SOME ASPECTS OF THE BIOLOGY AND TAXONOMY OF RABBITFISHES (FAMILY: SIGANIDAE) FROM KENYAN INSHORE MARINE WATERS

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Declaration

Student declaration

This thesis is my original work and has not been presented for a Degree in any other University or any other award.

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Supervisors' declaration

We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

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Dedication

This thesis is dedicated to my family, special feeling of gratitude to them; I will always remember their words of encouragement and push for determination.

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Abstract

Rabbitfishes (Siganidae) are valuable commercial species in many parts of the world. Along the East African coast, they constitute important food and commercial marine fish resources. However information on their biology and taxonomy is scanty. Therefore this study was aimed at bridging the knowledge gap on their taxonomy and distribution. Data was collected on rabbitfish specimens landed at six (6) landing sites along the Kenya coast. Morpho-meristic measurements and counts were made on 234 specimens. A total of six (6) species: *Siganus canaliculatus, S. sutor, S. stellatus, S. luridus, S. rivulatus* and *S. argenteus* were recorded. Msambweni landing site recorded all the 6 species, followed by Shimoni and Malindi with 5 each, then Kilifi with 4 while Mombasa and Vanga with only 3 species.

In the present study *S. stellatus* had the highest mean length (SL), body depth (BD), dorsal fin base length (DFbL) and anal fin base length (AFbL). *Siganus luridus* had the lowest mean SL, BD, DFbL and AFbL. The morphometric data was subjected to Principal Component Analysis (PCA) in PaST software programme. Characters identified in the PCA to contribute to most of the variation were subjected to the non-parametric Mann-Whitney U-test at $\alpha < 0.05$.

PCA results showed clear separation of polygons for two species *S. stellatus* and *S. luridus* with *S. luridus* specimens in the positive part of 2nd PC and *S. stellatus* specimens in the positive part of 1st PC. Polygons of the other four species; *S. canaliculatus, S. sutor, S. rivulatus* and *S. argenteus* overlapped in the negative part of 2nd PC, suggesting close similarity in their body morphometry. Mann-Whitney U-test confirmed significant difference between specimens of *S. stellatus* and *S. luridus* (p<0.05) for 7 morphometric characters. The differences were observed between characters of *S. luridus* and *S. argenteus*, while the least differences in ED and GAspL were between *S. canaliculatus* and *S. sutor*. PCA for *S. rivulatus* specimen from Msambweni (south) and Malindi (north) coast clear separation of polygons with Malindi specimens falling on the negative part of 1^{st} PC and Msambweni specimens in the positive part. Subsequent character analysis of *S. rivulatus* from Msambweni and Malindi, confirmed significant difference in ED and GAspL ($p \leq 0.05$). Therefore, there is need for further research on taxonomy of *S. rivulatus* including analysis of molecular genetic variation to confirm whether Msambweni and Malindi rabbitfishes are separate stocks of the same species or two different species.

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Abbreviations and Acronyms

FAO	Food and Agriculture Organization of the United Nations
KMFRI	Kenya Marine and Fisheries Research Institute
Mld	Malindi
MPA	Marine Protected Areas
Msa	Msambweni
NEM	Northeast Monsoon
NMK	National Museum of Kenya
SEM	Southeast Monsoon
SDF	State Department of Fisheries
WIO	Western Indian Ocean
K	Condition factor
LWR	Length-weight relationship
N	Number
PC	Principal Component
PCA	Principal Component Analysis
SD	Standard Deviation
SL	Standard length
TL	Total length
W	Body weight

CHAPTER 1: INTRODUCTION

1.1 Background

Rabbitfishes (Siganidae), also commonly known as spine foots, are widely distributed in shallow coastal habitats throughout the Indo-Pacific waters. Although rabbitfishes were originally restricted to the tropical Indo-Pacific region, they are now found in the eastern Mediterranean basin, where they entered from Red Sea through Suez Canal which opened in 1869 (Daniel *et al.*, 2009). Tharwat and Al-Owfeir (2003) reported that *Siganus rivulatus* as one of the species that penetrated through the Suez Canal and is now common in the Mediterranean basin. Rabbitfishes are valuable commercial species in many parts of the world (Woodland, 1990). Along the East African coast, they are among the most important commercial marine fish resources (Nzioka, 1984; Ntiba and Jaccarinni, 1988; 1997; Kamukuru, 2009; Wambiji, 2010; Nzioka, 2012). In the Western Indian Ocean (WIO) region rabbitfishes are a major target species for the local basket trap fishery (*malema*) (Wambiji *et al*., 2008).

Most rabbitfishes are exclusively marine water; however *Siganus vermiculatus* Valenciennes 1835 that inhabits estuaries has as well been successfully introduced into freshwater habitats (Tharwat and Al-Owfeir, 2003). Preferred habitats for rabbitfishes include littoral to sub-littoral marine areas. They mainly inhabit reefs, shallow lagoons, sea grasses and mangrove habitats. According to Gorospe and Demayo (2013) rabbitfishes frequently come out of reefs crevices where they take refuge at night, into very shallow waters less than 6 meters deep to feed on algae during the day. Gundermann *et al*., (1983) divided rabbitfishes into 2 groups based on their colouration and habitat preference with the first group including species that live in pairs, site specific, brightly coloured and strictly associated with coral reefs. The coral species are delicate, sensitive to changes in salinity and generally show inter-specific behaviour e.g. *Siganus corallinus*. The second group consist of species which school at some stage in life, forage over a wide area and are generally gray or drub. They are robust and apparently more adaptive to wide variations in salinity and temperature. The schooling species are important food fishes which support artisanal fisheries in many parts of the world for example *S, canaliculatus, S. sutor, S. stellatus, S. luridus, S. rivulatus* and *S. argenteus* (Duray, 1998). Species of the family Siganidae, locally referred to as *Tafi, Tassi* au *chafi* are important fishes of the artisanal fishery along Kenyan coast. This is probably due to their presence in inshore habitats which are easily accessible to the small, low technology fishing crafts of the artisanal fisher. They are also among the preferred food fishes with high demand in most coastal towns, largely because they 'are extremely tasty' (Adel and Al-Owafeir, 2003).

The Kenya coast is characterized by extensive lagoons, coral reefs, mangroves and sea grass beds. Despite these rich habitats, marine fisheries are limited due to a narrow shelf, resulting in a small inshore fishing area (Chuenpagdee *et al*., 2006). The other factors that influence the small-scale fisheries include the monsoon winds: the northeast monsoon (NEM) running from October-March and southeast monsoons from April-September further limit fishing activities to inshore waters when the sea conditions are rough (Obura, 2001). Marine fisheries have been estimated to contribute only about 10% of Kenya's total fish production with the huge fraction of the total national fisheries catch coming from the Lake Victoria fisheries (FAO, 2012). However, the Kenya marine fisheries sector remains critical to the food security and livelihood of the coastal communities (Aloo *et al*., 2004), just like in many developing countries around the world. Malleret-King (2000) estimated that fisheries provide 80% of the total income to 70% of some coastal communities. Robinson and Samoilys (2013) reported that the families Lethrinidae and Siganidae are the dominant marine fish resources in the artisanal fishery landings along the Kenyan Coast accounting for 39.2% and 39.1% of the total artisanal catches along the Kenya coast.

Rabbitfishes are harvested by artisanal fishers along the entire Kenya coastline from the shore to the outer edge of fringing reef at depths less than 20 m. The fishers use small boats measuring less than 10 m long, dominated by dug-out canoes or outrigger boats (*ngalawa*) often propelled by oars and sails although outboard engines are slowly picking up (De Souza, 1988). The artisanal gears used in fishing for rabbitfishes include gill nets, intertidal wiers (*uzio*), hand-lines (*mishipi*) and basket traps (*malema*). Previous studies by De Souza (1988), Wambiji *et al*. (2008) and Samoilys *et al*. (2011) show that basket traps (*malema*) are the most popular gears in the artisanal fishery.

Artisanal fishing in the inshore or near-shore waters is carried out using small-sized vessels and labour intensive methods with little or no modern technology input augmented by low investment (FAO, 2009). In Kenya the artisanal fisheries represent the bulk of total the total marine landings which have been estimated at 80% (Kaunda-Arara *et al*., 2003). The fisheries target a wide variety of fish species including demersal reef and small-pelagic species inhabiting inshore waters, as well as commercially-important invertebrates such as shrimp, octopus and lobster (Samoilys *et al*., 2011).

1.2 Problem Statement and Justification of the Study

Several studies have been published on some rabbitfish species along Kenyan Coast (Ntiba and Jaccarini, 1988, 1990, 1992; Wambiji *et al*., 2008; Wambiji, 2010; Agembe, 2012;

Nzioka, 2012). Most of these studies were focused on biological aspects such as age and growth parameters, fecundity estimates, gonad maturation, spawning times and estimation of important reproductive parameters mainly of species *S. sutor*. Wambiji *et al*. (2008) and Nzioka (2012) reported on morphometrics of 3 species: *S. stellatus, S. canaliculatus* and *S. sutor* while Robinson and Samoilys (2013) reported on the spawning aggregation of *S. sutor*. Thus, only 3 species of the family Siganidae in Kenya marine waters have been studied to some detail, with *S. sutor* being the most studied species, whereas *S. luridus, S. rivulatus* and *S. argenteus* are yet to be studied.

Previous studies have reported varying numbers of rabbitfish species in Kenyan waters, ranging from 3 to 6 species (FAO, 1984; Anam and Mostarda, 2012; Everett *et al*., 2012). The National Museums of Kenya (NMK) reference collection holds 23 rabbitfish specimens, collected mainly from Malindi; comprising only 3 species *S. stellatus, S. sutor* and *S. canaliculatus.* Fish landing statistics at Kenya Marine and Fisheries Research Institute (KMFRI) and State Department of Fisheries (SDF) do not identify rabbitfishes to species level, but only lumps them together as “Rabbit fishes”. According to some basket trap fishers at the Old Town, Likoni, Msambweni and Malindi fish landing sites, about 6-7 rabbitfish species are landed by artisanal fishers during the October-March period, identified as spawning season for the species (Robinson and Samoilys, 2013). However, so far there has been no comprehensive study of the taxonomic composition of rabbitfishes along the Kenya coast.

