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Population Characteristics of Selected Small Pelagic Fish Species along the Tanzanian Coast

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Abstract

Although small pelagic fishing in Tanzania is rising, lack of information on population structure has been a significant concern in its management. This study aimed to determine the species composition, length-weight relationship and length at first maturity of *Amblygaster sirm*, *Encrasicholina heteroloba*, *Encrasicholina punctifer*, *Stolephorus commersonii*, and *Spratelloides gracilis* landed at Kilwa Kivinje, Kipumbwi and Shangani along the Tanzanian coast. These landing sites were chosen because of their locations and importance in the small pelagic fishery. Sampling was done monthly from October 2018 to June 2020. The catch composition was site specific such that *E. heteroloba* dominated at Kilwa Kivinje and Shangani, while *E. punctifer* dominated at the Kipumbwi site. Further analysis shows allometric coefficient to be greater than 3 for *A. sirm* and *E. punctifer*, indicating positive allometric growth, while for *S. commersonii* and *S. gracilis*, the allometric coefficient was less than 3, indicating negative allometric growth. Our findings showed that length at first maturity (L_{50}) differed, implying that these species start spawning at different sizes, an essential biological reference for sustainable small pelagic fish exploitation. We recommend seasonal closure of the fishery to maintain reproductive seasons since many species are multiple spawners.

Keywords: Population, Small pelagic, Maturity, Tanzania.

Introduction

Small pelagic fishery plays significant roles in coastal communities' economy (Checkley et al. 2017). They are the most harvested fish group globally, accounting for between 20% and 30% of global commercial landings (FAO 2011). The annual SPFs catch fluctuates depending on environmental factors and fishing effort (Sekadende et al. 2020). SPFs also constitute the main prey of most cetaceans, piscivorous fishes, and seabirds (Bachiller and Irigoien 2015), which move the organic matter to higher trophic levels. In Tanzania, SPFs are fished for commercial and nutritional purposes (Bodiguel and Breuil 2015). The Fisheries Department of Tanzania reported annual catches of about 57,000 metric tons of SPFs in 2020 (Sekadende et al. 2020), accounting for 12% of the overall total fish landings. Dried SPFs are sold in the local and regional markets such as Burundi, the Democratic Republic of Congo (DRC), Malawi, and Rwanda (Bodiguel and Breuil 2015). The *Amblygaster sirm*, *Encrasicholina heteroloba*, *Encrasicholina punctifer*, *Stolephorus commersonii* and *Spratelloide gracilis* are the most widespread and commercially important SPFs (Bodiguel and Breuil 2015, Sekadende et al. 2020) and are consumed raw or processed. Large concentrations of SPFs are apparently fished in the near-shore water fishing grounds of Bagamoyo, Dar es Salaam, Kilwa, Mafia, Mtwara, and Tanga by using ring nets, and some few fishers use purse seine fishing gears (Bodiguel and Breuil 2015). Though considerable information are accrued on the morphometric and meristic characterization of these species from Tanzanian marine waters (Bianchi 1985, Smith 2003), very little information is available on the catch composition, length-weight relationship and length at first maturity.

Basic information such as species composition, length-weight relationship (LWRs), and length at first maturity is essential for assessing stock's health and fishery sustainability (King 1995). Previous studies elsewhere have considered the LWRs and condition factor in describing the stock condition of small pelagic fishes (Nair et al. 2015). The LWR of an ideal fish exactly follows the cube law (Le Cren 1951). Studies by Froese (2006) indicated that the value of exponent '*b*' in the cube law becomes precisely 3 if the fish retains the same shape and specific gravity and grows isometrically during their lifetime. According to Froese (2006), an ideal fish with a '*b*' value of 3 is very difficult to observe in the natural environment as most fishes '*b*' values are either less than or greater than 3, representing negative or positive allometric growth (Le Cren 1951, Froese 2006).

