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Biological aspects of fish species from subsistence fisheries in "Bons Sinais" estuary, Mozambique

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ABSTRACT

Knowledge on biological aspects of commercially exploited fish is an important tool for assessing and managing of data-poor fisheries. In this study, we have collected information on biological aspects of commercial fish species, namely in the Bons Sinais estuary (BSE), Mozambique. Fish species were caught using a beach seine and a traditional fishing gear known as *Chicocota*, both used by local fishing communities for subsistence fisheries. The results revealed that most specimens caught were juveniles and below the size at first maturity. In general, mean body height (BH) estimated across all species (2.24 cm) was below the minimum mesh size established by Mozambique Fisheries Law (3.8 cm). Estimated W–L regression analysis were statistically significant with the coefficient of determination (r^2) explaining from 91 to 98% of the variance. The allometric coefficient *b* ranged from 2.728 (*Stolephorus indicus*) to 3.357 (*Johnius dussumieri*). All the species exhibited positive or isometric allometric growth, except S. indicus, which exhibited negative growth. This study provides new information that can be used to enhance sustainable fishery management in data-poor fisheries.

1. Introduction

Marine fisheries account for more than 90% of Mozambique total fish production, of which around 80% originates from small-scale fisheries (FAO, 2007; Doherty et al., 2015). Fish plays an important role of food security, nutrition, livelihoods and local and national economies, mainly in those places with high levels of poverty, where inhabitants depend on the sea and its resources for survival (Basurto et al., 2017). Fishing activities have become a serious threat to marine ecosystems and the sustainability of estuarine and coastal fishing communities in Mozambique (Blythe et al., 2014). Concerns about fisheries resources from Mozambican coastal waters in terms of knowledge on biological aspects and fishing gears of target and endangering fish have risen in this country (FAO, 2007).

Knowledge about the size structure of fish populations is an important management parameter used to monitor juveniles' capture and selectivity level of the fishing gears (Jul-Larsen et al., 2003; Hicks and McClanahan, 2012; Froese and Pauly, 2017). Moreover, parameters from Weight–length (W–L) relationship equations are also useful for fish stock assessment models, estimation of the population biomass from length observation, calculation of condition indices and for comparisons of life-history among different habitats (Bagenal and Tesch, 1978; Petrakis and Stergiou, 1995; Froese, 2006; Froese and Pauly, 2017). Such information is sufficient to derive empirical relationships that can be used for management of stocks until specific data become available, being essential to regions with data-poor fisheries (Froese and Binohlan, 2000; Geromont and Butterworth, 2015).

No information on biological aspects is currently available for fish caught in subsistence fisheries in the Bons Sinais estuary (BSE). The present study reports the first assessment on the biological aspects, in terms of size–frequency distribution and W–L relationships, for 13 commercially important fish species caught by subsistence fisheries in the BSE, Mozambique. Thus, this study will provide an important baseline information that would be useful for researchers and fishery managers in the BSE, Mozambique.

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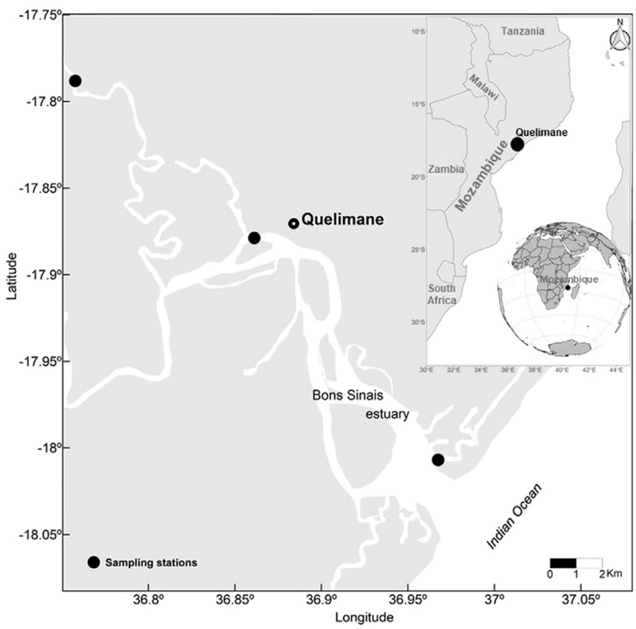

Fig. 1. Sampling stations along the Bons Sinais estuary, Quelimane, Mozambique.