The purpose of this study was therefore to address the knowledge gap on the taxonomic status of rabbitfishes in Kenya and provide baseline biological data on the species that comprise "rabbitfish complex" in Kenya marine waters. Further the study was designed to validate the species composition of rabbitfishes caught by the artisanal fishers along the Kenyan coast; focusing on identification of additional morphological characters for differentiation of the species, especially the landed and/or preserved specimens. This is because existing species descriptions currently in use are largely based on colour patterns of live specimens which fade rapidly upon landing and or preservation (Woodland and Randall, 1979; Burgan *et al*., 1979; Randall and Kulbicki, 2005). Proper identification of species and information on some aspects of their biology are important for the management of their populations which are exploited in the artisanal fishery along the Kenyan coast.

1.3 Objectives

The broad objective of this study was to describe the taxonomic composition of rabbitfishes landed from the Kenyan coastal waters and to provide scientific information on some aspects of their biology including length-weight relationship and condition of rabbitfishes in the artisan fishery.

The specific objectives of the study were:

1. To validate the number of rabbitfish species in Kenya marine waters.
2. To elaborate morphological characteristics useful in distinguishing rabbitfishes along the Kenyan coast.
3. To determine length-weight relationship and condition factor of rabbitfishes landed along Kenyan coast.

CHAPTER 2: LITERATURE REVIEW

2.1 Biology and Taxonomy of Rabbitfishes

Rabbitfishes belong to the class Actinopteri, order Perciformes and family Siganidae (Eschmeyer *et al*., 2016). The family Siganidae is divided into two genera: *Siganus* and *Lo*, with a total of 27 known species. The genus *Siganus* is commonly referred to as rabbitfishes, spinefoots or siganids and comprises 22 species distinguished by their deep, compressed body, snout resembling that of a rabbit, 13 dorsal, 7 anal and 2 ventral fin strong spines. They possess a leathery skin, smooth, small and closely adherent scales, and thus are frequently mistaken to be scale-less. Their body colouration ranges from olive-green to brown depending on the species (Herre and Montalban, 1928; Munro, 1967 and Duray, 1998). The genus *Lo* has five (5) species. Their bodies are characterized by extended snouts and prominent face stripes earning them the name of "foxface fishes". None of these *Lo* species has been recorded in Kenyan marine waters. The shapes of the snout, caudal fins, body depths and shapes have been useful in distinguishing the members of the two genera (Woodland, 1990).

Rabbitfishes spines are strong, sharp and have venom glands that contain a painful toxin. Most species are counter-shaded, but some reef species such as *Siganus vulpinus* have colouration similar to those of butterflyfishes (Helfman *et al*., 2009). Jaikumar (2012) noted that "species in the genus *Siganus* are all extremely similar to each other in most of their traits". They also possess one procumbent spine in front of the first dorsal-fin spine; part of the proximal pterygeophore cartilage on which the median spine sits. The procumbent spine may be completely embedded or protrude from a small groove. Their teeth are in a single row of incisiform shape, very compressed and closely set in both upper and lower jaws (Woodland, 1990). It is noted, however, that such similarities are not taxonomically useful in discriminating species (Duray, 1998).

Rabbitfishes are herbivores, grazing on algae, seaweeds and sea grasses. As such, they are quite important to the reef ecosystem since their grazing keep the thick mats of filamentous and leafy algae from smothering the corals. They are cable of keeping the mat to about 1 to 2 mm thick and can strip vegetation from a 10m width around the reef. Other rabbitfish species use the reef mainly for shelter but "hover above it in brilliant, shifting shoals, while feeding on phytoplankton (Moyle and Cech, 2000). The species deposit feaces in the small crevices where they hide, which is important in promoting the growth and diversity of corals (Duray, 1998). Predation is the most important cause of death on the reefs where most rabbitfishes live; it has been reported that very few larval stages survive. Defense against predation pressure to the members of this family is in the form of sharp, strong poisonous spines (Moyle and Cech, 2004).

Rabbitfish species school in small to large groups, with species such as *S. rivulatus* and *S. luridus* splitting off into pairs or small units after the start of spawning activity (Moyle and Cech, 2004). They migrate to their traditional spawning locations which vary among species just before the start of spawning season (Robinson and Samoilys, 2013). Wide spacing throughout the reef during spawning activities occurs as a result of aggressive behaviour of individual pairs or groups towards other groups (Moyle and Cech, 2004). Some species show lunar synchronized spawning activity suggesting that their reproduction depends on the appearance of the new moon, a phenomena which is common with many other coastal species (Harahap et *al*., 2001; Robinson and Samoilys, 2013). Two spawning seasons have been reported for the East African coast running from January to February in Kenya and May to June in Tanzanian waters (Ntiba and Jaccarini, 1990; Kamukuru, 2009). On the other hand, Robinson and Samoilys (2013) reported that spawning aggregation of *S. sutor* takes place between November and March in Kenya.

Identification of rabbitfishes is difficult because of the morphological differences between species are very few. Existing descriptions for species differentiation are largely based on colouration of live fish (Woodland and Randall, 1979; Burgan *et al*., 1979). However, colour changes with age and emotional state of the fish, as well as in death and preservation of specimen are common (Herre and Montalban, 1928; Fowler, 1967; Woodland, 1972; Rau and Rau, 1980; Masuda *et al*., 1980; Randall and Kulbicki, 2005). Although there are no obvious external differences between males and females in this group, females are relatively larger than males in some species (Moyle and Cech, 2000).

2.2 Morphological Characters

Morphometric and meristic refer to the measurable and countable characters common to all fishes. These characters have been used to identify fish species in numerous studies; Nzioka (2012) compared the morphometric and meristic variation between populations of *S. sutor* as the populations are isolated and thus tend to reduce their genetic and ability to adapt to variation in environmental factors that influence changes in morphometric characters. Previous studies by Murta (2000) and Poulet *et al*. (2004) suggest that morphological differences occur also within species.

2.3 Length-Weight Relationship and Condition Factor

Knowledge of length-weight relationship (LWR) and condition factor (*K*) of fishes is important in fisheries science. The LWR have a number of important applications in fish stock assessment (Morey *et al*., 2003); and sustainable exploitation and management of fish species population (Anene, 2005). Dan-Kishiya (2013) stated that LWR provide valuable information on the habitat where the fish lives while Kulbicki *et al*. (2005) stressed the importance of LWR in modeling aquatic ecosystems. Length and weight data are valuable standard results of fish sampling programs such as estimation of standing crop biomass (Mansor *et al*., 2010) and monitoring seasonal variations in fish growth (Pervin and Mortuza, 2008). Therefore, data on a well-designed LWR of a fish species is important for fish stock assessment and parameters *a* and *b* (slope and y-intercept of the L-W regression curve, respectively) can be used for length-weight conversion. LWR are also important in fisheries management for comparative growth studies (Moutopoulos and Stergiou, 2002) as well as for estimation of Fish Condition factor (*K*) of fish species and fish biomass through length frequency analysis (Dan-Kishiya, 2013).

In fisheries science, Fish Condition factor is used to refer to the “condition”, “fatness” or wellbeing of fish. It is based on the hypothesis that heavier fish of a particular length are in a better physiological condition (Bagenal and Tesch, 1978). The condition factor in fish serves as an indicator of physiological state of the fish in relation to its welfare (Le Cren, 1951; Dan-Kishiya, 2013) and provides important information that can be used to compare two populations, climate and other conditions (Weatherly and Gills, 1987). Fish Condition factor is also a useful index for monitoring feeding intensity, age and growth rates in fish (Ndimele *et al*., 2010). It is strongly influenced by both biotic and abiotic environmental conditions and can be used as an index to assess the status of the aquatic system in which fish live (Anene, 2005). Thus, condition factor is important in understanding the life-cycle of fish species and it contributes to adequate management of the species, hence maintaining the equilibrium in the ecosystem (Imam *et al*., 2010).

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

This study was conducted at six selected landing sites along ~600 km stretch of the Kenya coast (Figure 1). Spatially, the Kenyan coastline extends from Vanga (4°32′34.04″S 39°9′47.49″E) on the southern border with Tanzania to Kiunga (1.7455° S, 41.4888° E) on the north border with Somali (Maina, 2012). The Coast is part of the Western Indian Ocean (WIO) eco-region which is characterized by an almost continuous fringing coral reef. Other features of this important Coast include mangrove forests and estuaries as well as a number of archipelagoes. An estimated 3.0 million people inhabit this coast and depend on marine resources for employment and food in the form of shell and fin-fishes. Statistics have estimated that the Kenya's marine fish resources contribute over 70% of the dietary protein consumed by the coastal population (Aloo *et al*., 2004).

3.2 Climatic Conditions

The East African Coast of Africa including the Kenya coast experiences a tropical humid climate, with two distinct seasons; the Northeast Monsoon (NEM) and the Southeast Monsoon (SEM). The SEM season occurs between April and September, and is characterized by high cloud cover; heavy rains averaging 900 mm/year, strong winds and low air temperatures averaging 25°C. The NEM season which runs from October through March, is marked by weak winds and high air temperatures (> 30°C) (Okeyo, 2010). The rains occur during wet months of April to July when daily sunshine period averages about 7.3 hrs in July and 9.3 hrs in December (Munga *et al*., 2012).