Size at first maturity is essential for setting a management strategy for the exploited fishery. It helps in decision-making on the mean size of fish stocks when related to other biological history information (Sileesh et al. 2020). The size at first maturity is the length at which 50% of individuals attain gonadal maturity (Karna and Panda 2011). Although it is difficult to determine the state of fish maturity stages (Karna and Panda 2011), direct observations of gonad maturity stages can assist in identifying the fish as either adult or juvenile. Studies on the length at first maturity of small pelagic fishes from Tanzanian marine waters are rare (Bodiguel and Breuil 2015). Most studies on length at first maturity have focused on other groups, such as coral reef fishes (Gaspare and Bryceson 2013) and the reproductive biology of Penaeid prawns (Mwakosya 2016). Therefore, this study, among other aspects, investigated the length at first maturity of selected small pelagic fishes in Tanzanian marine waters to better understand their population characteristics.

Materials and Methods

This study was carried out at Kilwa Kivinje, Kipumbwi and Shangani sites in Tanzania Mainland (Figure 1). These sites were selected based on their location and importance for small pelagic fishing in Tanzanian marine waters. These sites experience two monsoon wind seasons: Northeast which starts from November to March, and southeast, from April to October (McClanahan 1988). The monsoon winds facilitate water mixing and turbulence resulting in the transport of organic and inorganic nutrients from below the thermocline to the euphotic zone (McClanahan 1988). The coastal area also experiences annual precipitation of between 1029 and 1289 mm (Francis and Mahongo 2012), which is responsible for nutrients from river runoffs to marine ecosystems such as coral reefs, mangroves and salt marshes. The sampling points were selected because they are among the most potential areas for the small pelagic fishery in Tanzania (Bodiguel and Breuil 2015).

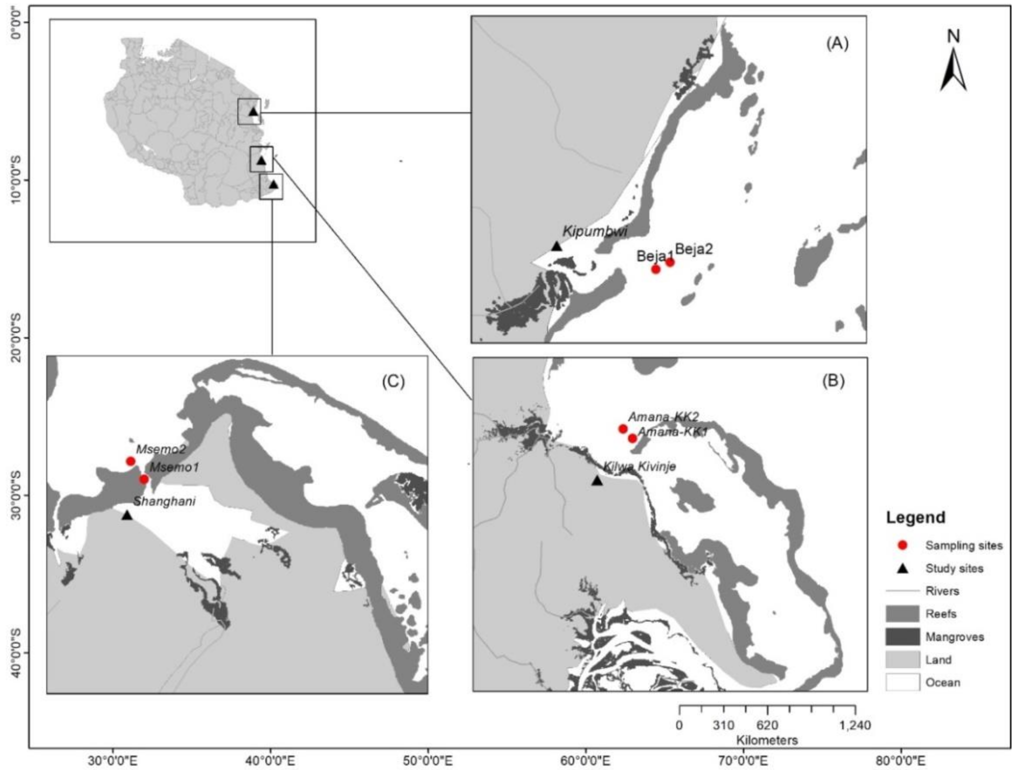

Figure 1: Maps showing sampling locations and small pelagic fishes landing sites. Map A: Kipumbwi sites, Map B: Kilwa Kivinje sites and Map C: Shangani sites.

