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Cover image: Ngalawa (traditional dugout, outrigger canoe) being readied for a boat race in the 2018-2019 Kraken cup, Kilwa, Tanzania. © Rahim Saggaf

Morphological and meristic characters of six rabbitfish species (Family: Siganidae) in Kenya

Rashid O. Anam[1], Chrisestom M. Mwatete[2], Nina Wambiji[1]

[1] Kenya Marine and Fisheries Research Institute, PO Box 81651 – 80100 Mombasa, Kenya

[2] Department of Biological Sciences, Pwani University, PO Box 195-80108, Kilifi, Kenya

* Corresponding author: rashidanam@yahoo.com

Abstract

Siganus species (rabbitfishes) are caught by artisanal fishers in Kenyan marine waters. The identification of recently captured rabbitfish species is based on colour patterns, but colours fade after death or during preservation, making species identification more difficult. Morphometric measurements and meristics are then useful in differentiating between species. Twenty-four morphological and twelve meristic characteristics of rabbitfish were obtained from samples collected at six landing sites along the Kenyan coast. Principal Component Analysis (PCA) and Mann-Whitney U-tests were used to evaluate variability among the species. Four of six rabbitfish species showed similar body morphometry and could not be distinguished using PCA analysis, but *Siganus stellatus* and *S. luridus* differed from the other species and each other. No clear morphological evidence of separate stocks of individual rabbitfish species was found, apart from *S. rivulatus* for which the sample size was small. It is recommended that existing taxonomic descriptions are updated to include additional distinctive characters documented in this study.

Keywords: taxonomy, Siganidae, morpho-meristic, length-weight, body condition

Introduction

The Siganidae (rabbitfishes or spine foots) are widely distributed throughout tropical and subtropical Indo-Pacific regions, primarily in shallow waters less than 15 m deep. They also occur in the eastern Mediterranean basin, having invaded that water body through the Red Sea and Suez Canal which has been open since 1869 (Renanel *et al*., 2018). Tharwat and Al-Owfeir (2003) reported *Siganus rivulatus* as one of the first siganids to enter the Mediterranean basin, where it is now common. Most rabbitfish species are exclusively marine, apart from *Siganus vermiculatus* which is estuarine and has successfully been introduced to freshwater habitats (Tharwat and Al-Owfeir, 2003). Rabbitfishes are valuable commercial species in many parts of the world (Woodland, 1990).

Rabbitfishes in the Western Indian Ocean (WIO) region are harvested by artisanal fishers using a popular local basket trap (*malema*) (Wambiji *et al*., 2016; 2008; Kamukuru, 2009), gill nets, intertidal wiers (*uzio*) and hand-lines (*mishipi*). In Kenya, they are among the most common species in landings of marine artisanal fisheries (39% of landings by weight; Robinson and Samoilys, 2013).

The Siganidae comprises of two genera: *Siganus* and *Lo,* with 29 known species. *Siganus* is distinguished by a deep compressed body, a snout resembling that of a rabbit, 13 dorsal, seven anal and two strong ventral fin spines. They possess a leathery skin, smooth, small and closely adherent scales, and are frequently mistaken to be scaleless. *Lo* comprises of five species, with extended snouts and prominent face stripes earning them the name of "foxface fishes". Snout shapes, caudal fins, body depths and shapes have been useful in distinguishing the members of these two genera (Woodland, 1990).

Rabbitfish graze on algae, seaweeds and sea grasses and are important to reef ecosystems because their grazing prevent corals from being smothered by mats of

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filamentous and leafy algae. Their faeces in reef crevices promote growth and diversity of corals (Duray, 1998). Siganids show lunar synchronized spawning activity, similar to other reef fish species (Harahap *et al.*, 2001; Robinson and Samoilys, 2013).