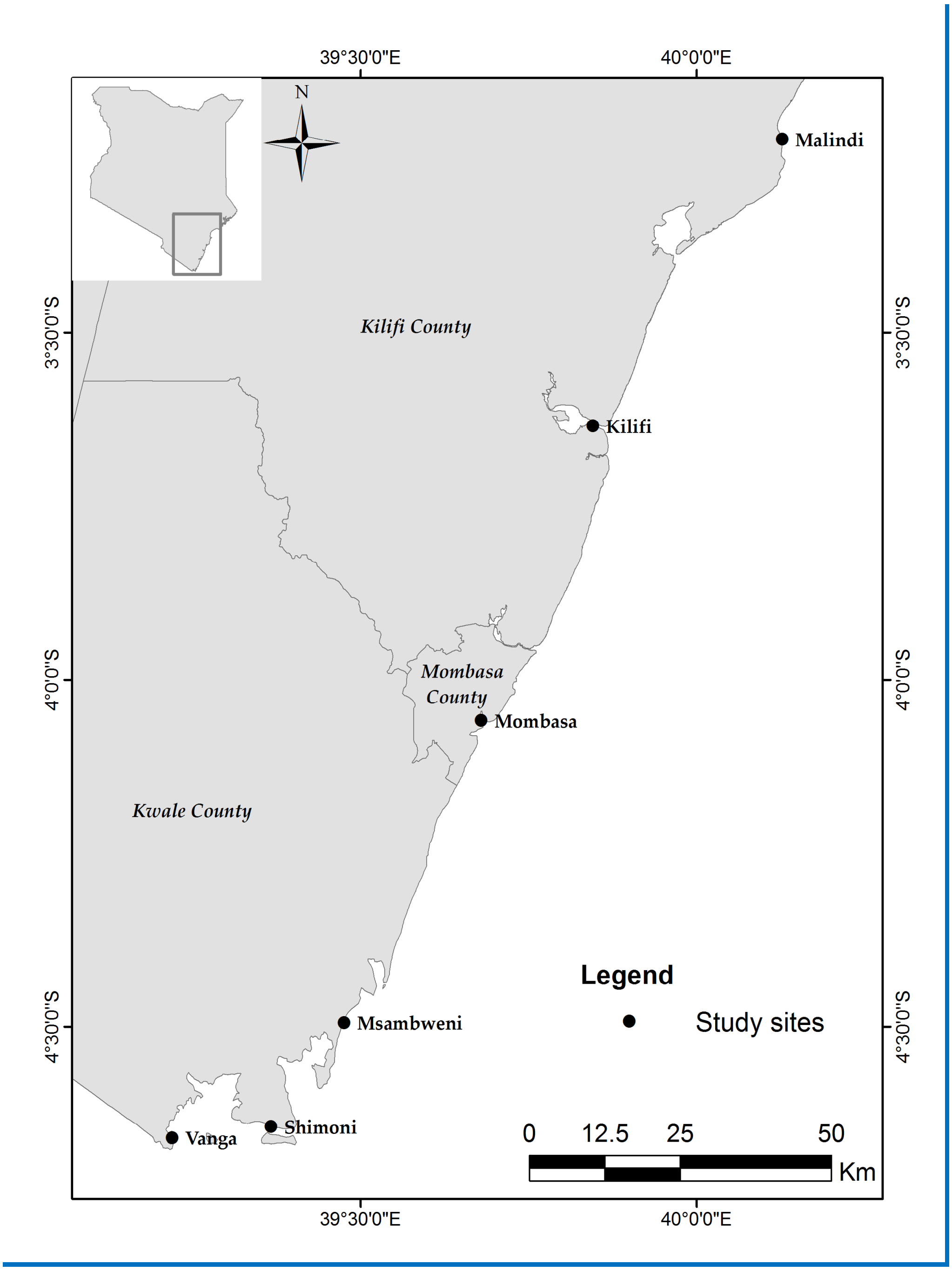

Figure 1: A map of Kenya (inset) showing the Kenya Coast locations of the study sites used in this study

3.3 Fish Landing Sites

The present study was conducted at six selected landing sites; Vanga, Shimoni and Msambweni in the south coast and Mombasa, Kilifi and Malindi in the north coast. Vanga (4°32′34.04″S 39°9′47.49″E) is Kenya's southernmost coastal fishing village lying about 171 km from the city of Mombasa. The village is only accessible through a 17 km rough road from the Kenya/Tanzania boarder post at Lungalunga (Trillo, 2013). The village is built within mangrove area and the fishing areas are characterized by some of the most complex mangrove ecosystem along the coast estuaries and creeks close to shore in proximity to patch and island reefs interspersed with sea grass beds. The Shimoni landing site straddles at 4.6472° S, 39.3804° E and is part a fishing village which lies about 73 km south of Mombasa off the Pemba channel. It is an important fishing settlement that also borders the Kisite-Mpunguti Marine National Park and Reserve (Agembe *et al*., 2010). The Shimoni fishing area is rich in valuable natural and tourism resources including coastal forests, patch and fringing coral reefs, sea-grass beds, reef flats, sand bars, important bird areas and mangrove forests which support a highly diverse ecosystem (Gomes *et al*., 2012). The Msambweni landing site (4.4653° S, 39.4813° E) is a small fishing village located about 55 km south of Mombasa city. Fishing is the primary source of income in this village, with rich fishing grounds located within complex mangrove bays, estuaries and creeks close to shore near patch and island reefs. Some of the largest mangrove trees are located within Gazi Bay where some of the most important fishing grounds of the Msambweni fishers are located (Malleret-King *et al*., 2002). Because of its reef and extensive beaches, snorkeling tourism has gained a huge popularity over the two last decades (Koornhof, 1997).

In the Mombasa fishing areas (4.0435° S, 39.6682° E) on the north coast, inshore fishing activities take place all the year round in the shallow waters ≤5m deep. Mombasa lies within a 200 km fringing reef with shallow lagoons, sea grass beds with narrow channels connecting it with the open ocean (Malleret-King *et al.*, 2002). Some areas the fertile fishing ground were shelved off for marine protected area (MPA); the Bamburi Marine Reserve (Dugong, 2000). On the other hand, the Kilifi fishing sites (3.5107° S, 39.9093° E) lies off the Kilifi resort town on the north coast of Kenya, about 56 km northeast of Mombasa city. The Kilifi town lies on the Kilifi Creek which is part of the Goshi River estuary (Weiss and Heinrich, 2006). Like the rest of the coastal villages and towns, fishing is one of the historical economic activities. Most of the rich fishing grounds in Kilifi lie within the 200 km fringing reef with shallow lagoons, sea grass beds and narrow channels opening into the open-ocean (Malleret-King *et al*., 2002). The northern most site of Malindi fish landing site (3.2192° S, 40.1169° E) is located on the Malindi Bay. The Athi-Sabaki-Galana system drains into the bay. Fishing is one of the major economic activities in Malindi, partly due to its proximity to rich fishing grounds including the Kenya North banks and the Sabaki River mouth. The Malindi fishing area has fringing reef with high coral diversity running from Malindi-Watamu with deep offshore banks close to the continental shelf. Mida Creek which forms part of the Malindi fishing grounds is a diverse groundwater-fed shallow mangrove and sea grass creek (Malleret-King *et al*., 2002). However, Malindi has shelved off some of its fishing grounds to the Malindi and Watamu National parks and Reserve (Kaunda-Arara and Rose, 2006).

3.4 Field Sampling and Species Identification

Field sampling was conducted for three consecutive days at each of the selected sites during November, 2013 through September, 2014. All landed catch was sorted to species level and the rabbitfish specimens isolated for further analysis. While the specimens were still fresh; initial identification features such as caudal fin shapes, colour patterns on the body and fins that were distinctive enough to help in identifying landed specimens were observed and recorded (Table 1).

Table 1: Features useful in identification of dead or preserved rabbitfishes

Morphometric Character	*S. canaliculatus*	*S. sutor*	*S. luridus*	*S. argenteus*	*S. rivulatus*
Caudal fin shape	Moderately lunate	Slightly forked	Truncate		
Caudal fin colour	Dark	Dark	Dark	Light or Silvery	Light or Silvery
Caudal fin lobe tip shape	Sharply pointed	Moderately pointed		Sharply pointed	Sharply pointed
Caudal fin lobe lengths	Nearly equal	Unequal		Equal	Equal
On lateral line origin	Dark patch or blotch				
On caudal fin	4-5 dark, 3-4 light bars		6-7 dark, 6 light bars	Light bars	
On dorsal fin base	Dark spots	Dark spots	Dark spots	Light spots	
On anal fin base	Dark spots	Dark spots	Dark spots		Dark spots
Stripes on dorsal fin base					Dark
On anal fin rays			3-4 dark bars		
On caudal peduncle base	Broad vertical dark bars			Broad vertical dark bars	Narrow vertical dark bars
On each caudal lobe		3 light vertical stripes		3-4 dark/light vertical stripes	4 dark vertical stripes
On operculum edge				Dark vertical bar	
On pelvic fin		Dark spots			
On pelvic fin				4-5 light/4 dark bars	
Pectoral fin colour					Olive green
On dorsal part of head					Dark patch
Above lateral line		7-9 dark patches			
On upper part of caudal peduncle		Silvery patch			
Spawning			Gravid ~8 months a year		

Further length measurements and the weight of the rabbitfish specimens were taken and recorded at the landing site. For each specimen, the standard length (SL) and total length (TL) were measured on a fish measuring board to the nearest 0.1 cm. The SL and TL were measured from the tip of the snout (mouth closed) to the caudal peduncle base and tip of the longest caudal fin, respectively (Fischer and Bianchi, 1984; Anam and Mostarda, 2012). Body weight (BW, g) was measured to the nearest 0.1 g using a top loading balance (Ashton Meyers, model 7765).

At each landing site, ten (10) individuals of rabbitfish species were collected and chilled in ice before transfer to the Kenya Marine & Fisheries Research Institute (KMFRI) laboratory for morphological study. On arrival at the laboratory, the specimens were immediately preserved at -20^{o} C pending further processing.

3.4.1 Laboratory Work

Before any morphological measurements and meristic counts were conducted on the preserved specimen, they were thawed at room temperature for about two hours. Then each specimen was dried using soft tissue paper to remove excess water from the body surfaces. Measurements were then taken from the left lateral aspect of each specimen. Morphometric measurements were then conducted from left aspect of each specimen as outlined in Table 2.