Data collection

The fish samples for this study were collected monthly between October 2018 and June 2020 from fishers at the landing sites. The fish species identification was done by using the method described in the FAO species identification guide by Bianchi (1985) and Smith (2003). SPFs are landed by small-scale fishers, mainly operating in coastal waters. They employ mostly inboard or outboard engines, dinghies and ring nets with 8 to 10 mm mesh sizes. About 10 kg of fish samples were purchased daily from ring net fishing fleets operating in the study sites. Afterward, the samples were sorted into individual species, and the species composition and numbers were determined. Samples were taken to determine the individual wet weight and morphometric parameters such as individual standard length, sexes, and maturity stages. A total of 50 specimens per sampling were collected, and 100 specimens were measured for two sampling days per site per month during the study period.

Determination of species composition

The frequency and abundance of fish species were determined according to İnnal (2020): Abundance (%) = $\frac{Ni}{Nt}$ X 100…......(i) Where Ni was the number of specimens of the species and Nt was the total number of specimens.

Determination of length-weight relationship

A length-weight relationship (LWR) was determined based on body length and weight. The individual fish were weighed to the nearest 0.1 g by using an electronic top pan weighing balance, Asca, Cm-12, after removing the adhered water and other remains from the body’s surface. The length measurement of fish was taken to the nearest 0.1 cm by using a fish measuring board. Fish lengths were measured as the distance from the tip of the fish's snout, with the mouth closed, to the end of the caudal peduncle. The weight-length relationship was calculated according to Le Cren (1951) using the expression:

$W = aL^b$...................................(ii)

Where: W is the body weight (g), L is the standard length (cm), a is the intercept of the regression, and *b* is the regression coefficient (slope).

Determination of length at first maturity

The ovaries and testes were examined based on the macroscopic scale of gonadal changes, according to King (1995). The colour, texture, and relative occupation of gonads in the abdominal cavity were used during the assessment. The macroscopic classification was based on five maturity stages: Immature, Maturing, Mature, Ripe and Spent. All individual fish staged as maturity stages 3, 4 and 5 gonads were classified as mature, and those with maturity stages 1 and 2 were classified as immature. The sizes at maximum reproductive capacity when 25%, 50% and 90% of the fish were mature (L_{25}, L_{50} and L_{90}) were determined separately for each sex per site and fitted to a logistic regression curve using a Bayesian approach logistic model (Sileesh et al. 2020):

$$P(x)=\frac{e^{(b_0+b_1x)}}{1+e^{(b_0+b_1x)}} \text{ ……………(iii)}$$

Where: p(x) is the probability that a fish is mature in a given standard length x, the model b_0 and b_1 parameters were used to determine the shape and location of the sigmoid curve. Standard length corresponding to the L_{25}, L_{50}, and L_{90} proportions of the model of which a specific percentage of mature fish was computed using the equation below.

$$X = \frac{\ln\left(\frac{p}{1-p}\right) - b_0}{b_1} \text{ …………..……….(iv)}$$

Where: b_0 and b_1 are the estimates of the parameters in the logistic regression model.

Statistical analysis

For LWR, the student t-test was applied to test whether the slope was growing isometric (*b* = 3) or allometric in site, sex, season and maturity. Results with $p \leq 0.05$ were considered statistically significant for all statistical tests. All statistics and figures were done using the R programme (R Core Team 2019) and MS-Excel 2019.

Results

Species composition

The species composition differed across sites. *E. heteroloba* dominated in Kilwa Kivinje (73.6%) and Shangani (47.5%), while *E. punctifer* dominated in Kipumbwi. Shangani landing site had the highest species richness (n = 18) compared to Kilwa Kivinje (n = 13) and Kipumbwi (n = 8) (Figure 2).

