus*	Moorish Idol	2	2	2	1	1	2	1	2	1.63	1	2	3	3	2	1.30	2.08	Low	32
48	Gobiidae	*Valenciennea puellaris*	Maiden goby	2	2	3	1	1	1	2	2	1.75	1	1	1	3	1	1.02	2.03	Low	33
49	Labridae	*Cirrhilabrus exquisitus*	Exquisite wrasse	2	1	1	1	1	1	1	2	1.25	2	2	3	3	2	1.59	2.02	Low	34
50	Labridae	*Anampses meleagrides*	Spotted wrasse	2	2	3	1	1	1	1	2	1.63	1	2	2	3	2	1.20	2.02	Low	35

Appendix III. continued

No.	Family	Latin Name	Common Name	Average maximum age	Minimum population doubling time	Fecundity	Average maximum size	Av size at maturity	Von Bertalanffy (*K*)	Reproductive strategy	Trophic level	Productivity	Availability	Habitat niche	Desirability / market value	Encounterability	Post capture mortality	Susceptibility	Overall Risk Values	Overall Risk Category	Vulnerability Risk Ranking
51	Ostraciidae	*Ostracion meleagris*	White spotted boxfish	2	1	2	1	2	2	1	2	1.63	2	1	3	3	1	1.15	1.99	Low	36
52	Scorpaenidae	*Pterois antennata*	Spotfin lionfish	2	2	1	1	1	2	1	3	1.63	1	2	3	3	1	1.15	1.99	Low	36
53	Balistidae	*Rhinecanthus aculeatus*	Picasso trigger	2	1	2	2	1	1	2	2	1.63	2	1	3	3	1	1.15	1.99	Low	36
54	Serranidae	*Nemanthias carberryi*	Threadfin anthias	2	3	1	1	1	1	1	2	1.50	2	2	3	3	1	1.30	1.98	Low	37
55	Labridae	*Gomphosus caeruleus*	Indian ocean bird wrasse	2	2	2	2	1	1	1	2	1.63	2	1	1	3	2	1.10	1.96	Low	38
56	Chaetodontidae	*Heniochus acuminatus*	Pennant coralfish	2	1	3	1	2	1	1	2	1.63	1	2	1	3	2	1.10	1.96	Low	38
57	Chaetodontidae	*Chaetodon falcula*	Saddleback butterflyfish	1	1	1	1	1	1	1	2	1.13	2	2	2	3	3	1.59	1.95	Low	39
58	Tetraodontidae	*Arothron nigropunctatus*	Blackspotted puffer	2	2	1	2	2	1	1	2	1.63	1	1	3	3	1	1.07	1.95	Low	40
59	Monacanthidae	*Oxymonacanthus longirostris*	Harlequin filefish	2	2	2	1	1	1	1	2	1.50	1	3	3	3	1	1.22	1.93	Low	41
60	Scorpaenidae	*Dendrochirus brachypterus*	Shortfin turkeyfish	2	2	2	1	1	1	1	3	1.63	1	2	1	3	1	1.05	1.93	Low	42
61	Scorpaenidae	*Pterois radiata*	Clearfin lionfish	2	2	1	1	1	2	1	3	1.63	1	2	1	3	1	1.05	1.93	Low	42
62	Gobiidae	*Valenciennea sexguttata*	Sixspot goby	2	1	3	1	1	1	2	2	1.63	1	1	1	3	1	1.02	1.92	Low	43
63	Acanthuridae	*Acanthurus tennentii*	Doubleband surgeonfish	2	2	1	2	2	1	1	1	1.50	1	2	2	3	2	1.20	1.92	Low	44
64	Blenniidae	*Meiacanthus mossambicus*	Mozambique fangblenny	2	1	2	1	1	1	2	2	1.50	2	2	2	3	1	1.20	1.92	Low	44
65	Acanthuridae	*Acanthurus leucosternon*	Powder-blue surgeonfish	2	2	1	2	1	1	1	1	1.38	1	2	3	3	2	1.30	1.89	Low	45
66	Pomacentridae	*Chromis nigrura*	Blacktail chromis	1	1	2	1	1	1	2	2	1.38	1	3	2	3	2	1.30	1.89	Low	45
67	Pomacentridae	*Dascyllus carneus*	Cloudy dascyllus	1	1	2	1	1	1	2	2	1.38	2	3	1	3	2	1.30	1.89	Low	45
68	Labridae	*Pseudocheilinus hexataenia*	Sixline wrasse	2	1	2	1	1	1	1	2	1.38	1	2	3	3	2	1.30	1.89	Low	45
69	Acanthuridae	*Acanthurus lineatus*	Striped surgeonfish	2	2	1	2	2	1	1	1	1.50	1	1	2	3	2	1.10	1.86	Low	46
70	Pomacentridae	*Chromis dimidiata*	Chocolatedip chromis	2	1	2	1	1	1	2	2	1.50	1	2	1	3	2	1.10	1.86	Low	46
71	Labridae	*Thalassoma hebraicum*	Goldbar wrasse	2	2	2	1	1	1	1	2	1.50	1	1	2	3	2	1.10	1.86	Low	46
72	Chaetodontidae	*Chaetodon lunula*	Raccoon butterflyfish	1	1	1	1	1	1	1	2	1.13	1	2	3	3	3	1.44	1.83	Low	47
73	Chaetodontidae	*Chaetodon unimaculatus*	Teardrop butterflyfish	1	1	1	1	1	1	1	2	1.13	1	3	2	3	3	1.44	1.83	Low	47
74	Tetraodontidae	*Canthigaster valentini*	Honeycomb toby	1	2	3	1	1	1	1	2	1.50	1	2	1	3	1	1.05	1.83	Low	48
75	Labridae	*Cheilinus trilobatus*	Tripetail wrasse	1	2	1	2	2	1	1	2	1.50	1	1	2	3	1	1.05	1.83	Low	48