Siganids exhibit few morphological differences, making them difficult to differentiate from each other. Descriptions currently used for their identification are based on colouration of live specimens (Woodland and Randall, 1979). However, colours change with age, after death and in preserved specimens (Masuda *et al.*, 1980; Randall and Kulbicki, 2005). Fisheries studies depend mainly on landed (dead) and preserved specimens, hence other identification features (apart from colour) are useful in species identification. Morphometric and meristic characteristics are two powerful tools for fish identification. Morphometric characteristics describe aspects of body form, whereas meristic characteristics are related to discrete numbers (counts) that are repeated. Morphological plasticity is an adaptive response to complex ecological conditions under which fish species live. A mixture of environmental factors, such as temperature, salinity, dissolved oxygen, radiation, water depth and current flow may induce morphological variations between fishes (Brraich and Akhter, 2015). Other factors, such as reproduction and gonad development may also influence fish morphology (Fakunmoju *et al.*, 2014; Kashefi *et al.,* 2012).

Accurate identification to species level is an essential step in fisheries research and management, and formulation of conservation strategies. The aim of this study was to compare morphometric and meristic characteristics of six rabbitfish species known from Kenya.

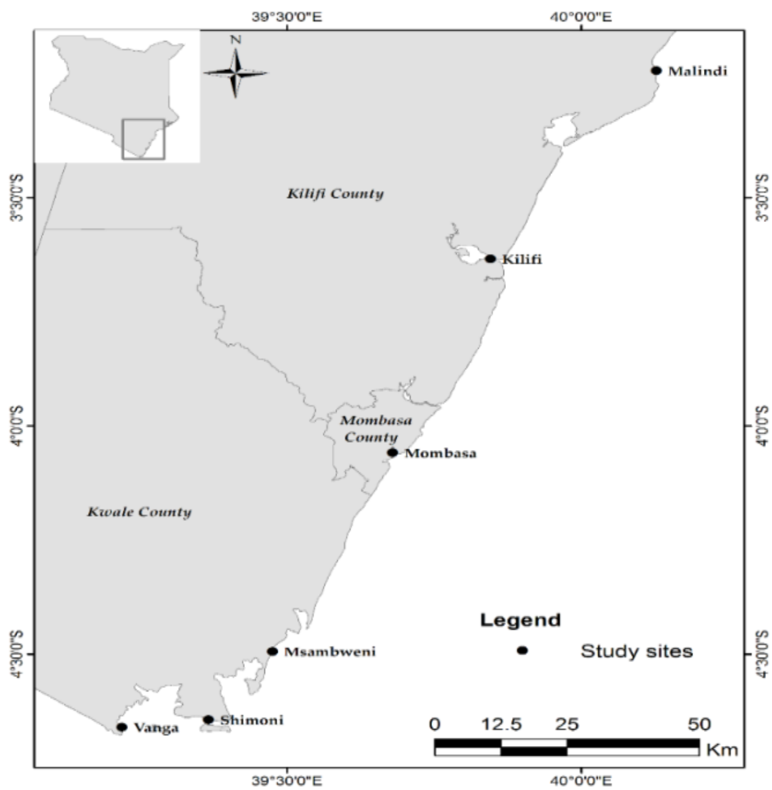

Figure 1. Map of Kenya (inset) showing the Kenyan coast and locations of the study sites.

Materials and methods

Study Sites

This study was conducted at six landing sites in Kenya: Vanga, Shimoni and Msambweni in the south, and Mombasa, Kilifi and Malindi in the north (Fig. 1). Vanga is located within a mangrove area, with fishing occurring in a complex mangrove ecosystem, estuaries and creeks, near patch and island reefs interspersed with sea grass beds. Shimoni borders on a Marine National Reserve (Agembe *et al.*, 2010) with fishing taking place on patch and fringing coral reefs, sea-grass beds, reef flats and sand bars. Msambweni has complex mangrove bays, estuaries and creeks close to the shore near patch and island reefs and is also a popular tourist resort (Koornhof, 1997). In Mombasa, inshore fishing take place year round in shallow lagoons (<5m deep), on sea grass beds with narrow channels opening into the open sea (Malleret-King *et al.*, 2002), with some limitations in the marine protected areas (MPA; e.g. Bamburi Marine Reserve; Marsh *et al.*, 2002). Fishing in Kilifi is mainly in Kilifi Creek (part of the Goshi River estuary; Weiss and Heinrich, 2006), shallow lagoons, sea grass beds and narrow channels opening into the open sea (Malleret-King *et al.*, 2002). The Malindi fish landing site is located on Malindi Bay, adjacent to the Athi-Sabaki-Galana river system, with fringing reef and high coral diversity, and includes Mida Creek with shallow mangrove and sea grass habitats (Malleret-King *et al.*, 2002). The Malindi and Watamu National Parks restrict fishing in some areas (Kaunda-Arara and Rose, 2006).