Length-weight relationship

The statistical model for the length-weight relationships for all species showed a good fit, with the coefficients of determination (R^2) ranging from 0.672 to 0.999 (Table 1). The regression coefficient (slope) represents the expected increase in fish length per unit increase in fish weight; however, when the slope is negative, the increase becomes negative. The slope (*b*) value for all the species studied ranged from 1.542 to 3.285. *A. sirm* showed positive allometric growth (*b* > 3) in site, sex, season and maturity ($p < 0.05$). *S. gracilis* had negative allometric growth (*b* < 3) except during the immature stage and during the Northeast monsoon season, when the *b* value was greater than 3 ($p < 0.05$). *S. gracilis* showed a good fit, with R^2 ranging from 0.754 to 0.967 and their *b* values from 2.201 to 3.285. Overall, *E. heteroloba* had isometric growth of *b* = 3 showed no significant differences in the site, sex, season and maturity ($p > 0.05$). All samples of *E. punctifer* had positive allometric growth (*b* > 3), which ranged from 3.011 to 3.256 (Table 1). *S. commersonii* had negative allometric growth (*b* < 3) for all factors, sex, season and maturity, ranging from 1.542 to 2.787 (Table 1).

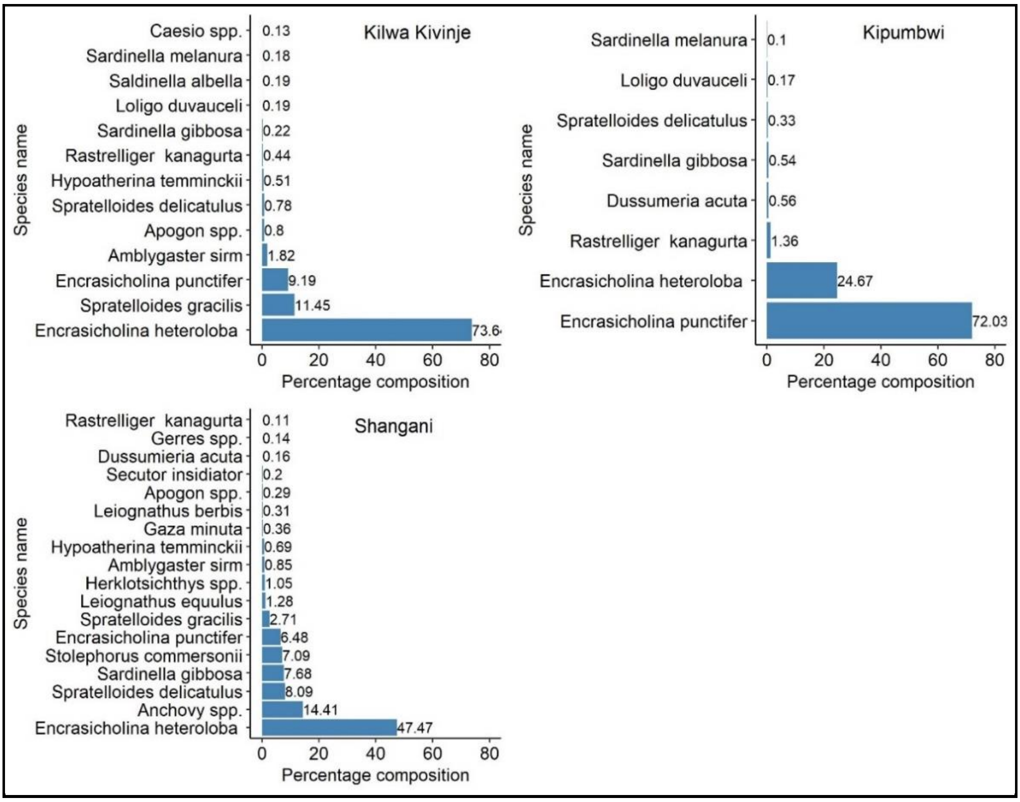

Figure 2: Percent fish species composition by study sites sampled over the study period.

Length at first maturity

Length at 50% maturity (L_{50}) ranged from 5.93 cm (*S. gracilis*, male) at Kilwa Kivinje to 16.30 cm (*A. sirm*, male) at Shangani (Table 2). The length at maturity L_{50} was examined separately for male and female populations to understand the differences between the sexes.