Appendix III. continued

No.	Family	Latin Name	Common Name	Average maximum age	Minimum population doubling time	Fecundity	Average maximum size	Av size at maturity	Von Bertalanffy (*K*)	Reproductive strategy	Trophic level	Productivity	Availability	Habitat niche	Desirability / market value	Encounterability	Post capture mortality	Susceptibility	Overall Risk Values	Overall Risk Category	Vulnerability Risk Ranking
76	Pomacanthidae	*Centropyge multispinis*	Dusky angelfish	2	1	2	1	1	1	1	2	1.38	1	2	2	3	2	1.20	1.82	Low	49
77	Acanthuridae	*Ctenochaetus truncatus*		2	1	3	1	1	1	1	1	1.38	1	2	2	3	2	1.20	1.82	Low	49
78	Labridae	*Halichoeres hortulanus*	Checker board wrasse	2	1	2	1	1	1	1	2	1.38	1	2	2	3	2	1.20	1.82	Low	49
79	Labridae	*Macropharyngodon bipartitus*	Rare wrasse	2	1	2	1	1	1	1	2	1.38	2	2	1	3	2	1.20	1.82	Low	49
80	Tetraodontidae	*Canthigaster janthinoptera*	Honeycomb toby	1	2	2	1	1	2	1	2	1.50	1	1	1	3	1	1.02	1.82	Low	50
81	Tetraodontidae	*Canthigaster solandri*	Spotted sharpnose	1	2	3	1	1	1	1	2	1.50	1	1	1	3	1	1.02	1.82	Low	50
82	Chaetodontidae	*Chaetodon auriga*	Threadfin butterflyfish	1	1	2	1	1	1	1	2	1.25	1	2	2	3	3	1.30	1.80	Low	51
83	Chaetodontidae	*Chaetodon guttatisimus*	Peppered butterflyfish	1	1	1	1	1	1	2	2	1.25	1	2	2	3	3	1.30	1.80	Low	51
84	Chaetodontidae	*Chaetodon leucopleura*	Somali butterflyfish	1	1	1	1	1	1	2	2	1.25	1	2	2	3	3	1.30	1.80	Low	51
85	Pomacentridae	*Dascyllus trimaculatus*	Three spot damsel	2	1	1	1	1	1	2	2	1.38	1	3	1	3	2	1.15	1.79	Low	52
86	Blenniidae	*Exallias brevis*	Leopard blenny	2	1	1	1	1	1	2	2	1.38	2	1	2	3	1	1.10	1.76	Low	53
87	Labridae	*Paracheilinus carpenteri*	Pink flasher	2	1	2	1	1	1	1	2	1.38	1	2	2	1	3	1.10	1.76	Low	53
88	Blenniidae	*Ecsenius midas*	Persian blenny	2	1	1	1	1	1	2	2	1.38	1	1	3	3	1	1.07	1.74	Low	54
89	Serranidae	*Pseudanthias squamipinnis*	Sea goldie	2	1	2	1	1	1	1	2	1.38	1	1	3	3	1	1.07	1.74	Low	54
90	Blenniidae	*Salarias fasciatus*	Jewelled blenny	2	1	2	1	1	1	2	1	1.38	1	1	3	3	1	1.07	1.74	Low	54
91	Blenniidae	*Atrosalarias fuscus*	Highfin blenny	2	1	2	1	1	1	2	1	1.38	2	1	1	3	1	1.05	1.73	Low	55
92	Pomacanthidae	*Centropyge acanthops*	Orangeback angelfish	1	1	3	1	1	1	1	2	1.38	1	1	1	3	2	1.05	1.73	Low	55
93	Labridae	*Thalassoma hardwicke*	Sixbar wrasse	1	1	2	1	1	1	1	3	1.38	1	1	2	3	1	1.05	1.73	Low	55
94	Chaetodontidae	*Chaetodon kleinii*	Sunburst butterflyfish	1	1	1	1	1	1	1	2	1.13	1	2	2	3	3	1.30	1.72	Low	56
95	Chaetodontidae	*Chaetodon xanthocephalus*	Yellowhead butterflyfish	1	1	1	1	1	1	1	2	1.13	1	2	2	3	3	1.30	1.72	Low	56
96	Chaetodontidae	*Chaetodon zanzibarensis*	Zanzibar butterflyfish	1	1	1	1	1	1	1	2	1.13	1	2	2	3	3	1.30	1.72	Low	56
97	Gobiidae	*Valenciennea strigata*	Blueband goby	1	1	1	1	1	1	2	3	1.38	1	1	1	3	1	1.02	1.71	Low	57
98	Syngnathidae	*Doryrhamphus excisus*	Bluestripe pipefish	1	1	1	1	1	1	2	2	1.25	1	2	3	3	1	1.15	1.70	Low	58
99	Pomacentridae	*Abudefduf sexfasciatus*	Scissortail sergeant	2	1	1	1	1	1	2	1	1.25	1	2	1	3	1	1.05	1.63	Low	59
100	Blenniidae	*Aspidontus taeniatus*	False cleanerfish	2	1	1	1	1	1	2	1	1.25	1	1	1	3	1	1.02	1.62	Low	60
101	Chaetodontidae	*Chaetodon dolosus*	African butterflyfish	1	1	1	1	1	1	1	2	1.13	1	3	2	1	3	1.15	1.61	Low	61
102	Acanthuridae	*Acanthurus triostegus*	Convict surgeonfish	1	2	1	1	1	1	1	1	1.13	1	1	2	3	2	1.10	1.57	Low	62