Data collection

Field sampling was conducted for three consecutive days per month at each landing site between November 2013 and September 2015. Freshly landed rabbitfish were selected from artisanal catches and sorted to species level based on distinctive features such as caudal fin shapes, and colour patterns on body and fins (Anam and Mostarda 2012) (Table S1). During field sampling, standard length (SL) and total length (TL) of 1554 specimen was measured on a measuring board (±0.1 cm) from the tip of the snout (mouth closed) to the caudal peduncle base and tip of the longest caudal fin respectively, according to Fischer and Bianchi (1984) and Anam and Mostarda (2012). Body weight (BW, g ± 0.1g) was recorded on a top loading balance (Ashton Meyers, model 7765).

A total of 234 specimens of the six species were purchased for morpho-meristic studies, chilled in ice and taken to KMFRI laboratories where they were deep frozen at -20^o C for at least one week before undertaking morphometric and meristic measurements.

Frozen specimens were thawed at room temperature and dried with soft tissue paper to remove excess water. Identification features were recorded on these specimens, as well as additional specimens obtained from the National Museum of Kenya, and preserved in formalin and 70% alcohol. Measurements of 24 morphometric characters were taken with Vernier calipers from the left lateral aspect of each specimen (Table S2) and twelve meristic characters were counted on each specimen (Table S 3) (Fischer and Bianchi, 1984).

Data Analysis

Morphometric data were expressed as a percentage of standard length to remove size effect, and a Principal Component Analysis (PCA) was used to identify components accounting for variance in multi-dimensional data. Identified variables were linear combinations of original variables (Davies, 1986; Harper, 1999). The non-parametric Mann-Whitney U-test was used as a post-hoc test for the differences discerned from PCA analysis at $\alpha \le 0.05$. Meristic data were analyzed for dorsal spines and rays, anal spines and rays, pectoral rays and branched and un-branched caudal fin rays.

Regressions of the form $W = aL^b W$ where W = weight (g), L = total length (cm), and a and b = regression constants were fitted to length and weight data using a least squares method. Data were log-transformed (Log W = log a + blog L) for comparisons among species. Condition factors were calculated employing the formula: $K = 100\ W/L^{b:}$ (Fulton, 1904; Wootton, 1990).

Results

All six rabbitfish species were recorded at Msambweni, five at Shimoni and Malindi respectively, four at Kilifi, and three at Mombasa and Vanga (Table 1). *S. canaliculatus* and *S. sutor* occurred at all sites. *S. canaliculatus*, *S. sutor*, *S. stellatus*, *S. luridus* and *S. rivulatus* were landed in all seasons, while *S. argenteus* were landed seasonally during the South East Monsoon only, although the sample size for this species was small (n = 9) (Fig. 2). Most *S. canaliculatus*, *S. sutor* and *S. stellatus* were landed during the North East Monsoon, but landings of *S. luridus* and *S. rivulatus* were roughly equal between seasons.

Morphometric measurements of the six rabbitfish species (Table 2) indicated that the mean length was largest for *S. stellatus* and smallest for *S. luridus*. Meristic counts of the six species (Table 3) were comparable for most species except for *S. stellatus* caudal fin rays that differed from those of other species. Gill raker counts also differed between *S. luridus* and *S. argenteus* and from counts of the other species. Raw meristic data were therefore not analyzed with PCA.