Mature *A. sirm* in stage 3 were found in all months sampled except in November 2019 and April 2020 at Kilwa Kivinje and Shangani sites, respectively (Figure 3). In January 2020, at Kilwa Kivinje, *A. sirm* had a high percentage of immature individuals. At Kilwa Kivinje, all months had mature stage 3 of *E. heteroloba* in variance magnitude through October to December 2019, and January 2020 had a large percentage of mature individuals. At Kipumbwi, all months had mature stage 3; however, December 2018 had a small percentage of mature *E. heteroloba*. Likewise, mature stage 3 was found at the Shangani site, with the lowest percentage noted in May 2020. Mature *E. punctifer* was found in all months; however, a high percentage of immature was observed in December 2019 at Kilwa Kivinje site. At Kipumbwi, mature stage 3 was observed in all months except April 2019 and April 2020. Immature stages were dominated *S. commersonii* catches, while mature stage 3 was revealed in all months except July 2019, January 2020, April 2020 and May 2020. Few samples and most immature *S. gracilis* found in this study from Kilwa Kivinje and Shangani did not bring a meaningful conclusion on the spawning period. Based on a few data obtained at Kilwa Kivinje in October 2018 (n = 32), June 2019 (n = 50), November 2019 (48) and December 2019 (n = 50), a large percentage (49%) of mature *S. glacilis* was observed.

Table 1: Length-weight relationship (LWR) of selected small pelagic species sampled at Kilwa Kivinje, Kipumbwi and Shangani landing sites. SL = Standard length (cm) and BW = Weight (g), N = Number of individuals, a = Intercept, *b* = Slope, R^2 = Coefficient of determination, p-value = Probability of regression coefficient (slope) among factors per species, NE = Northeast monsoon, SE = Southeast monsoon.

Fish name	Factors	N	SL (cm)	BW (g)	a	*b*	R^2	P
	Kilwa Kivinje	572	7.1-19.1	4.14-96.5	0.009	3.137	0.98	
	Shangani	1169	4.2-22.4	0.66-164.39	0.007	3.257	0.99	
A. sirm	Male	885	6.3-22.4	3.2-164.39	0.007	3.231	0.98	
	Female	814	6.1-19.1	2.49-100.49	0.007	3.233	0.98	
	NE	1056	4.2-22.4	0.66-164.39	0.007	3.262	0.98	$p < 0.05$
	SE	685	4.3-22.4	0.9-164.39	0.008	3.199	0.99	
	Immature	948	6.1-18.4	2.49-89.77	0.008	3.195	0.98	
	Mature	572	7.2-22.4	4.26-164.39	0.008	3.223	0.96	
	Kilwa Kivinje	230	4.6-8.7	0.82-3.2	0.024	2.445	0.82	
	Shangani	151	2.8-6	0.2-1.7	0.012	2.681	0.91	
S. gracilis	Male	78	4.6-6.8	0.99-2.67	0.021	2.533	0.89	
	Female	103	4.6-8.7	1.0-3.5	0.035	2.236	0.81	$p < 0.05$
	NE	201	3.2-7.9	0.25-3.2	0.005	3.285	0.95	
	SE	131	4.8-8.7	0.82-4.5	0.019	2.564	0.78	
	Immature	124	2.8-8.7	0.2-3.3	0.008	3.046	0.97	
	Mature	87	5.3-7.9	1.39-3.5	0.038	2.201	0.75	
	Kilwa Kivinje	1299	4.4-8.7	1.0-7.3	0.008	3.073	0.89	
	Kipumbwi	514	3.4-9.0	0.3-7.7	0.008	3.104	0.98	
	Shangani	630	0.37-8.6	0.12-5.25	0.015	2.723	0.82	
E. heteroloba	Male	932	4.4-8.7	0.72-7.3	0.012	2.893	0.9	$p > 0.05$
	Female	1102	4.3-9.0	0.69-7.7	0.008	3.102	0.93	
	NE	678	4.4-8.6	0.88-6.73	0.011	2.931	0.934	
	SE	1356	4.3-9.0	0.69-7.7	0.008	3.082	0.91	
	Immature	1182	4.3- 9.0	0.69-7.7	0.009	3.057	0.91	
	Mature	847	5.1-8.7	1.36-7.3	0.013	2.857	0.87	
	Kilwa Kivinje	297	5.5-8.8	1.78-6.46	0.01	3.003	0.91	
	Kipumbwi	1394	3.1-9.0	0.32-8.71	0.008	3.163	0.98	
	Shangani	100	3.0-6.6	0.22-3.51	0.007	3.256	0.95	
E. punctifer	Male	761	3.2-9.0	0.34-7.67	0.008	3.126	0.96	$p < 0.05$