APPENDIX IV. Check list of 244 fish species traded in Kenya’s Marine Aquarium Fishery as derived in this study.

Acanthuridae
1 *Acanthurus blochii*
2 *Acanthurus leucosternon*
3 *A. lineatus*
4 *A. dussumieri*
5 *A. nigrofuscus*
6 *A. nigricauda*
7 *A. tennenti*
8 *A. triostegus*
9 *A. xanthopterus*
10 *Ctenochaetus binotatus*
11 *Ctenochaetous strigosus*
12 *Ctenochaetus flavicauda*
13 *Naso annulatus*
14 *Naso elegans*
15 *N. brevirostris*
16 *N. hexacanthus*
17 *N. vlamingi*
18 *N. lopezi*
19 *Paracanthurus hepatus*
20 *Zebrassoma desjardinii*
21 *Zebrassoma gemmatum*
22 *Z. scopas*
23 *Z. veliferum*

Antennariidae
24 *Histrio histrio*
25 *Antennarius striatus*

Alustomidae
26 *Alustomus chinensis*

Balistidae
27 *Balistapus consipicullum*
28 *B. undulates*
29 *Canthidermis maculatus*
30 *Melichthys indicus*
31 *Odonus niger*
32 *Pseudobalistes fuscus*
33 *Rhinecanthus aculeatus*
34 *Rhinecanthus rectangulus*
35 *Sufflamen bursa*
36 *Paraluteres prionurus*

Blenniidae
37 *Atrosalarius fuscus fuscus*
38 *Exallias brevis*
39 *Meiacanthus mossambicus*
40 *Meiacanthus lineatus*
41 *Salarius fasciatus*
42 *Plagiotremus tapeinosoma*
43 *Plagiotremus rhinorhyncus*
44 *Istiblennius periopthalmus*
45 *Salarius fasciatus*

Caracanthidae
45 *Caracanthus madagascariensis*

Carangidae
46 *Gnathanodon speciosus*

Caesoinidae
47 *Caesio lunare*

Centriscidae
48 *Aeoliscus strigatus*

Chaetodontidae
49 *Chaetodon auriga*
50 *C. dolosus*
51 *C. falcula*
52 *C. guttassimus*
53 *C. kleinii*

54 *C. leucopleura*
55 *C. lineatus*
56 *C. lunula*
57 *C. madagaskariensis*
58 *C. melannotus*
59 *C. meyeri*
60 *C. trifascialis*
61 *C. trifasciatus*
62 *C. interruptus*
63 *C. vagabundus*
64 *C. xanthocephalus*
65 *C. zanzibariensis*
66 *Forcipiger flavissimus*
67 *F. longisrostris*
68 *Heniochus acuminatus*
69 *H. monocerus*
70 *Hemitaurichthys zoster*

Cirrhitidae
71 *Cirrhichthys oxycephalus*
72 *Paracirrhites arcatus*
73 *P. forsterri*

Dasyatidae
74 *Dasyatis kuhlii*
75 *Taeniura lymma*

Diploprionini
76 *Pogonoperca punctata*

Diodontidae
77 *Diodon holocanthus*
78 *Diodon hystrix*
79 *Diodon liturosus*

Ephippidae
80 *Platax orbicularis*
81 *P. teira*

Gobiidae
82 *Amblygobius aurora*
83 *Ablygobius semicinctus*
84 *Gobiodon citrinus*
85 *Ecsenius midas*
86 *Istigobius ornatus*
87 *Lotilia graciliosa*
88 *Valencienna helsdingeni*