Table 2: Morphometric characters measured on each rabbitfish specimen examined in this study

Characters	Abbreviations	Description
Standard length	SL	Tip of upper jaw to tail base
Head depth	HD	Vertical measurement across anterior end of gill opening
Snout length	SnL	Tip of upper jaw to anterior border of eye
Eye diameter	ED	Greatest bony diameter of orbit
Body depth	BD	Maximum depth measured from base of dorsal spine
Pre-dorsal distance	PDD	Tip of upper jaw to anterior base of dorsal fin
Pre-pectoral distance	PPD	Tip of upper jaw to anterior base of pectoral fin
Pre-ventral distance	PVD	Tip of upper jaw to anterior base of ventral (pelvic) fin
Pre-anal distance	PAD	Tip of snout (upper jaw) to anterior base of anal fin
Pectoral-anal fin distance	PtAFD	Distance from anterior base of pectoral fin to anterior base of anal fin
Ventral-anal fin distance	VtAFD	Distance from anterior base of ventral fin to anterior base of anal fin
Dorsal fin base length	DFbL	Distance from anterior to posterior base end of dorsal fin
Dorsal fin ray length	DFL	Longest dorsal fin length
Dorsal spine length	GDspL	Longest dorsal spine (5th or 8th) length
Pectoral fin length	PFL	Distance from anterior to posterior end of the pectoral fin
Ventral fin length	VFL	Distance from anterior to posterior end of ventral fin
Ventral spine length	VspL	Longest (1st) ventral spine length
Anal fin base length	AFbL	Distance from anterior to posterior base end of the anal fin
Anal fin ray length	AFL	Longest anal fin length
Anal spine length	GAspL	Longest anal spine (3rd or 4th) length
Lower jaw length	LwJL	Straight line between the snout tip and posterior edge of mandible
Lower jaw width	LwJW	Distance between the posterior ends of the mandible
Caudal peduncle length	CPL	Distance from posterior end of dorsal/anal fin to base of column
Caudal peduncle width	CPW	Depth of caudal peduncle taken in middle of its length

3.4.2 Morphometric Measurements

Following the procedures described in Fischer and Bianchi (1984), point to point measurements were taken on 24 morphometric characters to the nearest 0.1 cm using vernier calipers (Mutitoyo, Japan) as follows: Standard length (SL) was measured -from the tip of the snout to a vertical line passing through the base of caudal fin; Head depth (HD)-from anterior end of dorsal fin across anterior end of gill opening; Snout length (Snl)- from the tip of the snout to the anterior margin of the eye; Eye diameter (ED)-as horizontal diameter between the fleshy margins of the orbit; Body depth (BD)-as the greatest distance from the dorsal midline to the ventral midline of the body; Pre-dorsal distance (PDD)-from the tip of upper jaw to anterior base of dorsal fin; Pre-pectoral distance (PPD)-from the tip of upper jaw to anterior base of pectoral fin.

The Pre-ventral distance (PVD) was measured -from the tip of upper jaw to anterior base of ventral (pelvic) fin; Pre-anal distance-from the tip of snout (upper jaw) to anterior base of anal fin; Pectoral anal fin distance (PtAFD)-from anterior base of pectoral fin to anterior base of anal fin; Ventral anal fin distance (VtAFD)-from anterior base of ventral fin to anterior base of anal fin; Dorsal fin base length (DFbL)-from anterior to posterior base end of dorsal fin; Dorsal fin ray length (DFL)-from mid-point of 9^{th} and 10^{th} spines to the longest ray; Dorsal spine length (GDspL)-from the base to the tip of the longest spine (5^{th} or 8^{th}); Pectoral fin length (PFL)-from anterior to posterior end of the pectoral fin; Ventral fin length (VFL)-from anterior to posterior end of ventral fin; Ventral spine length (VspL)-from the base to the tip of 1^{st} spine; Anal fin base length (AFbL)-from anterior to posterior base end of the anal fin; Anal fin ray length (AFL)-from mid-point of 3^{rd} and 4^{th} to longest ray; Anal spine length (GAspL)-from the base to the tip of the longest spine (3^{rd} or 4^{th});

Lower jaw length (LwJL)-from snout tip to the posterior edge of mandible; Lower jaw width (LwJW)-from posterior to anterior ends of mandible; Caudal peduncle length (CPL)-as horizontal distance from the rear end of the anal fin base to a vertical at the caudal fin base and Caudal peduncle width (CPW)-as the least vertical distance of caudal peduncle.

3.4.3 Meristic Counts

The meristic characters counted on each individual are shown in Table 3. The counts were done using a dissecting pin, for the Dorsal spines (Dspine), Rays (Dray); Anal spines (Aspine), Anal rays (Aray) and Pectoral fin rays (Pectray). Single (un-branched) and branched rays caudal fin rays (Crays) were counted on each caudal fin using hand lenses. Gill rakers (Grakers) were counted under dissecting microscope using a pointed pin starting with the upper then the lower limb of the first left gill arch (Fischer and Bianchi, 1984).

Table 3: Meristic characters counted on each rabbitfish specimen sampled in the present study

Characters	Abbreviations	Description
Dorsal fin spines	Dspine	Number of dorsal fin spines
Dorsal fin rays	Dray	Number of branched rays on dorsal fin
Anal fin spines	Aspine	Number of anal fin spines
Anal fin rays	Aray	Number of branched rays on anal fin
Pectoral fin rays	Pectray	Number of pectoral fin rays
Caudal fin rays	Crays	Number of single & branched caudal fin rays
	ULSCray	Number of single caudal rays in upper lobe
	BCray	Number of branched caudal rays
	LLCray	Number of single caudal fin rays in lower lobe
Gill rakers (Grakers)	ULGr	Number of gill rakers on upper limb of gill arch
	LLGr	Number of gill rakers on lower limb of gill arch
	TGr	Number of gill rakers on both limbs of gill arch

3.5 Data Analyses

Length-weight relationship (LWR) was estimated using the equation: $\text{Log}_{10}W = \log_{10} a + b\log_{10}TL$, where W is the body weight, TL is the total length, a intercept and b is the slope of the regression line (Le Cren, 1951). The relationship was estimated from the data of the six (6) rabbitfish species. The condition factor (K) was computed using the expression: $K = 100W/L^{b:}$ Where: K = condition factor, W= total body weight (g), L= total length (cm), 100=constant and b= slope of the regression curve (Fulton, 1904; Wootton, 1990).

Morphometric measurements were expressed as a percentage of standard length (SL) to remove size effect. The standardized morphometric measurements were exported to PaST (PAlaeontological STatistics, version: 2.17). Morphometric data were then subjected to

Principal Component Analysis (PCA). PCA is a procedure for finding hypothetical variables (components) that accounts for as much of the variance in multi-dimensional data as possible, the resultant new variables identified being linear combinations of the original variables (Davies, 1986; Harper, 1999). The non-parametric Mann-Whitney U-test was used for univariate comparisons to evaluate differences between species on the characters contributing to most of the variation. Significant differences were considered at ($\alpha < 0.05$). Because raw meristic data were quite similar for most species, they were not subjected to PCA.

CHAPTER 4: RESULTS

4.1 Species Composition

A total of six (6) rabbitfish species; *S. canaliculatus, S. sutor, S. stellatus, S. luridus, S. rivulatus* and *S. argenteus* are landed by the artisanal fishers. The total number of rabbitfishes recorded at each landing site during the study is presented in Table 4. All the six (6) rabbitfish species were recorded at Msambweni fish landing site; Shimoni and Malindi recorded five (5) species; Kilifi recorded four (4); while Mombasa and Vanga each had three (3) species. Only two (2) species; *S. canaliculatus* and *S. sutor* were recorded in all the six (6) landing sites, with 118 and 103 specimens recorded in Msambweni and Shimoni respectively, while Mombasa recorded 67 and 62 specimens of the same species. Five species; *S. canaliculatus, S. sutor, S. stellatus, S. luridus* and *S. rivulatus* were landed during both the NEM (October-March) and SEM (April-September) seasons, while *S. argenteus* was only landed during the SEM season (Table 5). However the abundance of *S. canaliculatus, S. sutor* and *S. luridus* recorded during 2013/2014 SEM was higher compared to the numbers recorded in 2014/2015 SEM suggesting a probable decline in abundance. On the other hand, *S. stellatus* numbers showed higher abundance in NEM season, and during 2014/2015 SEM. *Siganus rivulatus* only occurred in NEM and 2014/2015 SEM.

Table 4: Abundance (number) of rabbitfish species recorded at the six landing sites along the Kenyan coast during the study period

Species	Vanga	Shimoni	Msambweni	Mombasa	Kilifi	Malindi	Sub-total
S. canaliculatus	75	104	118	67	76	93	533
S. sutor	98	103	94	62	91	78	526
S. luridus	0	43	126	86	92	10	357
S. stellatus	5	26	34	0	8	37	119
S. rivulatus	0	0	5	0	0	4	9
S. argenteus	0	2	7	0	0	0	9
Grand total	178	278	384	215	267	222	**1554**

Table 5: Temporal distribution of the six rabbitfishes recorded along the Kenya coast

Date	*S. canaliculatus*	*S. sutor*	*S. stellatus*	*S. luridus*	*S. rivulatus*	*S. argenteus*	Grand-Total
				NEM			
Nov., 2013	77	62	86	0	0	0	77
Dec., 2013	217	134	84	3	0	2	217
Jan., 2014	158	91	147	9	0	0	158
Feb., 2014	4	0	0	0	0	0	4
Mar., 2014	0	0	37	10	0	0	0
Apr., 2014	0	0	0	0	0	0	0
				SEM			
Apr., 2014	0	0	0	0	0	0	0
May, 2014	0	11	0	13	0	0	24
Jun., 2014	21	0	49	13	0	0	83
Jul., 2014	28	0	0	0	0	0	28
Aug., 2014	97	98	13	24	0	0	224
Sept., 2014	7	11	16	20	4	0	58
				NEM			
Oct., 2014	2	0	0	6	0	2	10
Nov., 2014	0	0	7	18	0	0	25
Dec., 2014	0	0	0	8	0	0	8
Jan., 2015	0	0	0	0	0	0	0
Feb., 2015	0	0	0	0	0	0	0
Mar 2015	0	0	0	0	5	7	12

4.2 Meristic Counts

A total of 234 specimens of the six (6) rabbitfish species recorded during the present study were analyzed for meristic characters including spines and rays of all the fins; dorsal, anal, pectoral and caudal fins as well as the number of gill rakers were counted. Results of the analysis of the meristic characters for the specimens of the six (6) rabbitfish species recorded along the Kenya coast are summarized in Table 6. Results showed similar meristic counts in most of the species except for differences in caudal fin ray counts in *S. stellatus* that was different from the rest of the species. Similarly, *Siganus luridus* and *S. argenteus* differed in their gill raker counts, and the two species were also different from the rest of the species in terms of the gill raker counts.