Fish name	Factors	N	SL (cm)	BW (g)	a	*b*	R^2	P
	Female	852	3.4-9.0	0.37-8.71	0.009	3.085	0.96	
	NE	736	3.5-9.0	0.39-7.18	0.009	3.053	0.94	
	SE	877	3.2-9.0	0.34-8.71	0.008	3.147	0.98	
	Immature	874	3.2-8.8	0.34-7.11	0.01	3.011	0.94	
	Mature	739	5.6-9.0	1.92-8.71	0.008	3.15	0.93	
S. commersonii	Male	241	3.3-9.5	0.48-7.2	0.024	2.587	0.89	$p < 0.05$
	Female	279	4.1-9.7	0.39-8.36	0.021	2.649	0.89	
	NE	217	4.0- 9.7	0.39-7.2	0.033	2.375	0.85	
	SE	303	3.3- 9.0	0.48-7.6	0.017	2.787	0.97	
	Immature	395	4.0-9.4	0.39-6.49	0.021	2.655	0.85	
	Mature	103	6.5-9.7	3.54-7.42	0.222	1.542	0.67	

Table 2: Summary of length at first maturity for studied species by study sites over the study period

Site	**Species**	**Sex**	$L_{25\%}$	$L_{50\%}$	$L_{90\%}$
Shangani	*S. commersonii*	Male	7.27	7.72	8.61
	S. commersonii	Female	7.31	7.79	8.76
Kilwa Kivinje	*E. heteroloba*	Male	6.18	6.43	6.96
	E. heteroloba	Female	6.22	6.84	8.06
Kipumbwi	*E. heteroloba*	Male	6.10	7.01	8.83
	E. heteroloba	Female	7.19	7.87	9.23
Shangani	*E. heteroloba*	Male	5.52	6.03	7.06
	E. heteroloba	Female	5.55	6.10	7.20
Shangani	*A. sirm*	Male	14.19	14.95	16.47
	A. sirm	Female	14.53	16.30	19.84
Kilwa Kivinje	*A. sirm*	Male	13.03	14.13	16.33
	A. sirm	Female	13.51	15.01	18.00
Kilwa Kivinje	*E. punctifer*	Male	6.34	6.65	7.27
	E. punctifer	Female	6.56	7.05	8.03
Kipumbwi	*E. punctifer*	Male	5.95	6.32	7.06
	E. punctifer	Female	6.46	6.92	7.84
Kilwa Kivinje	*S. gracilis*	Male	5.61	5.93	6.58
	S. gracilis	Female	5.42	6.12	7.51