The PCA of standardized morphometric data showed significant variation in morphometric characters of *S. stellatus* and *S. luridus*, but the mean values of most morphometric characteristics were similar between the other four species (Fig. 3). The first principal component accounted for 64.3 % of total variation and the second for 19.9 %. Factor loadings showed that the first

Table 1. Numbers of rabbitfish of each of six species recorded per landing site.

Species	Site						Sub-total
	Vanga	Shimoni	Msambweni	Mombasa	Kilifi	Malindi	
S. canaliculatus	75	104	118	67	76	93	553
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							1554

component was defined by snout length (SnL), pre-pectoral distance (PPD) and pre-ventral distance (PVD), while the second component was defined by pre-pectoral distance (PPD), pre-anal distance (PVD), pectoral-anal fin distance (PtAFD), ventral-anal fin distance (VtAFD) and caudal peduncle width (CPW) (Table 4). Mann-Whitney U-test results (Table S4) confirmed significant differences ($p < 0.05$) between *S. stellatus* and *S. luridus* in head depth (HD), SnL, eye diameter (ED), body depth (BD), PVD, dorsal fin base length (DFbL) and ventral fin length (VFL). *S. luridus* and *S. argenteus* differed in ED, PPD, VtAFD, DFbL, dorsal fin ray length (DFL), dorsal spine length (GDspL), pectoral fin length (PFL), VFL, ventral spine length (VspL) and caudal peduncle length (CPL). *S. canaliculatus* and *S. sutor* differed only in ED and anal spine length (GAspL).

The morphometry of *S. rivulatus* differed between two collection sites at Msambweni and Malindi based on a small sample size (n = 9). The first principal component explained 54.7 % of total variation and the second explained 19.6 % (Fig. 4), and factor loadings are shown in (Table S5). Subsequent Mann-Whitney U-tests showed significant difference in ED and GDspL at $p \leq 0.05$.

The length-weight relationships of six rabbitfish species (n=1554; Table 5) resulted in *b*-values between 2.554 and 3.537, within an expected range of 2.3 to 3.5 proposed by Bagenal and Tesch (1978). Rabbitfish species collected from most landing sites exhibited mixed growth patterns: *S. sutor*, *S. luridus* and *S. stellatus* displayed isometric growth, however, *S. luridus* from Msambweni showed positive allometric growth. *S. canaliculatus* data exhibited isometric growth at all sites except at Malindi where it showed negative allometric growth. *S. argenteus* and *S. rivulatus* also displayed negative allometetric growth, but in both cases sample sizes were small with a weak fit for *S. rivulatus* ($r^2 = 0.378$).

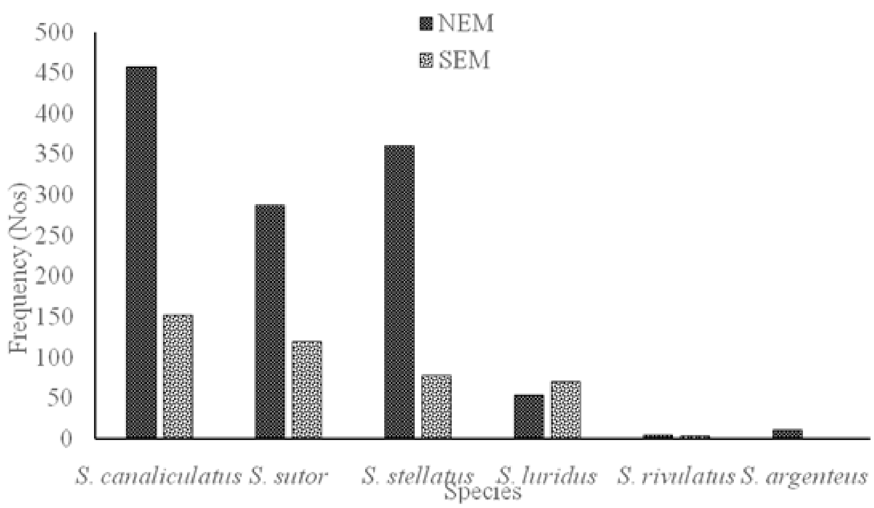

Figure 2. Seasonal distribution of rabbitfish samples in the present study.