89 *V. puellaris*
90 *V. sexguttata*
91 *V. strigata*

Haemulidae
92 *Plectorhincus orientalis*
93 *P. picus*

Hemiscyllidae
94 *Chiloscyllium sp.*

Holocentridae
95 *Myripristis vittatus*

Labridae
96 *Anampses caerulepunctatus*
97 *A. meleagrides*
98 *A. twistii*
99 *A. linieatus*
100 *Bodianus anthioides*
101 *B. axillaris*
102 *B. bilunulatus*
103 *B. diana*
104 *Cheilinus chlorourus*

105 *Cheilinus trilobatus*
106 *C. bimaculatus*
107 *C. oxycephalus*
108 *Cirrhilabrus exquisitus*
109 *Cirrhilabrus rubriventralis*
110 *Coris aygula*
111 *C. caudimacula*
112 *Coris cuvieri*
113 *C. formosa*
114 *C. gaimard*
115 *Epibulus insidiator*
116 *Gomphosus coeruleus*
117 *Halichoeres cosmetus*
118 *H. hortulanus*
119 *H. marginatus*
120 *H. scapularis*
121 *H. iridis*
122 *H. nebulosus*
123 *Hemigymnus fasciatus*
124 *H. melapterus*
125 *Hologymnosus annulatus*
126 *H. doliatus*
127 Labroides bicolor
128 *L. dimidiatus*
129 *Labropsis xanthonota*
130 *Macropharyngodon bipartitus*
131 *M. cyanoguttatus*
132 *Labrichthys unilineatus*
133 *Novaculichthys macrolepidotus*
134 *N. taeniorus*
135 *Paracheilinus carpenteri*
136 *P. mccoskerri*
137 *Pseudocheilinus hexataenia*
138 *P. evanidus*
139 *Pseudodax moluccanus*
140 *Pseudojuloides cerasinus*
141 *Stethojulis albivottata*
142 *Thalassoma amblycephalum*
143 *T. genivittatum*
144 *T. hardwicke*
145 *T. hebraicum*
146 *Thalassoma purpureum*
147 *Xyrichthys pavo*

Lutjanidae
148 *Lutjanus kasmira*
149 *Macolor niger*

Malacanthidae
150 *Malacanthus brevirostris*

Microdesmidae
151 *Nemateleotris magnifica*
152 *Ptereleotris evides*
153 *Ptereleotris tricolor*
Monacanthidae
154 *Aluterus monocerus*
155 *Aluteres scriptus*
156 *Oxymonacanthus longirostris*
157 *Paraluterus prionurus*

Mullidae
158 *Parupeneus cyclostomus*
159 *Parupeneus macronemus*

Muraenidae
160 *Echidna zebra*
161 *Rhinomoraena quaesita*

Notopteridae
162 *Xenomystus nigri*

Myliobatidae
163 *Aetobatus narinari*
164 *Myliobatis tobijei*

Ostraciidae

165 *Lactoria cornuta*
166 *L. diaphana*
167 *Ostracion cubicus*
168 *O. meleagrides*

Plotosidae

169 *Plotosus arab*
170 *P. lineatus*
171 *P. orbicularis*

Pomacanthidae

172 *Apolemichthys trimaculatus*
173 *A xanthurus*
174 *A. xanthotis*
175 *Centropyge acanthops*
176 *C. bispinnosus*
177 *C. multispinnis*
178 *Pomacanthus chrysurus*
179 *P. imperator*
180 *P. maculosus*
181 *P. semicirculatus*
182 *Pygoplites diacanthus*

Pomacentridae

183 *Abudefduf saxatilis*
184 *Abudefduf vaigiensis*
185 *A. sexfasciatus*
186 *Amphiprion akallopisos*
187 *Amphiprion allardii*
188 *Chromis dimidiata*
189 *Chromis nigrura*
190 *Chromis viridis*
191 *Chrysiptera annulata*
192 *Chrysiptera biocellata*
193 *Dascyllus aruanus*
194 *D. carneus*
195 *D. trimaculatus*
196 *Pomacentrus sulfureus*
197 *Pomacentrus caeruleus*
198 *Neopomacentrus azysron*
200 *Neoglyphidodon melas*

Scorpaenidae

201 *Dendrochirus brachypterus*
202 *D. zebra*
203 *Pterois antennata*
204 *P. radiata*
205 *P. miles*
206 *Rhinopias frondosa*
207 *R.alba*
208 *Sebasapistes cyanostigma*
209 *Taenianotus triacanthus*
210 *Scorpaenopsis venosa*

Scaridae

211 *Cetoscarus bicolor*

Serranidae

212 *Cephalopholis argus*
213 *Cephalopholis sexmaculata*
214 *Cephalopholis miniata*
215 *Epinephelus flavocaeruleus*
216 *Nemanthias carberryi*
217 *Pseudanthias evansi*
218 *P. kashiwae*
219 *P. squamipinnis*
220 *Pseudanthias cooperi*
221 *Variola louti*