Table 6: Results of meristic characters' count for the six (6) rabbitfishes analyzed during the study

Meristic character	*S. canaliculatus*	*S. sutor*	*S. stellatus*	*S. luridus*	*S. rivulatus*	*S. argenteus*
Dspines	XIII	XIII	XIII	XIII	XIII	XIII
Drays	10	10	10	10	10	10
Aspines	VII	VII	VII	VII	VII	VII
Arrays	9	9	9	9	9	9
Pectrays	17 (17-18)	17(17-18)	17(17-18)	17 (17-18)	17 (17-18)	17 (17-18)
Crays	18	18	20	18	18	18
ULSCrays	5	5	5	5	5	5
BCrays	10	10	10	10	10	10
LLCrays	4	4	5	4	4	4
Grakers	10	10	10	10	10	10
ULGrakers	VII	VII	VII	VII	VII	VII
LLGrakers	6-7+(17-18)	6-7+(17-18)	6-7+(17-18)	5-7+(15-17)	6-7+(17-18)	4-6+(17-18)

4.3 Descriptive Statistics for Morphometric Measurements

A total of 234 individuals of the six (6) rabbitfish species were recorded for both morphometric and meristic analysis. These included *S. canaliculatus* (60), *S. sutor* (62), *S. luridus* (55), *S. stellatus* (39), *S. rivulatus* (9) and *S. argenteus* (9) individuals. The results of descriptive statistics of all specimens used in this study are summarized in Table 7. The sizes of the specimens (SL, mean±SD) recorded in the study ranged from 20.1±1.7-22.0±1.8 for all of the combined samples. On average, *S. stellatus* recorded larger individuals; (SL, mean±SD) of 22.0±1.8 and body depth (mean±SD) of 46.1±2.3. The mean±SD for DFbL and AFbL of the same species ranged from 64.4±1.7-67.9±1.2 and 41.7±1.8-43.9±1.9, respectively. *Siganus stellatus* recorded the longest Dorsal and Anal fin base lengths with mean±SD of 67.9±1.2 and 43.9±1.9, respectively. On the other hand, *S. luridus* recorded the smallest individuals with standard length and body depth (mean±SD) of 14.1±1.4 and 34.0±2.2, respectively. *Siganus luridus* recorded the shortest Dorsal and Anal fin base lengths with mean±SD of 56.0±1.7 and 42.5±1.4, respectively.

Table 7: Results of morphometric characters analysis (Mean±SD) for specimens of the six rabbitfish species recorded during the study

	Siganus canaliculatus (n=60) Mean±SD	*S. rivulatus* (n=9) Mean±SD	*S. sutor* (n=63) Mean±SD	*S. argenteus* (n=9) Mean±SD	*S. stellatus* (n=36) Mean±SD	*S. luridus* (n=9) Mean±SD
SL	20.2±2	18.9±2.5	20.1±1.7	18.9±2.4	22.0±1.8	14.1±1.4
HD	25.3±3	23.5±3.0	20.0±1.9	25.2±1.8	25.6±21.6	26.7±2.0
Sn L	9.2±0.6	8.2±0.3	9.4±0.6	9.3±1.0	11.6±0.9	8.5±0.6
ED	6.0±0.7	6.9±1.7	6.1±0.7	7.7±0.3	5.8±0.7	7.1±0.9
BD	38.5±2.8	35.5±1.4	38.4±2.0	36.7±2.2	46.1±2.3	34.0±2.2
PDD	23.9±2	23.0±1.6	24.1±1.3	22.7±1.5	26.3±1.2	23.5±1.2
PPD	22.3±1.2	21.5±1.4	21.8±1.1	21.7±1.5	22.5±1.7	21.0±1.4
PVD	30.3±2	29.5±1.4	30.3±1.5	31.1±2.0	33.9±1.1	27.8±1.9
PAD	46.6±3.6	47.5±3.3	48.1±2.4	48.5±2.8	52.0±3.8	48.2±2.3
PtAFD	26.9±2	25.4±1.3	25.7±2.4	26.9±1.7	28.4±2.1	27.4±2.2
VtAFD	19.9±2	19.1±1.0	18.9±1.6	19.8±1.4	20.7±1.7	22.0±1.8
DFbL	64.4±1.7	68.1±1.9	65.8±2.5	68.6±1.4	67.9±1.2	56.0±1.7
DFL	36.3±2.5	38.5±2.3	38.4±2.1	39.5±2.1	38.5±2.0	37.6±2.2
GDspL	10.2±1.0	9.8±2.2	10.3±1.7	11.2±1.5	13.3±1.0	13.6±1.7
PFL	18.0 ±1.0	15.6±0.8	18.6±1.2	6.9±1.1	20.3±1.1	19.0±2.0
VFL	13.9 ±1.4	14.5±1.6	14.1±1.0	14.0±0.8	17.9±1.3	18.0±1.3
VspL	10.6±0.8	10.2±0.8	10.5±1.2	10.2±0.6	13.8±0.9	12.4±1.9
AFbL	41.7 ±1.8	44.4±1.5	41.9±2.0	43.6±1.9	43.0±1.9	42.5±1.4
AFL	30.3±1.0	34.6±1.0	29.9±2.0	34.2±1.3	34.1±1.5	31.1±2.1
GAspL	9.5±1.1	11.6±1.2	10.2±1.1	11.0±0.9	14.0±1.0	13.1±1.1
LwJL	5.2±0.2	5.1±0.67	5.2±0.4	4.6±0.4	5.7±0.5	5.4±0.3
LwJW	2.5±0.2	1.9±0.3	2.8±0.3	2.2±0.2	2.7±0.4	2.6±0.6
CPL	10.6 ±0.8	11.3±1.0	10.7±1.1	11.9±1.2	10.0±1.1	10.8±1.0
CPW	5.2±0.4	4.8±0.4	5.2±0.4	5.1±0.6	6.3±0.1	5.5±0.4

4.3.1 Principal Component Analysis of Morphometric Characteristics

A total of 118 specimens were subjected to detailed morphometric analyses after data clean-up to eliminate outliers from the original data of 234 specimens. The initial PCA applied to the data of the six (6) rabbitfish specimens showed clear separation of polygons for two groups; *S. stellatus* and *S. luridus* with *S. stellatus* specimens in the positive part of 1^{st} principal component and *S. luridus* specimens in the positive part of 2^{nd} principal component (Figure 2). The polygons of the other four species; *S. rivulatus, S. argenteus, S. canaliculatus* and *S. sutor* overlapped in the negative part of the 2^{nd} principal component. The 1^{st} principal component accounted for 64.3% of the total variation, while 2^{nd} principal component accounted for 47.2% (Table 8). The factor loadings showed that the 1^{st} principal component was defined mainly by ED (0.494), PPD (0.398) and PVD (0.249), while the 2^{nd} principal component was mainly defined by PPD (0.314), PAD (0.279), VtAFD (0.319) and DFbL (0.477) (Table 9). The results of Mann-Whitney U-test showed that specimens of *S. stellatus* and *S. luridus* significantly differed in seven of their morphometric characters; HD, SnL, ED, BD, PVD, DFbL and VFL ($p < 0.05$). The biggest difference (significant, $p < 0.05$) in morphometric characters were observed in ten characters between *S. luridus* and *S. argenteus* for ED, PDD, VtAFD, DFbL, DFL, GDspL, PFL, VFL, VspL and CPL. More similar morphometric characters were observed between *S. canaliculatus* and *S. sutor* in which only the ED and GAspL were significantly different ($p<0.05$).

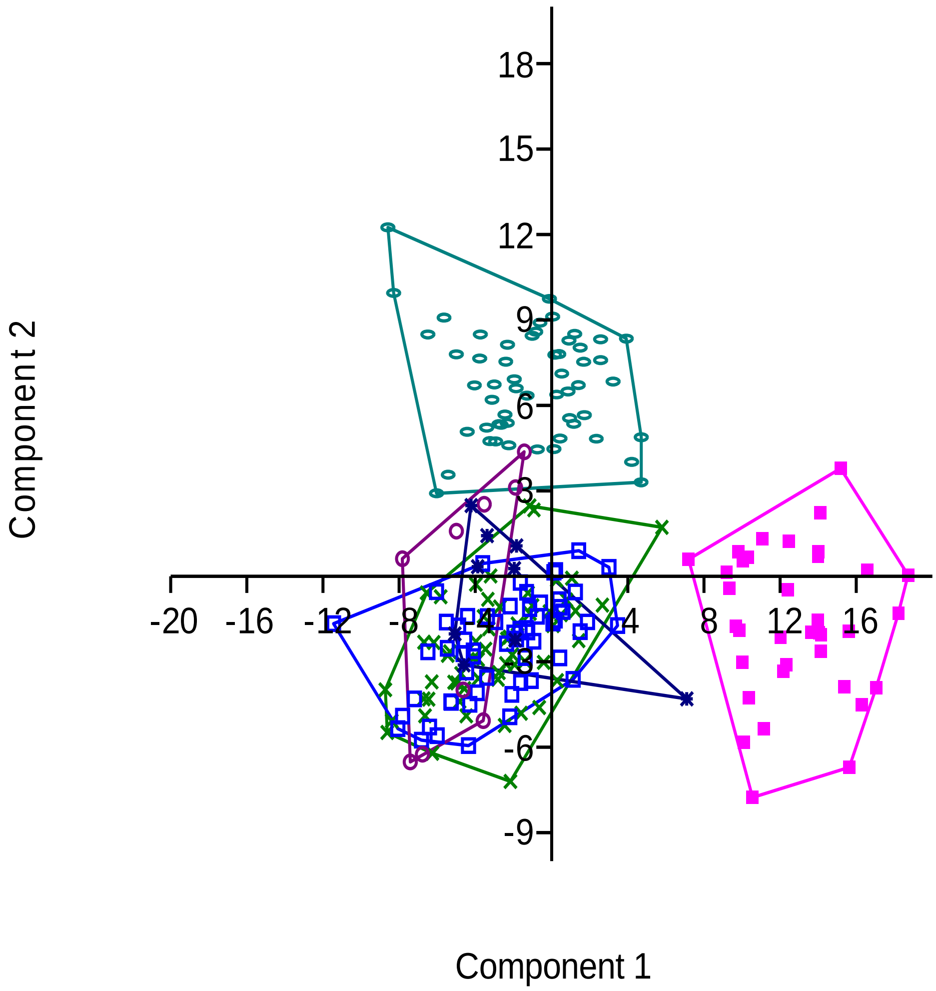

Figure 2: Plot of individual scores on the first and second components on metrics as percent of standard length of S. *canaliculatus* (Cross), *S. sutor* (Open Square), *S. luridus* (Oval), *S. stellatus* (Filled Square), *S. rivulatus* (Circle) and *S. argenteus* (Diamond).