Table 2. Descriptive statistics for the morphometric characters (Mean ± SD) of rabbitfish specimens recorded during the study. Abbreviations are summarized in Table S2.

	Siganus canaliculatus (n=60) Mean±SD	*Siganus rivulatus* (n=9) Mean±SD	*Siganus sutor* (n=62) Mean±SD	*Siganus argenteus* (n=9) Mean±SD	*Siganus stellatus* (n=39) Mean±SD	*Siganus luridus* (n=55) 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

The mean body condition of the six rabbitfish species was lowest for *S. luridus* and highest for *S. argenteus*. Condition factor-values of all six species ranged from 0.46 to 3.53. Condition factor-values of most species were > 1, indicating a good body condition. At the extremes, mean body condition values of 2.64 ± 0.08 were estimated for *S. argenteus* and 1.22 ± 0.37 for *S. canaliculatus* (Table 6).

Discussion

Relatively more rabbitfish species and specimens (as part of landings) were recorded at sites along the south coast compared to the north coast, plausibly attributed to differences in coral reef and sea grass cover (estimated at 19.5 % on the south coast and 11.1% on the north coast; Obura *et al*., 2002). Fringing reefs along the Kenya coast extend for a distance of about 200

Table 3. Counts of meristic characters for six rabbitfish species analyzed during the study. Abbreviations are summarized in Table S3.

Abbreviation	*S. canaliculatus*	*S. sutor*	*S. stellatus*	*S. luridus*	*S. rivulatus*	*S. argenteus*
Dspine	XIII	XIII	XIII	XIII	XIII	XIII
Dray	10	10	10	10	10	10
Aspine	VII	VII	VII	VII	VII	VII
Aray	9	9	9	9	9	9
Pectray	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
ULSCray	5	5	5	5	5	5
BCray	10	10	10	10	10	10
LLCray	4	4	5	4	4	4
ULGr	10	10	10	10	10	10
LLGr	VII	VII	VII	VII	VII	VII
TGr	6-7+(17-18)	6-7+(17-18)	6-7+(17-18)	5-7+(15-17)	6-7+(17-18)	4-6+(17-18)

km between Malindi and Vanga, and are more prominent on the south coast. Coral reef and sea grass cover are patchy along the north coast (Obura *et al*., 2002) as a result of river discharge and the proximity of the Somali current which brings cooler (17 - 22°C) nutrient rich (5 - 20 µm of nutrient) waters to the northern coast. This creates productive ecosystems in the north but with a higher silt load which may reduce coral reef and sea grass growth and cover. Habitat suitability can therefore explain the greater numbers and species of rabbitfishes along the south coast.

The PCA showed no morphological variation among *S. canaliculatus*, *S. sutor*, *S. rivulatus* and *S. argenteus* suggesting that they have similar body morphometry. However, Mann-Whitney U-tests revealed significant