Siganidae
222 *Siganus stellatus*
223 *Siganus canaliculatus*

Sphyraenidae
224 *Sphyraena barracuda*

Synanceiidae
225 *Synanceia verrucosa*

Syngnathidae
226 *Corythoichthys haematopterus*
227 *Doryramphus dactiliphorus*
228 *D. excisus*
229 *D. melanopleura*

Tetraodontidae
230 *Arothron citrinellas*
231 *A. hispidus*
232 *A. mappa*
233 *A. meleagris*
234 *A. nigropunctatus*
235 *A. stellatus*
236 *Canthigaster bennetti*
237 *C. janthinoptera*
238 *C. margaritata*
239 *C. smithae*
240 *C. solandri*
241 *C. valentini*

Torpedinidae
242 *Torpedo fuscomaculata*

Zanclidae
243 *Zanclus cornutus*

Somniosidae
244 *Somniosus pacificus?*

Appendix V. List of reef fish species overlapping between the artisanal and aquarium fishery in Shimoni area between January and December 2014 categorized by the gear type (H=handlines, RS = reefseines, GN=gillnets, BT = basket traps, MG=monofilament gillnets, SG=speargun) and value use (C: artisanal commercial; A: Aquarium)

Scientific Name	H	RS	GN	BT	MG	SG	Value Use
Abudefduf sexfasciatus	x		x				A
Abudefduf sordidus						x	A
Abudefduf sparoides	x	x		x			A
Abudefduf vaigiensis	x		x				A
Acanthurus leucosternon	x			x			A
Amphiprion allardi	x						A
Bodianus auxillaris	x			x			A
Chaetodon bennetti						x	A
Chaetodon lineolatus	x						A
Chaetodon lunula				x		x	A
Chaetodon trifasciatus					x		A
Dascyllus trimaculatus	x					x	A
Labroides dimidiatus	x						A
Malacanthus brevirostris	x						A
Novaculichthys taeniourus	x	x				x	A
Ostracion cubicus				x		x	A
Paracirrhites forsterri	x						A
Zanclus cornutus	x	x		x			A
Zebrasoma scopas				x			A
Acanthurus triostegus		x			x	x	C/A
Acanthurus xanthopterus			x	x			C/A
Anampses caeruleopunctatus	x				x	x	C/A

Scientific Name	**H**	**RS**	**GN**	**BT**	**MG**	**SG**	**Value Use**
Balistapus undulatus						x	C/A
Cephalopholis argus	x			x	x	x	C/A
Cephalopholis miniata	x				x	x	C/A
Cheilinus chlorourus	x			x	x	x	C/A
Cheilinus trilobatus	x			x		x	C/A
Coris africana	x			x		x	C/A
Coris caudimacula	x						C/A
Coris formosa	x	x					C/A
Dasyatis kuhlii						x	C/A
Epibulus insidiator						x	C/A
Halichoeres hortulanus	x			x			C/A
Halichoeres scapularis	x						C/A
Hemigymnus fasciatus					x	x	C/A
Hologymnosus doliatus	x			x			C/A
Hologymnus annulatus				x			C/A
Lutjanus kasmira	x			x			C/A
Macolor niger	x						C/A
Naso annulatus						x	C/A
Naso brachycentron		x					C/A
Naso brevirostis				x			C/A
Naso hexacanthus						x	C/A
Naso elegans						x	C/A
Naso vlamingi		x					C/A
Parupeneus cyclostomus	x		x	x			C/A
Platax orbicularis						x	C/A
Pomacanthus chysurus						x	C/A
Pomacanthus imperator	x			x		x	C/A

Scientific Name	**H**	**RS**	**GN**	**BT**	**MG**	**SG**	**Value Use**
Pomacanthus semicirculatus						x	C/A
Pseudobalistes fuscus						x	C/A
Rhinecanthus aculeatus		x					C/A
Siganus stellatus	x	x	x	x	x		C/A
Thalassoma hebraicum	x	x	x				C/A
Thalassoma lunare	x						C/A
Variola louti	x			x		x	C/A
Xyrichthys pavo	x						C/A

APPENDIX VI. List of the fish species recorded as recruits and juveniles in the study sites showing their presence (+) / absence (-) and ranked by occurrence frequency (OF), KIL=Kilifi, KUR=Kuruwitu, MWI=Mwipwa, WAS=Wasini

