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

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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 morphology 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 feet) 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 signiids 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 (Bbraich 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.

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 takes 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 7763).

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°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 S3) (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 α ≤ 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 \( W = aL^bW \) 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 \( (\log W = \log a + b \log L) \) for comparisons among species. Condition factors were calculated employing the formula: \( K = 100W/L^b \) (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
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 \((n=1554; \text{Table } 5)\) resulted in \(b\)-values between 2.544 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 allometric growth, but in both cases sample sizes were small with a weak fit for \(S. rivulatus\) \((r^2 = 0.378)\).

![Figure 1](image1.png)

**Figure 1.** Percentage distribution of rabbitfish samples in the present study.

![Figure 2](image2.png)

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

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

| Species    | Vanga | Shimoni | Msambweni | Mombasa | Kilifi | Malindi | Sub-total |
|------------|-------|---------|-----------|---------|--------|---------|-----------|
| \(S. canaliculatus\) | 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      |
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 km.

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

| Species              | Mean±SD | Species              | Mean±SD | Species              | Mean±SD | Species              | Mean±SD | Species              | Mean±SD |
|----------------------|---------|----------------------|---------|----------------------|---------|----------------------|---------|----------------------|---------|
| *S. canaliculatus*    |         | *S. rivulatus*       |         | *S. sutor*           |         | *S. argenteus*       |         | *S. stellatus*       |         |
| (n=60)               |         | (n=9)                |         | (n=62)               |         | (n=9)                |         | (n=39)               |         |
| SL                   | 20.2±2  | HD                   | 25.3±3  | Sn L                 | 9.2±0.6 | ED                   | 6.0±0.7 | BD                   | 38.5±2.8 |
|                      |         |                      |         |                      |         |                      |         |                      |         |
|                      | 18.9±2.5| 20.0±1.9             | 9.4±0.6 | 6.1±0.7              | 38.4±1.4| 21.5±1.4             | 21.8±1.1| 30.3±2.0             | 29.5±1.4 |
|                      |         | 18.9±2.4             | 9.3±1.0 | 7.7±0.3              | 36.7±2.2| 21.8±1.1             | 21.7±1.5| 30.3±1.5             | 31.1±1.5 |
|                      |         | 20.0±3.4             | 11.6±0.9| 5.8±0.7              | 46.1±2.3| 22.5±1.7             | 22.5±1.7| 31.1±2.0             | 33.9±1.1 |
|                      |         | 14.1±1.4             |         |                      |         | 27.8±1.9             |         |                      |         |
|                      |         |                      |         |                      |         | 48.2±2.3             |         | 34.0±2.2             |         |
|                      |         |                      |         |                      |         | 27.4±2.2             |         | 37.6±2.2             |         |
|                      |         |                      |         |                      |         | 13.6±1.7             |         | 42.5±1.4             |         |
|                      |         |                      |         |                      |         | 31.1±2.1             |         | 12.4±1.9             |         |
|                      |         |                      |         |                      |         | 18.0±1.0             |         | 12.4±1.9             |         |
|                      |         |                      |         |                      |         | 11.3±0.6             |         | 11.3±0.6             |         |
|                      |         |                      |         |                      |         | 10.1±1.0             |         | 10.1±1.0             |         |
|                      |         |                      |         |                      |         | 14.0±1.0             |         | 14.0±1.0             |         |
|                      |         |                      |         |                      |         | 17.9±1.3             |         | 17.9±1.3             |         |
|                      |         | 10.8±1.0             |         | 10.8±1.0             |         |                      |         |                      |         |
|                      |         | 6.3±0.6              |         |                      |         |                      |         |                      |         |
|                      |         | 5.5±0.4              |         |                      |         |                      |         |                      |         |

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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

| 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           |
| LLCrGr       | 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) |

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 | 3.870 | 0.814 |
| *S. luridus*   | Shimoni   |            | 114| 0.358 | 2.855 | 0.585 |
|                | Msambweni |            | 76 | 0.022 | 3.537 | 0.878 |
|                | Mombasa   |            | 82 | 0.937 | 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 | 0.999 |
|                | 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      | Sharply pointed     |          |
| Caudal fin lobe lengths                 | Nearly equal            | Unequal              | Equal               | 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          | Dark spots          | Dark spots          |
| On anal fin base                        | Dark spots              | Dark spots           | Dark spots          | Dark spots           |                     |                     |
| Stripes on dorsal fin base              |                         | 3-4 dark bars        |                     |                     |                     |                     |
| Anal and dorsal fin rays                | Broad vertical dark bars |                      | Broad vertical dark bars | Narrow vertical dark bars |                     |                     |
| On caudal peduncle base                 | 3 light vertical stripes |                      | 3-4 dark/light vertical stripes | 4 dark vertical stripes |                     |                     |
| On each caudal lobe                     |                        |                      |                     |                     |                     |                     |
| On operculum edge                       | Dark vertical bar       |                      |                     |                     |                     |                     |
| On pelvic fin                           | Dark spots              |                      |                     |                     |                     |                     |
| On pelvic fin                           |                         |                      |                     |                     |                     |                     |
| 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 |                    |                      |                     |                     |                     |                     |
| 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           | 0.123 | 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 | 0.087 |
| Lower jaw width         | LwJW          | 0.001 | 0.021 |
| Caudal peduncle length  | CPL           | 0.001 | 0.112 |
| Caudal peduncle width   | CPW           | 0.046 | 0.003 |