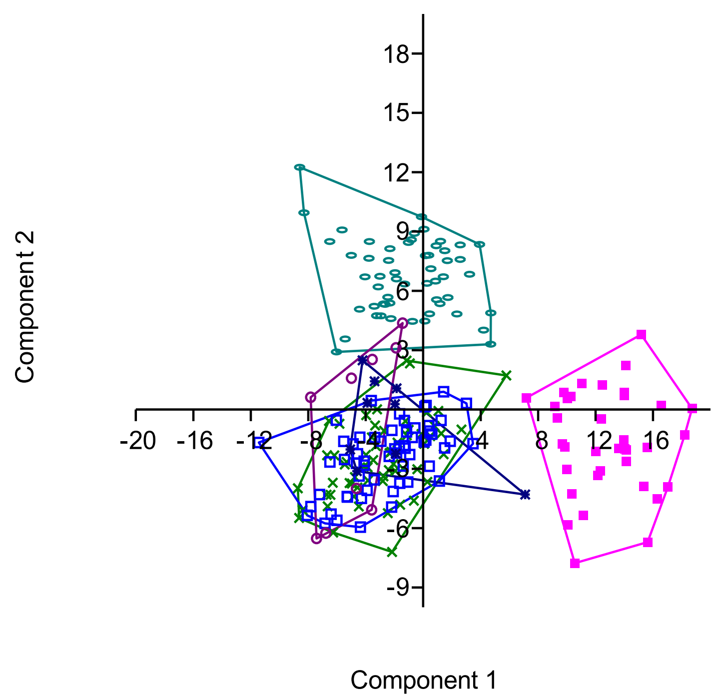

Figure 3. Plot of individual scores on first and second components of morphometric as a percentage of standard length of *S. canaliculatus* (Cross), *S. sutor* (Open Square), *S. luridus* (Oval), *S. stellatus*(Filled Square), *S. rivulatus*(Circle) and *S. argenteus* (Diamond).

Table 4. Loading of percentage standard metrics of morphometric measurements for *S. stellatus* (n = 36) and *S. luridus* (n = 25) specimens from Kenya coast. Values in bold indicate significant difference.

Morphometric Characters	Abbreviations	PC 1	PC 2	Morphometric Characters	Abbreviations	PC 1	PC 2
Head depth	HD	0.169	0.015	Dorsal spine length	GDspL	0.084	0.193
Eye depth	ED	-0.071	0.050	Pectoral fin length	PFL	-0.028	0.109
Snout length	SnL	0.494	-0.048	Ventral fin length	VFL	0.096	0.182
Body depth	BD	0.153	0.002	Ventral spine length	VspL	0.039	0.235
Pre-dorsal distance	PDD	0.088	0.162	Anal fin base length	AFbL	0.165	0.037
Pre-pectoral distance	PPD	0.398	0.314	Anal fin ray length	AFL	0.045	0.024
Pre-ventral distance	PVD	0.249	0.002	Anal spine length	GAspL	0.014	0.030
Pre-anal distance	PAD	0.117	0.279	Lower jaw length	LwJL	0.008	0.007
Pectoral-anal fin distance	PtAFD	-0.027	0.319	Lower jaw width	LwJW	0.007	0.039
Ventral-anal fin distance	VtAFD	0.142	0.477	Caudal peduncle length	CPL	0.104	0.012
Dorsal fin base length	DFbL	0.076	0.104	Caudal peduncle width	CPW	0.067	0.319
Dorsal fin ray length	DFL	-0.025	0.244				

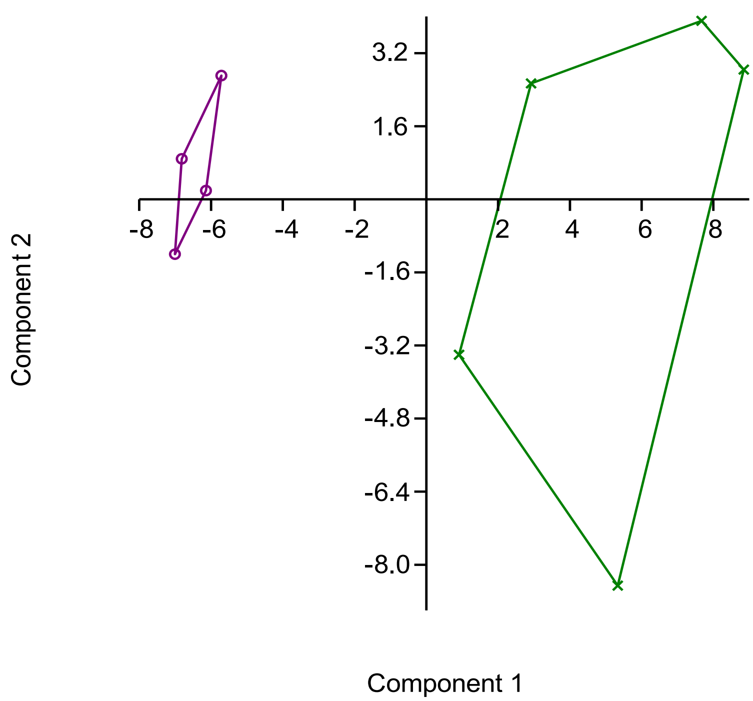

Figure 4. Plots of individual scores on first and second principal components as a percentage of standard length for *S. rivulatus* collected from Msambweni (Cross) and Malindi (Open Circle) along the Kenyan coast.