2. Material and methods

2.1. Biological data

Sampling was carried out from November 2017 to September 2019, during the winter and summer seasons, in the upper (17°47'36.86" S, 36°45'25.83" E), middle (17°52'47.04" S, 36°51'30.11" E) and lower zones (18°0'31.52" S, 36°57'58.17" E) of the BSE, which is located in Quelimane, Mozambique (Fig. 1; Table A.1). The upper zone is characterized by high freshwater discharge with low values of salinity; the middle zone by the presence of brackish waters, as a result of the salt and freshwater mixing (mixing zone), and lower zone by the influence of marine waters, showing values of salinity higher than the previous zones. The fish specimens were captured with two artisanal, fishing gears: beach seine and *Chicocota*. The latter fishing gear consists of a cone-shaped cod-end with mesh size less than 0.3 cm (Tietze et al., 2011; Short et al., 2018). *Chicotota* is a fixed gear, settle on the bottom during spring tides and positioned in the middle of the main estuarine channel. The cumulative contribution of these two gears allowed us to cover the species in the main channel and on the edge of the estuary where the beach seine is commonly used. In the laboratory, the individual's total length (TL, centimeters-cm), body height (BH, cm) and weighed in total weight (TW, grams-g) were measured. Specimens were identified

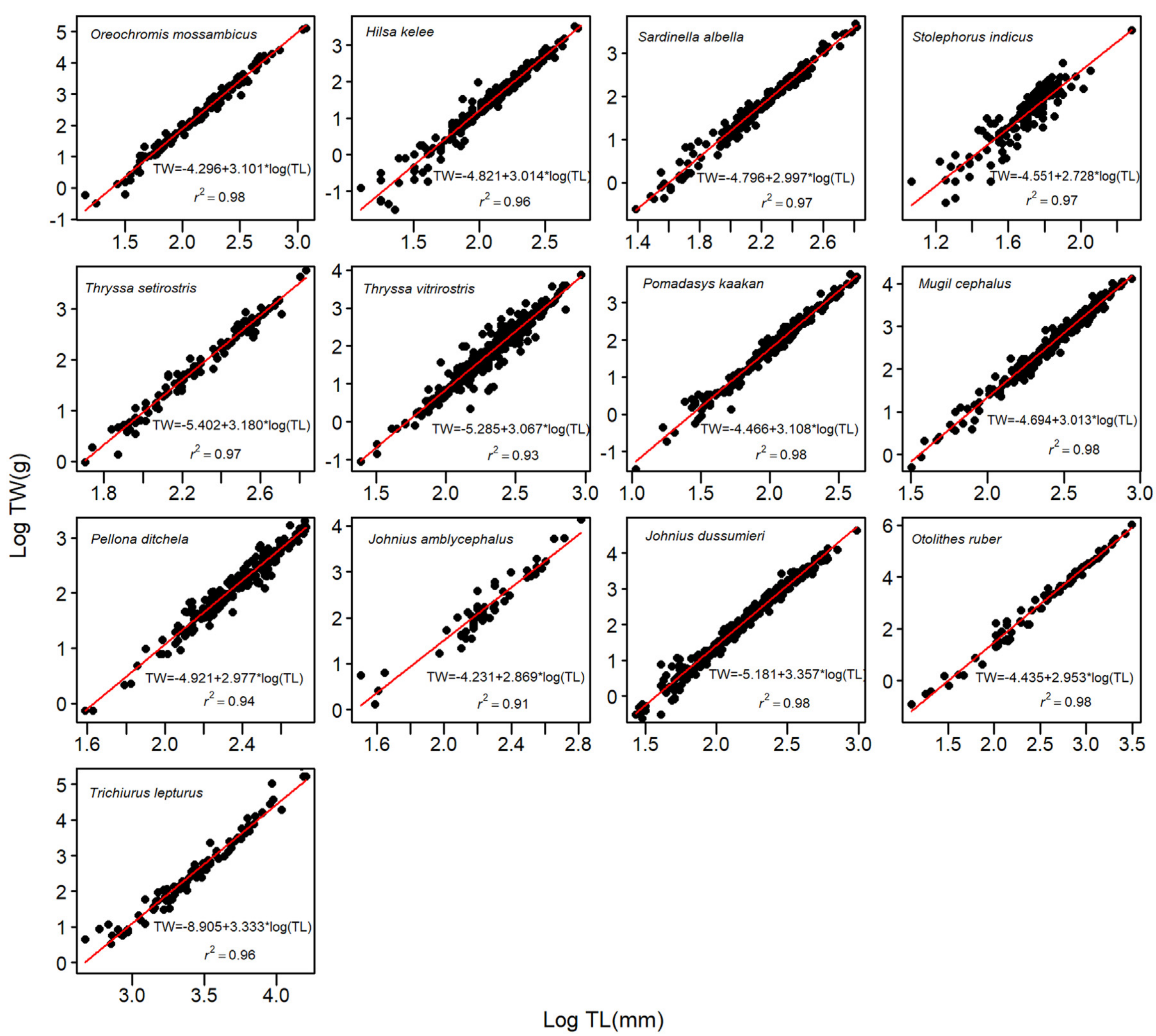

Fig. 2. Weight–length relationships for fish species from the Bons Sinais estuary, Mozambique. TL = total length, TW = total weight.