Table 8: Total variability of principal components and contributing Eigen values to the analysis of the six rabbitfish species

PC	Eigen value	% variance
1	64.3	47.2
2	19.9	14.6
3	11.0	8.1
4	7.0	5.1
5	5.3	3.9

Table 9: Loading of percentage standard metrics of morphometric measurements for *S. stellatus* (n = 36) and *S. luridus* (n = 25) specimens from the Kenya coast

Morphometric characters	PC 1	PC 2
Head depth	0.169	0.015
Eye depth	-0.071	0.050
Snout length	**0.494**	-0.048
Body depth	0.153	0.002
Pre-dorsal distance	0.088	0.162
Pre-pectoral distance	**0.398**	**0.314**
Pre-ventral distance	**0.249**	0.002
Pre-anal distance	0.117	**0.279**
Pectoral-anal fin distance	-0.027	**0.319**
Ventral-anal fin distance	0.142	**0.477**
Dorsal fin base length	0.076	0.104
Dorsal fin ray length	-0.025	0.244
Dorsal spine length	0.084	0.193
Pectoral fin length	-0.028	0.109
Ventral fin length	0.096	0.182
Ventral spine length	0.039	0.235
Anal fin base length	0.165	0.037
Anal fin ray length	0.045	0.024
Anal spine length	0.014	0.030
Lower jaw length	0.008	0.007
Lower jaw width	0.007	0.039
Caudal peduncle length	0.104	0.012
Caudal peduncle width	0.067	**0.319**

To test the effect of distance on morphometric characters of the same rabbitfish species from different geographical locations, PCA was applied to the data of each species from two different landing sites. Analysis for *S. canaliculatus*, *S. sutor* and *S. stellatus* was performed on the data recorded from Malindi and Vanga, while for *S. luridus,* data from Shimoni and Malindi was analyzed for *S. luridus* and data analyzed for *S. argenteus* was collected from Shimoni and Msambweni. The PCA results for the five (5) species showed no clear separation of polygons. However, PCA on *S. rivulatus* data recorded only in Msambweni (n=9) and Malindi (n=9) resulted in a clear separation of the polygons.

The Malindi specimens were located in the negative part of the 1st principal component while the Msambweni specimens were in the positive part of 1st PC (Figure 3). The 1st PC accounted for 54.7% of the total variation while the 2nd principal component accounted for 19.6 % (Table 10). The factor loadings showed that the 1st principal component was defined mainly by HD (0.224), ED (0.229), PDD (0.235), PAD (0.396), GDspL (0.219) and GAspL (0.204) while the 2nd PC was defined by HD (0.625), PAD (0.312), DFbL (0.389) and DFL (0.371) as shown in Table 11. In the subsequent analysis Mann-Whitney U-test for specimens of *S. rivulatus* from Msambweni (south-coast) and Malindi (north-coast), showed significant differences in ED and GAspL ($p \leq 0.05$).

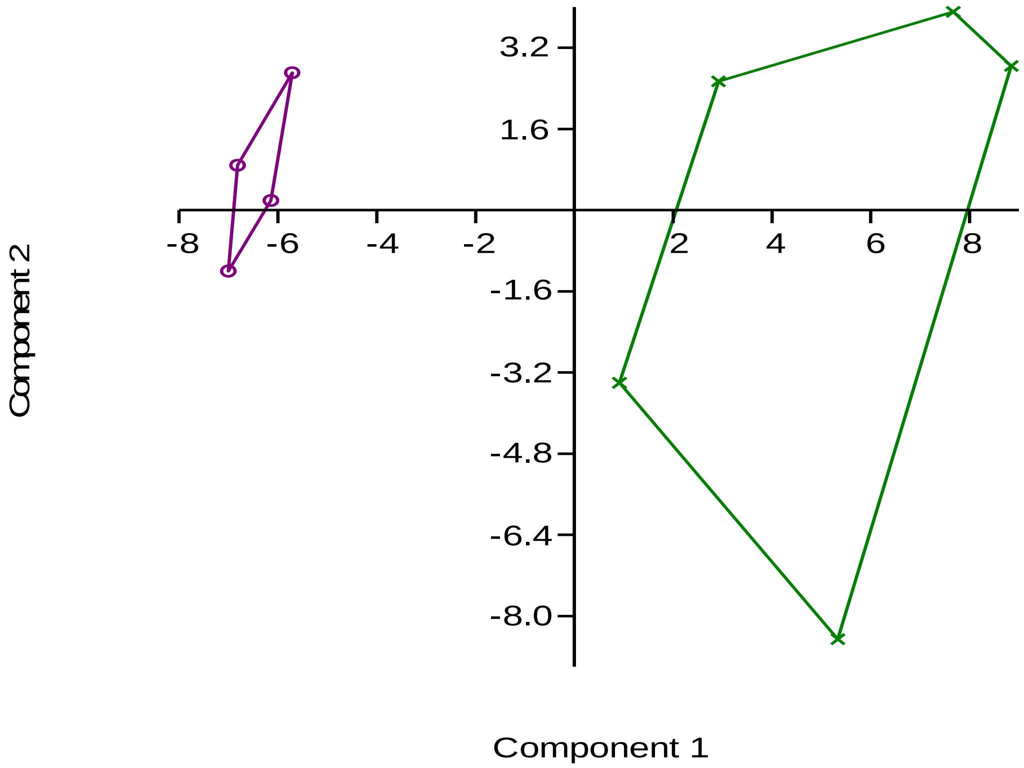

Figure 3: Plots of individual scores on the first and second principal components as percentage of standard length for *S. rivulatus* specimens collected in Msambweni (Cross) and Malindi (Open Circle) along Kenya coasts

Table 10: Total variability of principal components and contributing Eigen values to the analysis of *S. rivulatus* specimens from Msambweni and Malindi landing sites, along Kenya coast

PC	Eigen value	% variance
1	42.6	54.7
2	15.3	19.6
3	8.5	11.0
4	4.7	6.1
5	3.4	4.3

Table 11: Loading of percentage standard metrics of morphometric measurements on PC1 and PC2 for *S. rivulatus* specimens collected from Msambweni and Malindi along Kenya coast

Morphometric characters	PC 1	PC 2
Head depth	0.224	**0.625**
Eye depth	0.134	0.124
Snout length	0.096	0.072
Body depth	0.229	0.041
Pre-dorsal distance	0.235	0.063
Pre-pectoral distance	0.196	0.022
Pre-ventral distance	0.125	0.089
Pre-anal distance	**0.396**	**0.312**
Pectoral-anal fin distance	0.121	0.157
Ventral-anal fin distance	0.020	0.087
Dorsal fin base length	0.099	**0.389**
Dorsal fin ray length	0.027	**0.371**
Dorsal spine length	0.219	0.198
Pectoral fin length	0.080	0.100
Ventral fin length	0.105	0.185
Ventral spine length	0.083	0.047
Anal fin base length	0.136	0.207
Anal fin ray length	0.050	0.089
Anal spine length	0.204	0.068
Lower jaw length	0.087	0.037
Lower jaw width	0.001	0.021
Caudal peduncle length	0.001	0.112
Caudal peduncle width	0.046	0.003

4.4 Length-Weight Relationship

A total of 1320 rabbitfish specimens from the six (6) landing sites along the Kenya coast were analyzed for LWR. LWR results of the six (6) rabbitfish species recorded from all the six (6) landing sites are summarized in Tables 12. The results show that estimated *b*-values ranged from 0.736 to 3.537. The highest *b*-value 3.537 was recorded from the analysis of *S. luridus* for Mombasa data, while the lowest *b*-value 0.736 was obtained from *S. canaliculatus* for Malindi data.

Table 12: Length-weight relationship of six rabbitfish species recorded along Kenya coast. (n = sample size; a = regression intercept; b = length exponent; r^2 = coefficient of determination)

Species	Site	Parameters			
		n	*a*	*b*	r^2
S. canaliculatus	Vanga	65	0.372	2.725	0.908
	Shimoni	90	0.248	2.625	0.948
	Msambweni	108	0.353	2.831	0.963
	Mombasa	57	0.530	2.898	0.906
	Kilifi	65	0.221	2.681	0.614
	Malindi	83	0.542	0.736	0.983
S. sutor	Vanga	93	0.199	2.554	0.948
	Shimoni	83	0.302	2.700	0.973
	Msambweni	87	0.221	2.681	0.788
	Mombasa	52	0.857	3.045	0.957
	Kilifi	82	0.627	2.947	0.957
	Malindi	30	0.018	3.370	0.814
S. luridus	Shimoni	114	0.358	2.855	0.585
	Msambweni	76	0.022	3.537	0.878
	Mombasa	82	0.957	3.194	0.955
	Kilifi	82	0.627	2.947	0.957
	Malindi	16	0.505	2.958	0.972
S. stellatus	Shimoni	38	0.460	2.914	0.992
	Msambweni	27	0.434	2.855	0.964
	Malindi	65	0.372	2.725	0.908
S. rivulatus	Malindi	4	0.030	1.967	0.378
	Msambweni	5	0.131	2.339	0.988
S. argenteus	Msambweni	7	0.055	1.904	0.982

4.5 Condition Factor (*K*) of Rabbitfishes

The calculated condition factors for the six (6) rabbitfish species ranged from 0.46 to 3.53. Total number, range for condition factor and the mean *K*-values for the six (6) species; *S. canaliculatus, S. sutor, S. luridus, S. stellatus, S. rivulatus* and *S. argenteus* are presented in Table 13. The results show that the *K*-values (mean±SD) ranged from 1.22±0.37 to 2.64±0.08. The highest mean of 2.64±0.08 was recorded for *S. argenteus,* while the lowest mean of 1.22±0.37 was obtained for *S. canaliculatus* values.