Table 5. Length-weight relationship of six rabbitfish species recorded along the Kenyan 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

Table 6. Estimated mean values of condition factor (K), range and sample size (n) of rabbitfish specimens examined during the study.

Species	n	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

character differences in several individual parameters such as eye diameter, body depth and lower jaw length, among others (see Table S4). Difference in lower jaw length may be related to variation in the habitat characteristics of the area where the fish lives. Morphological variations such as these could be an adaptive response to factors such as temperature, salinity, dissolved oxygen, radiation, water depth, current flow and food type (Turan, 2000; Tharwat and Al-Owfeir, 2003).

S. stellatus and *S. luridus* differed morphometrically from each other and from the other four species. The Mann-Whitney U-test results confirmed significant differences in HD, SnL, ED, BD, PVD, PtAFD, DFbL, DFL and VFL (Table S4). The two species also differed in the number of their caudal fin rays (Crays) and gill rakers (TGr), implying that they can easily be distinguished on the basis of their body morphometric characters. PCA outputs indicated no clear separation of *S. canaliculatus*, *S. sutor* and *S. stellatus* from Vanga and Malindi, and could also not separate *S. argenteus* from Shimoni and Msambweni, or *S. luridus* from Shimoni and Malindi. The five rabbitfish species therefore have similar body morphometry regardless of their geographical locations along Kenya coast. Conversely, the body morphometry of *S. rivulatus* from Msambweni differed from those at Malindi, resulting in a clear separation in the PCA. Although based on a small sample size, the implication is that geographical isolation may have given rise to differentiation attributed to variations in physico-chemical conditions.

Previous studies by Murta (2000), Poulet *et al.* (2004) and Turan (2004) suggested 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 (Table S4) confirmed that the *S. rivulatus* specimens from the two localities differed significantly in two of their morphometric characters, ED and GAspL; therefore, the two morphometric characters are useful in differentiating *S. rivulatus* species from the two sites.

The meristic counts of all the six rabbitfish species examined in the present study were similar in most species. The only differences found were in the number of caudal-fin ray counts for *S. stellatus*. Furthermore, gill raker counts differed between *S. luridus* and *S. argenteus* 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), although this has not yet been tested for rabbitfishes.

This study established key morphometric and meristic characteristics of six rabbitfish species from Kenya and found that the *b* exponents of the length-weight relationships of most species were close to 3, indicative of an isometric growth pattern. Similar values of *b* were reported for siganids in Kenya by Wambiji *et al*. (2008; 2010) and De Souza (1998) while *b* values varied slightly from those reported by Mbaru *et al*. (2011). However, *b*-values for *S. canaliculatus* from Malindi, *S. argenteus* and *S. rivulatus* exhibited negative allometric growth patterns. Biological parameters in fishes, including length-weight relationships, are affected to factors such as prevailing environmental conditions, ecosystem health, season, food, sex, time of year, stage of maturity, population differences, shape and fatness of the species (Mousavi-Sabet*et al*., 2014; Olapade and Tarawallie, 2014). The condition factors (K) obtained from this study suggested that the specimens were in a good condition, but the influences of season and specific environmental conditions still need to be evaluated.

Conclusions

Four of the six rabbitfish species showed similar body morphometry and could not be distinguished using PCA analysis. Two species (S. *stellatus* and *S. luridus*) differed from each other and from the other species. While existing species descriptions are useful in identifying live specimens, morpho-meristic characters become more useful in differentiating landed and preserved specimens that have lost their colours. No clear morphological evidence of separate stocks of individual rabbitfish species was found, apart from *S. rivulatus* for which the sample size was small. Meristic counts were similar for most species except *S. stellatus* and *S. luridus*, which differed in caudal-fin rays and gill-raker counts. All six species showed mixed growth patterns and their physiological condition factors were >1.