		Recruits						**Juveniles**					
	Species	KIL	KUR	MWI	SII	WAS	OF	KIL	KUR	MWI	SII	WAS	OF
1	*Canthigaster valentini*	+	+	+	+	+	5	+	+	+	+	+	5
2	*Cheilodipterus quinquilineatus*	+	+	+	+	+	5	+	+	+	+	+	5
3	*Ctenochaetus flavicauda*	+	+	+	+	+	5	+	+	+	+	+	5
4	*Gomphosus caeruleus*	+	+	+	+	+	5	+	+	+	+	+	5
5	*Halichoeres hortulanus*	+	+	+	+	+	5	+	+	+	+	+	5
6	*Labroides dimidiatus*	+	+	+	+	+	5	+	+	+	+	+	5
7	*Plectroglyphidodon lacrymatus*	+	+	+	+	+	5	+	+	+	+	+	5
8	*Stegastes nigricans*	+	+	+	+	+	5	+	+	+	+	+	5
9	*Thalassoma hardwicke*	+	+	+	+	+	5	+	+	+	+	+	5
10	*Thalassoma hebraicum*	+	+	+	+	+	5	+	+	+	+	+	5
11	*Zebrassoma scopas*	+	+	+	+	+	5	+	+	+	+	+	5
12	*Zebrassoma veliferum*	+	+	+	+	+	5		+		+	+	3
13	*Acanthurus nigrofuscus*	+		+	+	+	4	+	+	+	+	+	5
14	*Chaetodon auriga*		+	+	+	+	4	+	+	+	+	+	5
15	*Chaetodon guttatisimus*	+		+	+	+	4	+	+	+	+	+	5
16	*Chaetodon trifasciatus*		+	+	+	+	4	+	+	+	+	+	5
17	*Chromis viridis*	+	+		+	+	4	+	+	+	+	+	5
18	*Dascyllus trimaculatus*	+	+		+	+	4	+	+	+	+	+	5
19	*Hemigymnus fasciatus*		+	+	+	+	4	+	+	+	+	+	5
20	*Neoglyphidodon melas*		+	+	+	+	4		+	+	+	+	4
21	*Scarus frenatus*		+	+	+	+	4	+	+	+	+	+	5
22	*Scarus psittacus*		+	+	+	+	4	+	+	+	+	+	5
23	*Siganus sutor*	+	+	+	+		4	+	+	+	+	+	5
24	*Stethojulis albovittata*	+	+	+		+	4	+	+	+	+		4

		Recruits						**Juveniles**					
	Species	KIL	KUR	MWI	SII	WAS	OF	KIL	KUR	MWI	SII	WAS	OF
25	*Thalassoma amblycephalus*	+	+		+	+	4	+	+	+	+	+	5
26	*Thalassoma lunare*	+	+		+	+	4	+	+	+	+	+	5
27	*Abudefduf sexfasciatus*	+	+		+		3	+	+	+	+		4
28	*Abudefduf vaigiensis*		+	+	+		3	+	+	+	+		4
29	*Canthigaster bennetti*	+		+		+	3	+	+	+		+	4
30	*Chaetodon klenii*			+	+	+	3	+	+	+	+	+	5
31	*Chaetodon trifascialis*			+	+	+	3				+	+	2
32	*Cheilinus chlorourus*	+	+		+		3	+	+	+	+	+	5
33	*Chromis dimidiata*		+	+		+	3	+	+	+		+	4
34	*Chrysiptera annulata*	+	+	+			3	+		+			2
35	*Ctenochaetus strigosus*	+		+		+	3	+	+	+	+	+	5
36	*Dascyllus aruanus*	+	+			+	3	+	+	+	+	+	5
37	*Dascyllus carneus*	+			+	+	3					+	1
38	*Halichoeres scapularis*	+	+			+	3	+	+	+		+	4
39	*Labrichthys unilineatus*			+	+	+	3		+	+	+	+	4
40	*Meiacanthus mossambicus*		+	+		+	3		+	+	+	+	4
41	*Neopomacentrus azysron*		+		+	+	3		+		+	+	3
42	*Ostracion cubicus*		+	+	+		3		+	+	+	+	4
43	*Pomacentrus caeruleus*	+			+	+	3	+	+	+	+	+	5
44	*Pomacentrus trilineatus*	+		+		+	3	+		+	+	+	4
45	*Ptereleotris evides*			+	+	+	3			+	+		2
46	*Scarus falcipinnis*		+	+	+		3		+	+	+		3
47	*Abudefduf sparoides*	+	+				2	+	+	+	+		4
48	*Acanthurus lineatus*	+			+		2						0
49	*Acanthurus triostegus*	+	+				2	+	+			+	3
50	*Acanthurus xanthopteras*	+				+	2	+				+	2
51	*Amphiprion allardi*		+			+	2	+	+	+	+	+	5