Table 13: Estimated mean values of condition factor (K), range and sample size (n) of rabbitfish specimens examined during the study

Species	Number of Species	Range	Mean±SD
S. canaliculatus	468	0.88-2.86	1.22±0.37
S. sutor	465	1.26-3.53	2.08±0.43
S. luridus	302	0.46-2.87	1.24±0.56
S. stellatus	81	1.66-2.33	2.07±0.19
S. rivulatus	9	1.46-1.75	1.57±0.03
S. argenteus	9	2.26-2.98	2.64±0.08

CHAPTER 5: DISCUSSION

In the present study, six (6) species of rabbitfish were recorded at the six (6) landing sites. There were variations in the number of species recorded per site with Msambweni being the most specious where all the six, (6) species were recorded. *Siganus canaliculatus* and *S. sutor* occurred in all the six (6) sites, while *S. argenteus* was only landed in Msambweni and Shomoni. On the other hand, *S. rivulatus* was only recorded from the Malindi and Msambweni landing sites. The differences in the number of species recorded at various sites may be indicative of spatial differences in the distribution of rabbitfishes along the Kenya coast some species exhibit a wider distribution while others such as *S. rivulatus* and *S. argenteus* have more restricted distribution patterns. A study conducted in Philippine by Lavina and Alcala (1974) reported that *S. argenteus* occurred in the open ocean. In the present study, the two species; *S. rivulatus* and *S. argenteus* were caught between September and March coinciding with the spawning aggregation period of rabbitfishes (Robinson and Samoilys, 2013). The spawning aggregation also commonly referred to as *Vumbi la Tafi* (in Swahili) by the local fishers. Consequently, it is likely that *S. argenteus* migrates from the open ocean to inshore waters to spawn during that period.

The results of the present study indicate seasonal variations in the distribution, with high number of species and number of individuals recorded during the NEM season as compared to SEM. The difference in number of species in NEM may be related to calmer conditions experienced during this season which has been reported to result in improved artisanal fish catches (Obura, 2001). However, it could as well be related to the spawning aggregation which has been documented to occur in the NEM season (Robinson and

Samoilys, 2013). The fewer species and low number of individuals recorded in SEM may be attributed to rough conditions of the sea experienced during that season. It is noteworthy that some species such as *S. stellatus* which are considered as low value fish by the local dealers compared to *S. canaliculatus* and *S. sutor,* are often retained for own consumption the fishers and rarely landed or brought to the open market. However, in the present study, higher landings of *S. stellatus* at the open market were realized after the research offered to buy the species at the same price paid for *S. canaliculatus* and *S sutor* by the dealers.

A total of 1,554 individuals of rabbitfishes were recorded during the study, with more specimens collected in the south-coast landing sites compared to the north. Relatively, more species were also recorded in the south-coast than in the north. These findings could probably be attributed to the difference in coral reef and sea grass cover between the south-coast and north-coast Kenya. Obura *et al*. (2002) reported that the fringing reef along the Kenyan coast extends about 200 km long, with dominant coral reef and sea grass cover in the south coast while coral reef and sea grass cover are patchy in the northern part of the coast. This may be as a result of river discharges and closeness to the Somali current which pumps cold (17-22 °C) and highly nutrient rich (about 5 to 20 μm of nutrient) sub-surface water to the coastal region creating one of the most productive ecosystems in the ocean. The coral cover interspersed by sea grass beds in south coast Kenya is estimated at 19.5% compared to 11.1% in the north. The difference in species numbers and individuals recorded may also be attributed to variation in fishing pressure, habitat characteristics or recruitment variability between south and north coast fishing areas (Obura *et al*., 2002).

Local names are also important in identifying some rabbitfish species whose names are area-specific e.g. *Tafi mwarumba/mayai/kitumbo* refers to *S. luridus* while *S. stellatus* is locally referred to as *Tafi mwamba/manga/mayenge/ziwa*. *Siganus luridus* can also be identified based on the fact that it is gravid for about 8 months in a year, and the local fishers have christened this species as *Tafi mayai* au *Tafi kitumbo*. Other species; *S. canaliculatus*, *S. sutor*, *S. stellatus*, *S. rivulatus* and *S. argenteus* are reported to have specific spawning seasons spanning between January-February and May-June (Ntiba and Jaccarini, 1990; Kamukuru, 2009); November-March (Robinson and Samoilys, 2013).

The meristic counts of all the six (6) rabbitfish species examined in the present study were similar in most species. The only differences found in this study were the number of caudal-fin ray counts for *S. stellatus* that differed from the counts of the rest of the species. Furthermore, gill rakers counts differed between *S. luridus* and *S. argenteus* and as well as with the counts for the rest of the species. Variations in meristic and morphometric traits within a species or among closely related species has been attributed to a combination of environmental and genetic factors interacting on the developing embryos (Fowler, 1970). However, this was not investigated and thus cannot be stated with certainty for the present analysis.

PCA results on morphometric measurements of the six (6) rabbitfish species did not show clear separation of polygons for *S. canaliculatus*, *S. sutor*, *S. rivulatus* and *S. argenteus* specimens suggesting these species have similar body morphometry. However, Mann-Whitney U-test revealed significant character differences in, ED, BD, PPD, PVD, DFbL, DFL, GDspL, PFL, AFbL, AFL, LwJL and CPL. However, the in LwJL is mostly related to feeding habit and variation in habitat characteristics where the fish lives. Tharwat and Al-Owfeir (2003) reported that difference in the lengths of the lower jaw in some species could be attributed to the fact that some rabbitfishes were planktivorous while others herbivorous.

Clear separation of polygons for *S. stellatus* and *S. luridus* specimens reflects high morphometric differences between the two (2) species and also from the other four species where the polygons showed no clear separation. The Mann-Whitney U-test results confirmed a high magnitude of significant character differences in HD, SnL, ED, BD, PVD, PtAFD, DFbL, DFL and VFL. Similarly, specimens of these two species differed in the number of their caudal fin rays and gill rakers. This implies that *S. stellatus* and *S. luridus*; *S. luridus* and *S. argenteus* differed significantly in their morphometric characters. Therefore the species can be easily distinguished on the basis of their body morphometric characters only.

Results of the PCA of Vanga and Malindi specimens indicated no clear separation of polygons for three (3) *S. canaliculatus*, *S. sutor* and *S. stellatus*. Similar results were observed for *S. argenteus* from Shimoni and Msambweni, as well as *S. luridus* from Shimoni and Malindi. These findings suggest that the five (5) rabbitfish species are fairly similar in their body morphometry regardless of their geographical locations along Kenya coast. However *S. rivulatus* specimens from Msambweni and Malindi resulted in a clear separation of polygons. This separation of polygons for specimens of this species from the two fishing areas could be due to geographical isolation of the species leading to some degree of stocks differentiation of the same species due to variation in habitats characteristics. However, it is also probable that the specimens from the two (2) sites may belong to different species. Previous studies by Murta (2000), Poulet *et al*. (2004) and Turan (2004) suggest that morphological differences can also occur within species due to genetic and environmental factors during the early stages of fish growth. Mann-Whitney U-test results confirmed that the specimens from the two locations significantly differed in two of their morphometric characters, ED and GAspL; therefore, to differentiate specimens of *S. rivulatus* from the two geographical locations only ED and GAspL would be useful

Knowledge of LWR and condition factor (*K*) of fishes is important in fisheries science (Le Cren, 1951). The length-weight relationship analysis of data for the six (6) rabbitfish species examined from the six (6) landing sites along Kenyan coast showed a strong correlation between length and weight with coefficient of determination values (r^2) ranging from 0.378-1.0. The estimated *b*-values for rabbitfish specimens from most landing sites ranged between 2.554-3.537 which are within expected range of 2.3-3.5 proposed by Bagenal and Tesch (1978). The estimated *b*-values for rabbitfish specimens from most landing sites ranged between 2.554-3.537 which are within expected range of 2.3-3.5 proposed by Bagenal and Tesch (1978), *S. canaliculatus* with *b*-values ranging between 0.736-2.8. Rabbitfish species from various landing sites exhibited mixed growth patterns e.g. three rabbitfish species *S. sutor*, *S. luridus* and *S. stellatus* with *b*-values ranging between 2.55-3.194 displayed isometric growth pattern however, growth pattern for *S. luridus* in Msambweni was positive allometric. On the other hand, *S. canaliculatus* exhibited isometric growth in all landing sites except for Malindi specimens that exhibited negative allometric growth pattern a similar result obtained for *S. argenteus* and *S. rivulatus*.

The LWR parameters computed for three (3) rabbitfish species *b*-values; 0.736-3.370 for *S. stellatus*, *S. canaliculatus*, and *S. sutor* respectively. These are comparable with *b*-values of 2.597, 2,800, and 2.716 reported by Wambiji *et al*. (2008) but are different from 3.12-3.37 reported for *S. sutor* by Mbaru *et al*. (2011). The *b*-values obtained in this study compared well with 2.939 for *S. sutor* reported by De Souza (1988). Results of LWR for *S. luridus*, *S. rivulatus* and *S. argenteus* obtained in this study are reported for the first time in Kenya, therefore no previous results are available for comparison. The results of this study showed that there were differences in LWR of different populations of the same species. The LWR between fish species and different populations of the same species can be affected by a number of factors including season, habitat, gonad maturity, sex, diet, and preservation technique of samples and sample size which may be the cause of variation in *b*-values computed in various studies (Mousavi-Sabet *et al*., 2014).

The mean *K*-values of the six (6) rabbitfish species sampled along the Kenyan coast were >1.0, which indicates good physiological condition of the fish species along the Kenyan coast during the study period. The mean *K*-values calculated in the present study for the three species; *S. stellatus*, *S. canaliculatus*, and *S. sutor*; 2.07±0.19, 1.22±0.37 and 2.08±0.43, respectively, are comparable to estimates of 1.47±0,021, 1.259±0.010, 1.317±0.008 reported by Wambiji *et al*. (2008) and 1.0-1.18 and 0.9-1, for females and males of *S. sutor* reported by De Souza (1998). However these values differed from those

(0.14) reported by Mbaru *et al*. (2011) which could be due to variations in sampling strategies.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study established the occurrence of six (6) species of rabbitfish in Kenya inshore waters with spatial and temporal seasonal differences in abundance. Four (4) of the six (6) species generally showed similar body morphometry and, therefore could not be distinguished from PCA analysis. On the other hand, two (2) species; *S. stellatus* and *S. luridus* differed from each other and from the rest of the species. Meristic counts were similar for most species except for *S. stellatus* and *S. luridus* that differed in caudal-fin rays and gill-raker counts. *Siganus luridus* and *S. argenteus* differed in their gill-raker counts and as well from the counts for the other species.