It is recommended that existing taxonomic descriptions are revised to include the additional distinctive characters documented in this study, particularly for the accurate identification of landed and preserved specimens that have lost characteristic colour patterns and markings.

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Appendix

Table S1. Features used to identify dead or preserved rabbitfish specimens, based on personal observations.

Morphometric Character	*Siganus canaliculatus*	*Siganus sutor*	*Siganus luridus*	*Siganus argenteus*	*Siganus rivulatus*	*Siganus stellatus*
Caudal fin shape	Moderately lunate	Slightly forked	Truncate	Deeply forked with pointed lobes	Moderately forked	Emarginate in young, deeply forked in old
Caudal fin colour	Dark	Dark	Dark	Light or Silvery	Light or Silvery	Paler to dark lilac
Caudal fin lobe tip shape	Sharply pointed	Moderately pointed		Sharply pointed	Sharply pointed	
Caudal fin lobe lengths	Nearly equal	Unequal		Equal	Equal	Unequal
On lateral line origin	Dark patch or blotch					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	
Anal and dorsal fin rays			3-4 dark bars			Paler to dark lilac
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				
Caudal fin perimeter/caudal peduncle saddle						Paler
On upper part of caudal peduncle		Silvery patch				
Spawning			Usually gravid ~ 8 months a year			

Table S2. 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
Spine length Anal	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

Table S3. Meristic characters examined on each rabbitfish specimen.

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

Table S4. Mann-Whitney U-test confirmed significant morphological differences between species.

Morphometric characters	Abbreviation	Morphometric characters	Abbreviation
S. stellatus* and *S. Luridus			
Head depth	HD	Snout length	SnL
Eye diameter	ED	Body depth	BD
Pre-ventral distance	PVD	Dorsal fin base length	DFbL
Ventral fin length	VFL		
S. luridus* and *S. Argenteus			
Eye diameter	ED	Pre-dorsal distance	PDD
Ventral-anal fin distance	VtAFD	Dorsal fin base length	DFbL
Dorsal fin ray length	DFL	Dorsal spine length	GDspL
Pectoral fin length	PFL	Ventral fin length	VFL
Ventral spine length	VspL	Caudal peduncle length	CPL
S. canaliculatus*, *S. sutor, S. rivulatus* and *S. argenteus			
Eye diameter	ED		
Body depth	BD		
Lower jaw length	LwJL		
S. canaliculatus* and *S. sutor			
Eye diameter	ED		
Spine length Anal	GAspL		
***S. rivulatus* from Msambweni and Malindi**			
Eye diameter	ED		
Spine length Anal	GAspL		

Table S5. Loading of percentage standard metrics of morphometric measurements on PC1 and PC2 for *S. rivulatus* specimens collected from Msambweni and Malindi along the Kenyan coast. Values in bold show characters that differ significantly and can be used to distinguish the two species.

Morphometric characters	Abbreviations	PC 1	PC 2
Head depth	HD	0.224	0.625
Eye depth	SnL	0.134	0.124
Snout length	ED	0.096	0.072
Body depth	BD	0.229	0.041
Pre-dorsal distance	PDD	0.235	0.063
Pre-pectoral distance	PPD	0.196	0.022
Pre-ventral distance	PVD	0.125	0.089
Pre-anal distance	PAD	0.396	0.312
Pectoral-anal fin distance	PtAFD	0.121	0.157
Ventral-anal fin distance	VtAFD	0.020	0.087
Dorsal fin base length	DFbL	0.099	0.389
Dorsal fin ray length	DFL	0.027	0.371
Dorsal spine length	GDspL	0.219	0.198
Pectoral fin length	PFL	0.080	0.100
Ventral fin length	VFL	0.105	0.185
Ventral spine length	VspL	0.083	0.047
Anal fin base length	AFbL	0.136	0.207
Anal fin ray length	AFL	0.050	0.089
Anal spine length	GAspL	0.204	0.068
Lower jaw length	LwJL	0.087	0.037
Lower jaw width	LwJW	0.001	0.021
Caudal peduncle length	CPL	0.001	0.112
Caudal peduncle width	CPW	0.046	0.003