		Recruits						**Juveniles**					
	Species	KIL	KUR	MWI	SII	WAS	OF	KIL	KUR	MWI	SII	WAS	OF
52	*Anampses caeruleopunctatus*	+	+				2	+	+	+	+	+	5
53	*Apogon cookii*	+	+				2	+	+				2
54	*Apogon taeniophorus*	+		+			2	+			+	+	3
55	*Calotomus carolinus*	+	+				2	+	+				2
56	*Canthigaster solandrii*	+	+				2	+	+	+		+	4
57	*Cephalopholus argus*		+	+			2		+			+	2
58	*Chaetodon lunula*		+	+			2	+	+	+	+		4
59	*Chaetodon zanzibarensis*			+		+	2			+			1
60	*Cheilinus trilobatus*			+	+		2	+	+		+		2
61	*Chlororus sordidas*		+		+		2	+	+	+	+	+	5
62	*Chromis lepidolepis*			+	+		2	+	+				2
63	*Chrysiptera biocellata*	+	+				2	+	+				2
64	*Chrysiptera leucopoma*	+	+				2	+	+				2
65	*Chrysiptera unimaculata*	+	+				2	+	+				2
66	*Coris formosa*	+	+				2	+	+	+		+	4
67	*Gnathanodon speciosus*				+	+	2		+		+		2
68	*Halichoeres nebulosus*	+	+				2	+	+				2
69	*Hemigymnus melapterus*		+	+			2	+	+	+	+	+	5
70	*Macropharyngodon bipartitus*	+	+				2	+	+				2
71	*Neopomacentrus cyanomos*				+	+	2				+	+	2
72	*Plectroglyphidodon dickii*		+		+		2		+	+	+	+	4
73	*Pseudocheilinus hexataenia*		+			+	2	+	+	+	+	+	5
74	*Stethojulis strigiventa*	+	+				2		+		+		2
75	*Acanthurus binotatus*		+				1		+				2
76	*Acanthurus dussumieri*					+	1						0
77	*Acanthurus tennenti*		+				1	+					1
78	*Amphiprion akallopisos*				+		1				+		1

		Recruits						**Juveniles**					
	Species	KIL	KUR	MWI	SII	WAS	OF	KIL	KUR	MWI	SII	WAS	OF
79	*Anampses twisti*					+	1	+	+		+	+	4
80	*Centropyge multispinnis*	+					1	+		+		+	3
81	*Chaetododon trifasciatus*					+	1					+	1
82	*Chaetodon benneti*					+	1		+				2
83	*Chaetodon falcula*					+	1			+	+		2
84	*Chaetodon melannotus*		+				1		+	+	+	+	4
85	*Chaetodon meyerri*					+	1			+		+	2
86	*Chaetodon unimaculatus*				+		1		+		+		2
87	*Chaetodon vagabundus*				+		1		+	+	+	+	4
88	*Chromis atripectoralis*					+	1	+	+			+	3
89	*Chromis vanderbilti*	+					1	+					1
90	*Chrysiptera glauca*		+				1		+				1
91	*Chrysiptera talboti*			+			1						0
92	*Cirripectes filamentosus*				+		1		+				1
93	*Coris caudimacula*	+					1	+	+	+			4
94	*Corythoichthys flavofasciatus*		+				1		+			+	2
95	*Gnatholepis caurensis*		+				1	+	+	+		+	4
96	*Goby sp (like aurora)*	+					1						0
97	*Istiblennius periopthalma*					+	1						0
98	*Leptoscarus vaigiensis*		+				1		+		+		2
99	*Naso annulatus*	+					1	+		+			2
100	*Naso brevirostris*	+					1	+	+	+	+	+	5
101	*Naso hexacanthus*					+	1						0
102	*Naso lituratus*	+					1	+		+	+	+	4
103	*Naso unicornis*	+					1	+	+		+		3
104	*Ostracion meleagris*		+				1		+		+		2
105	*Ostorhinchus apogonoides*	+					1	+					1

		Recruits						Juveniles					
	Species	KIL	KUR	MWI	SII	WAS	OF	KIL	KUR	MWI	SII	WAS	OF
106	*Ostorhinchus aureus*	+					1	+			+	+	3
107	*Oxymonocanthus longirostris*				+		1			+			1
108	*Parapercis hexophtalma*		+				1	+	+		+	+	4
109	*Pomacanthus semicirculatus*	+					1	+	+	+	+	+	5
110	*Rhinecanthus aculeatus*		+				1		+				1
111	*Salarias fasciatus*		+				1	+	+				2
112	*Scolopsis ghanam*			+			1		+	+	+		3
113	*Abudefduf septemfasciatus*						0		+				2
114	*Acanthurus auranticavus*						0				+		2
115	*Acanthurus blochii*						0				+		1
116	*Acanthurus leucosternon*						0					+	1
117	*Acanthurus xanthocephalus*						0			+			1
118	*Aluterus scriptus*						0	+					1
119	*Amblyglyphidodon leucogaster*						0				+		1
120	*Anampses lineatus*						0			+	+		2
121	*Anampses meleagrides*						0			+	+	+	3
122	*Anyperodon leucogrammicus*						0			+			1
123	*Apogon kallopterus*						0	+					1
124	*Archamia fucata*						0				+		1
125	*Arothron nigropunctatus*						0	+	+				2
126	*Aspidontus taeniatus*						0		+				2
127	*Balistapus undulatus*						0	+	+				2
128	*Cantherhines dumerilii*						0	+		+			2
129	*Cantherhines fronticinctus*						0	+					1
130	*Cantherhines pardalis*						0	+	+				2
131	*Canthigaster janthinoptera*						0		+	+			2
132	*Canthigaster smithae*						0			+			2