While existing species description are useful in identifying live specimen, landed and preserved specimens could be more easily distinguished by other characters such as caudal-fin shapes and markings on the specimens' body and fins that remain visible. This study provide additional morphomeristic characters useful in differentiating landed and preserved specimens of the rabbitfish species. Based upon the present morphological characters analysis no clear evidence was obtained indicating the existence of separate stocks of the same rabbitfish species along Kenyan coast except for *S. rivulatus* specimens from Msambweni and Malindi which could either be separate stocks of the same species or two different species. Therefore, their clear separation would require further analysis with recommendation for more analytical process using advance technology such as molecular genetics.

6. 2 Recommendations

1. There is need of further research on the taxonomy of *S. rivulatus* including the analysis of its molecular genetic variation to confirm whether populations in the south Msambweni and north Malindi are different stocks of the same species or are actually different species.
2. There is a need for revision of existing taxonomic descriptions to include additional distinctive characters documented in this study for more accurate and quick identification especially of landed and preserved specimen given that colour patterns and markings fade upon death and preservation.
3. There is a need for further research to understand factors influencing the spatial and temporal distribution of the rabbitfishes along the Kenya coast. This should include any seasonal movement or migration.

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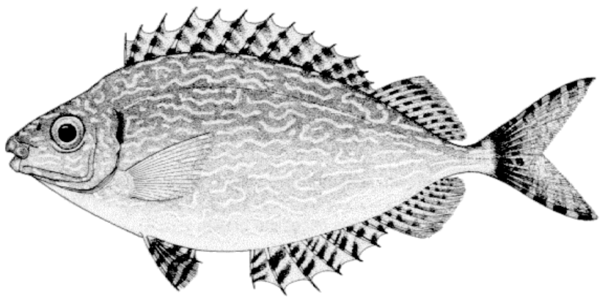
Appendix 1: Scientific and common names of rabbitfishes (Plates 1-6) recorded along Kenya coast in the present study and their original descriptions as in Anam and Mostarda (2012)

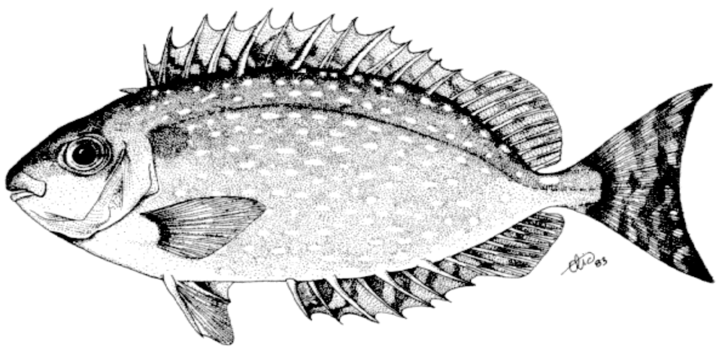
Plate 1: *Siganus argenteus*; Quoy & Gaimard, 1825



FAO

Streamlined rabbitfish with a forward- directed spine in front of dorsal fin, embedded in nape; longest dorsal spines are from the 3rd to 8th spines; caudal fin is deeply forked with pointed lobes. The species is light blue to bluish grey or brown with several spots which can join to form horizontal wavy lines, mostly on lower sides; colour fades rapidly at death so that head and trunk may be solid brown; pre-juveniles are reported to be yellow-brown to silver below.

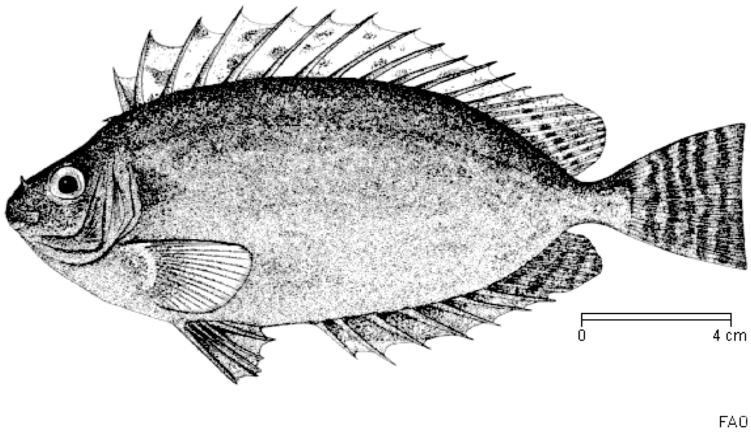
Plate 2: *Siganus canaliculatus;* Park, 1797



FAO

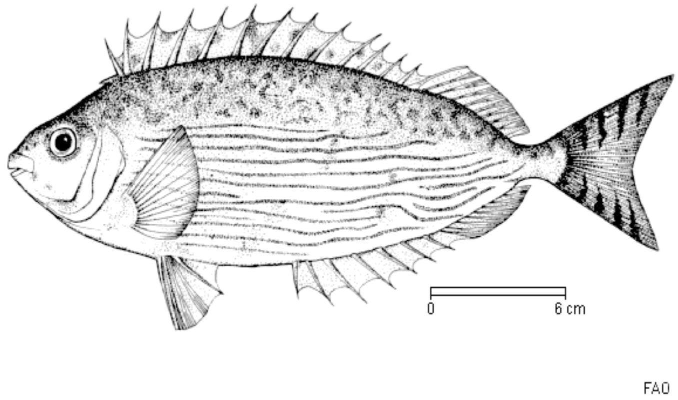
White-spotted rabbitfish head profile is slightly or markedly concave above eye; has forward-directed spine in front of dorsal fin; caudal fin almost emarginate in specimens under 10 cm, forked in larger fish. In life, colour is highly variable, depending on mood of fish and colour of substrate; greenish-grey above to silver on belly; numerous pearly blue spots covering nape and sides, arranged more or less in horizontal rows; frightened and injured fish is mottled brown.

Plate 3: *Siganus luridus*; Rüppell, 1829



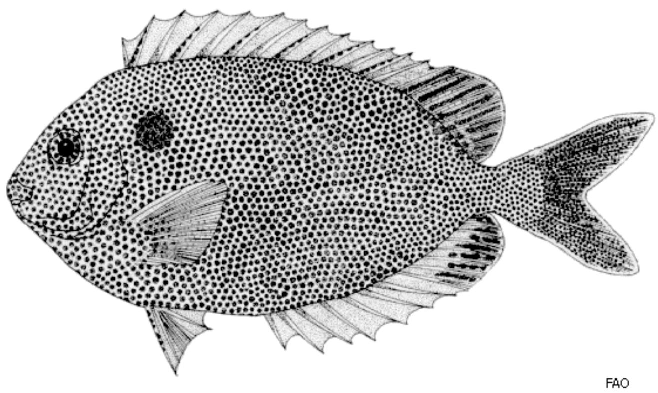
Dusky rabbitfish has forward-directed spine in front of dorsal fin; scales minute; cheeks with a few or many fine scales; 15-20 scale rows between lateral line and bases of leading dorsal-fin spines; anal fin with 7 spines and 9 soft rays. Head and sides olive green or very dark brown in colour; sides often conspicuously marked with pale reticulating lines, but sometimes patterns are very indistinct and disappearing at death; pectoral fins hyaline-yellow.

Plate 4: *Siganus rivulatus*; Forsskål & Niebuhr, 1775



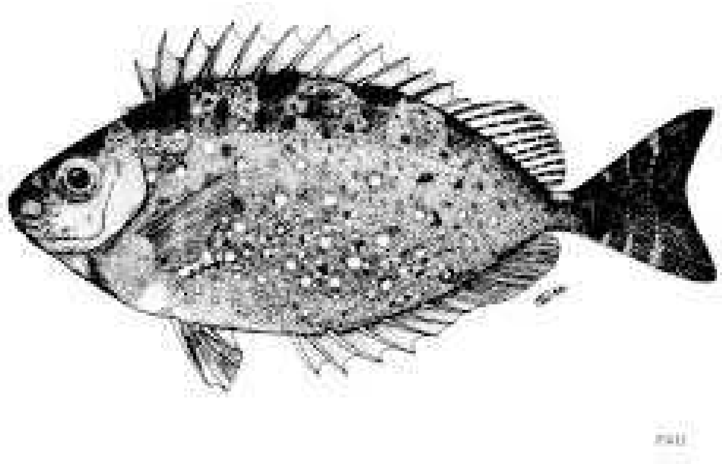
Marbled rabbitfish has forward-directed spine in front of dorsal fin; caudal fin only moderately forked; scales minute; 18-21 scale rows between lateral line and bases of leading dorsal spines. Head and body brown or olive-green, grading to pale below; horizontal golden lines running the length of the body to 2/3 of sides; lines becoming indistinct after death.

Plate 5: *Siganus stellatus;* Forsskål, 1775



Brown-spotted rabbitfish has forward-directed spine in front of dorsal fin; scales minute; cheeks strongly scaled; 23-28 scale rows between lateral line and base of leading dorsal spines. Colour in life, is grayish-green with brown spots all over head and trunk, spotted pattern extending onto all fins; the spots become very dark brown and the intermediate areas pale to dark lilac; trailing edges of soft parts of dorsal and anal fins, perimeter of caudal fin and a saddle over the caudal peduncle is markedly paler than the rest; a dark patch of about the size of orbit present at origin of lateral line.

Plate 6: *Siganus sutor*; Valenciennes, 1835



Shoemaker rabbitfish has forward-directed spine in front of dorsal fin; scales minute; cheeks either scale less or with a few or many very fine scales; 26-31 scale rows between lateral line and bases of leading dorsal spines. Colour in life, is green-grey to sandy above, paler below; sides with about 30 large spots, the largest bigger than the pupil; spots are evenly spaced over sides in 6 irregular rows, the upper row lying close to lateral line; after death, brown mottled with dark brown; spots absent.