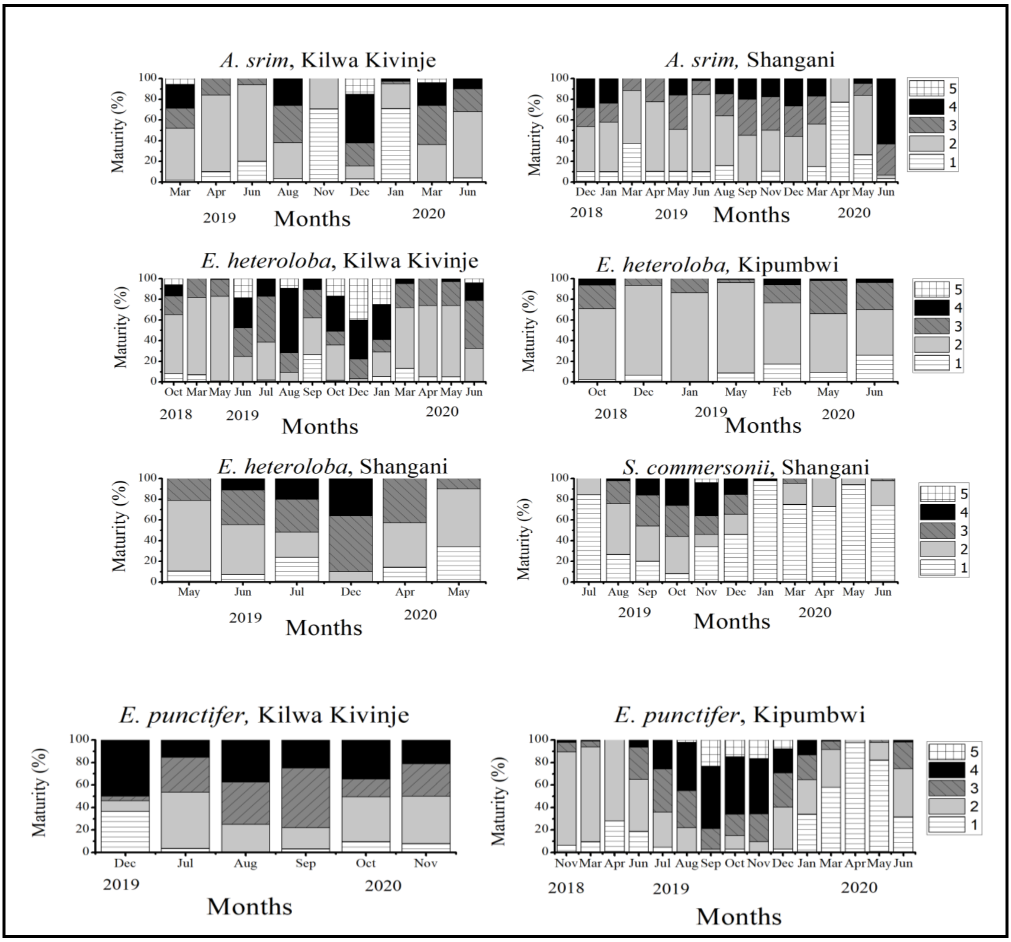

Figure 3: Monthly variations in gonadal maturity stages of selected species by study sites sampled over the study period: 1 = Immature; 2 = Maturing; 3 = Mature; 4 = Ripe; 5 = Spent.

Discussion

Species composition

In Kilwa Kivinje and Kipumbwi, fishers have been mainly fishing *E. heteroloba*, *E. punctifer,* and *S. gracilis* as these species form an important fishery in the area (Bodiguel and Breuil 2015). Similar observations of *E. heteroloba* and *E. punctifer* dominating catches in Kilwa Kivinje, and Tanga were reported by Sekadende et al. (2020). According to Hoedt (1994), *S. commersonii* inhabits offshore waters and is sometimes captured in small numbers, suggesting that it may be a solitary species. The complete absence of *S. commersonii* at Kilwa Kivinje and Kipumbwi landing sites, as found in this study, may indicate that the habitat conditions are not conducive for *S. commersonii* (Smith 2003). Some studies (Bianchi 1985, Smith 2003) linked *S. commersonii* with estuarine waters and mangrove lagoons habitats. Therefore, this study's findings are consistent with previous studies as both Kilwa Kivinje and Kipumbwi are far from well-established estuaries.

Length-weight relationship

Among the five studied species, only *A. sirm* and *E. punctifer* were found to have a positive allometric growth pattern throughout the year, which concurs with the findings of Devi et al. (2018) on *A. sirm* in India and that of Maack and George (1999) on *E. punctifer* in Indonesia. Therefore, as in India and Indonesia, Tanzanian marine waters provide suitable environment for *A. sirm* and *E. punctifer*. The *S. gracilis* inhabiting marine waters of Tanzania were found to have negative allometric growth (b < 3) except during North east monsoon and immature stages. The negative allometric growth observed in *S. gracilis* might be due to the species' condition or its phenotype (Froese 2006). Similar findings of negative allometric growth on *S. gracilis* were reported by Weng et al. (2005) in Taiwan. Froese (2006) indicated that an increase in height or width, more than in length in fish species results from changes in diet or habitat during development. Our results revealed that the *S. gracilis* does not have an isometric growth indicating that the length and weight of *S. gracilis* does not grow equally. Although our findings showed *E. heteroloba* to have an isometric growth pattern, the species was recently found to have positive allometric growth in Indonesia (Anggoro and Saputra 2019). Thus, the geographical differences and changes in diet may have influenced our findings.