		Recruits						Juveniles					
	Species	KIL	KUR	MWI	SII	WAS	OF	KIL	KUR	MWI	SII	WAS	OF
133	*Cetoscarus bicolor*						0			+	+	+	3
134	*Chaetodon leucopleura*						0		+				1
135	*Chaetodon lineolatus*						0		+		+		2
136	*Chaetodon madagascarensis*						0			+			1
137	*Chaetodon xanthocephalus*						0		+		+		2
138	*Chaetoton guttatisimus*						0			+			1
139	*Cheilinus fasciatus*						0			+			1
140	*Cheilinus sp*						0				+		1
141	*Cheilinus undulatus*						0				+		1
142	*Cheilio inermis*						0		+				1
143	*Chlorurus atrilunula*						0	+					1
144	*Cirrhitichthys oxycephalus*						0	+					1
145	*Cirripectes stigmaticus*						0			+	+		2
146	*Coris africana*						0	+	+				2
147	*Coris aygula*						0		+				1
148	*Coris gaimard*						0	+	+				2
149	*Cryptocentrus cryptocentrus*						0			+			1
150	*Cymbacephalus sp.*						0			+			1
151	*Dendrochyrus brachypteras*						0	+					1
152	*Diodon liturosus*						0		+				1
153	*Epibulus insidiator*						0		+				1
154	*Epinephelus merra*						0		+				1
155	*Exalias brevis*						0		+				1
156	*False stonefish*						0		+				1
157	*Gnathodentex aurolineatus*						0		+			+	2
158	*Gobiodon sp red*						0	+			+		2
159	*Grammistes sexlineatus*						0	+	+				2

		Recruits						Juveniles					
	Species	KIL	KUR	MWI	SII	WAS	OF	KIL	KUR	MWI	SII	WAS	OF
160	*Halichoeres marginatus*						0	+	+		+		2
161	*Hipposcarus harid*						0		+				1
162	*Istiblennius gibbifrons*						0		+				1
163	*Lethrinus harak*						0		+				1
164	*Lethrinus sp*						0	+	+				2
165	*Lutjanus bohar*						0				+	+	2
166	*Lutjanus fulviflamma*						0				+		1
167	*Macolor niger*						0			+			1
168	*Monotaxis grandoculis*						0		+		+		2
169	*Mullidoichthys flavolineatus*						0		+				1
170	*Nazo lopezi*						0		+				1
171	*Novaculichthys macrolepidotus*						0		+				2
172	*Novaculichthys taeniourus*						0	+	+				2
173	*Parapeneus cyclostomas*						0			+	+		2
174	*Parupeneus barberinus*						0	+	+	+	+	+	5
175	*Parupeneus bifasciatus*						0		+				1
176	*Parupeneus cyclostomas*						0		+				2
177	*Parupeneus rubescens*						0		+	+			2
178	*Plagiotremus tapeinosoma*						0		+		+		2
179	*Platax orbicularis*						0		+				1
180	*Platax teira*						0		+				1
181	*Plectorhinchus gaterinus*						0			+	+	+	3
182	*Plectorhinchus orientalis*						0		+				1
183	*Plectorhinchus picus*						0				+		1
184	*Pomacanthus imperator*						0		+				1
185	*Pomacentrus baenschi*						0	+					1
186	*Pomacentrus sulfureus*						0		+	+	+	+	4

		Recruits						Juveniles					
	Species	KIL	KUR	MWI	SII	WAS	OF	KIL	KUR	MWI	SII	WAS	OF
187	*Ptereleotris evides*						0		+				1
188	*Pterois antennata*						0	+					1
189	*Pterois miles*						0		+				2
190	*Pterois radiata*						0		+				2
191	*Rhinecanthus rectangulosus*						0	+					1
192	*Sargocentron diadema*						0			+			1
193	*Sargocentron sp*						0	+					1
194	*Saurida gracilis*						0		+	+	+		3
195	*Scarus bicolor*						0				+		1
196	*Scarus ghobban*						0		+	+	+	+	4
197	*Scarus rubrioviolaceus*						0				+		1
198	*Scarus scaber*						0		+		+	+	3
199	*Siganus canaliculatus*						0				+		1
200	*Siganus stellatus*						0		+			+	2
201	*Sphyraena jello*						0				+		1
202	*Sufflamen albicaudatus*						0	+					1
203	*Sufflamen chrysopterus*						0	+		+			2
204	*Synodus variegatus*						0			+			1
205	*Upeneus trygula*						0					+	1
206	*Zanclus cornutus*						0	+		+		+	3
207	*Zebrassoma desjardini*						0				+		1