The LWR indicated that '*b*' value for *S. commersonii* exhibits negative allometric growth, contrary to Nair et al. (2015), who found positive allometric growth in India. A change in the '*b*' value mainly reflects the change in the body form when the weight of the fish gets affected by environmental factors like temperature, food supply, spawning conditions and other factors like sex, age, fishing time and area (Nair et al. 2015). Since males and females had '*b*' values of less than 3, sex was not an essential factor leading to a negative allometric growth pattern in *S. commersonii* in Tanzanian marine waters, contrary to Nair et al. (2015) findings in India. The observed isometric growth for *E. heteroloba* and negative allometric growth pattern for *S. commersonii* in Tanzania marine waters indicate that environmental conditions played a significant role (Froese 2006).

Length at first maturity (L_{50})

The results on length at maturity (L_{50}) for *A. sirm* for males and females do not differ from a previous study conducted in Tanga, Tanzania (Sululu et al. 2021) and marine waters of Kilifi in Kenya (Bett et al. 2021). Likewise, the lengths attained at maturity by individuals of *E. heteroloba* and *E. punctifer* were similar to those reported by Rohit and Gupta (2008). However, our results showed that mature individuals of *S. commersonii* were relatively bigger than those sampled from Kerala cost in India (7.1 and 7.2 cm for males and females, respectively, Nair et al. 2015). Individuals of *Stolephorus indicus*, closely related to *S. commersonii* (Fricke et al. 2015), sampled along the Thoothukudi coast of India, were higher than the present findings, while those of *S. gracilis* sampled from Ryukyus matured at a very small size (5.0 cm, Ishimori et al. 2015). Such a large difference in the size of related individuals was attributed to various criteria such as the number, the sampling period, and the sample size used for analysis (Fontoura et al. 2009). In Tanzania, there are no national fishing regulations specifying the size at first maturity, minimum or maximum SPF sizes that may be caught and the best time of the year to catch them to prevent interference with their spawning activities (Bodiguel and Breuil 2015).

Similar to previous studies, our findings show that all studied species exhibit periodicity in spawning. However, the duration and frequency of spawning vary from one species to another, which agrees with Hoedt (1994) in Australia. Our results of *A. sirm* are consistent with Sululu et al. (2021) in northern Tanzania, who reported spawning peaks in September. For example, other studies, including Conand (1991), reported that spawning takes place from October to December in new Caledonia. In the present study, spawning peaks of *E. heteroloba*, *E. punctifer* and *S. commersonii* were observed from December to January and September to October, consistent with Hoedt (1994). The spawning season of the *S. gracilis* in Penghu waters in Taiwan is from February to November, peaks in March to April and July to August (Weng et al. 2005).

Conclusion and Recommendations

This study showed differences in small pelagic species composition along the coast of Tanzania, with *E. heteroloba* dominating at Kilwa Kivinje and Shangani sites while *E. punctifer* dominating at Kipumbwi site. Generally, the Tanzanian coast provides conducive habitat for *A. sirm*, *E. heteroloba* and *E. punctifer* as revealed by their allometric growth patterns. Few samples and most immature *S. commersonii* and *S. gracilis* found in this study from Kilwa Kivinje, and Shangani sites did not bring a meaningful conclusion on the spawning period. The present study has confirmed that these species are multiple spawners. Although the species are multiple spawners, our findings indicate peak spawning seasons to be June and December for *A. sirm*, *E. heteroloba* and September to October for *E. punctifer* and *S. commersonii*. Therefore, seasonal closure of the fishery for SPFs can be applied as an intervention for protecting species during their spawning seasons. We also recommend introducing fishery management techniques such as regulating mesh sizes in nets and fishing efforts to regulate the fishing activities in the area for the sustainability of SPFs.

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