Table 1
Descriptive statistics, size at first maturity (L_{50}) and estimation of the Weight–length relationship parameters of 13 species from the Bons Sinais estuary, Mozambique. N: sample size, Min: minimum, Max: maximum; *a*: intercept, *b*: slope, CI: confidence interval; r^2: coefficient of determination).

Family/species	N	L_{50}[a] (cm)	Total length (cm)		Total weight (g)		Linear model: log (TW) = log(*a*) + *b* log (TL)					Allometric coefficient[c]
			Min	Max	Min	Max	log *a*	log *a* (±95%CI)	*b*	*b* (±95%CI)	r^2	
Cichlidae												
Oreochromis mossambicus (Peters, 1852)	126	20	3.2	21.6	0.6	164.8	−4.296	−4.452 to −4.140	3.101	3.018 to 3.161	0.98	Positive
Clupeidae												
Hilsa kelee (Cuvier, 1829)	234	13	3.0	16.0	0.2	52.7	−4.821	−4.989 to −4.653	3.014	2.934 to 3.094	0.96	Isometric
Sardinella albella (Valenciennes, 1847)	169	10	4.0	16.7	0.5	39.8	−4.796	−4.956 to −4.636	2.997	2.923 to 3.070	0.97	Isometric
Engraulidae												
Stolephorus indicus (van Hasselt, 1823)	135	8.5	2.9	9.8	0.2	5.4	−4.551	−4.990 to −4.110	2.728	2.458 to 2.977	0.83	Negative
Thryssa setirostris (Broussonet, 1782)	95	11.8[b]	5.5	17.0	0.9	42.5	−5.402	−5.657 to −5.147	3.180	3.069 to 3.290	0.97	Positive
T. vitrirostris (Gilchrist & Thompson, 1908)	382	13	4.0	19.5	0.3	48.3	−5.285	−5.483 to −5.087	3.067	2.982 to 3.153	0.93	Isometric
Haemulidae												
Pomadasys kaakan (Cuvier, 1830)	206	48	2.8	13.9	0.2	43.1	−4.466	−4.601 to −4.331	3.108	3.04 to 3.174	0.98	Positive
Mugilidae												
Mugil cephalus Linnaeus, 1758	227	35	4.5	19.0	0.7	61.3	−4.694	−4.844 to −4.544	3.013	2.951 to 3.076	0.98	Isometric
Pristigasteridae												
Pellona ditchela Valenciennes, 1847	204	14	4.9	15.3	0.6	27.4	−4.921	−5.201 to −4.641	2.977	2.859 to 3.095	0.94	Isometric
Sciaenidae												
Johnius amblycephalus (Bleeker, 1855)	50	15.7[b]	4.5	16.7	1.1	62.6	−4.231	−4.807 to −3.655	2.869	2.615 to 3.123	0.91	Isometric
J. dussumieri (Cuvier, 1830)	280	12	2.9	19.8	0.5	102.9	−5.181	−5.354 to −5.007	3.357	3.292 to 3.423	0.98	Positive
Otolithes ruber (Bloch & Schneider, 1801)	73	28	3.0	33.0	0.4	414.6	−4.435	−4.665 to −4.205	2.953	2.863 to 3.042	0.98	Isometric
Trichiuridae												
Trichiurus lepturus Linnaeus, 1758	94	53	14.5	67.0	1.7	248.3	−8.905	−9.358 to −8.553	3.333	3.202 to 3.464	0.96	Positive

[a]Unpublished data from the National Institute of Fisheries Research of Mozambique (IIP).
[b]Froese and Pauly (2017).
[c]Table A.3 for *t*-test results.

to the species level, according to Bell-Cross (1972), Fischer et al. (1990) and Skelton (1993). Information on the size at first maturity (L_{50}) were obtained from the National Institute of Fisheries Research of Mozambique (IIP) (unpublished results). Information on L_{50} for *Thryssa setirostris* and *Johnius amblycephalus* was obtained from Froese and Pauly (2017). In this study, juveniles comprise fish smaller than the L_{50} (Miller and Kendall, 2009).

2.2. Data analysis

The following exponential equation describes the relationship between TW and TL: TW=aTL^b where a= intercept and b= slope. The slope is the allometric coefficient or the coefficient of growth (Le Cren, 1951; Ricker, 1973). However, a and b were obtained from the logarithmic form of the previous equation, fitted to the data as follows: log TW= log$a$ + $b$log TL (Le Cren, 1951; Jobling, 2008). Log–log plots were generated to identify outliers and to estimate 95% confidence limits for anti-log a and b (Froese, 2006). Student's t-test (t_s) was performed to determine whether a and b of the regression line differs significantly from zero, and to confirm whether b departed significantly from the isometric value of 3, according to Sokal and Rohlf (1987): $t_s = (b-3)/s_b$ where s_b= standard error of b (Zar, 2010). The coefficient of determination (r^2) and F-test was performed to evaluate the proportion of the variance for the dependent (TW) that is explained by the independent variable (TL) (Kissel and Poserina, 2017). All statistical analyses were carried out with R version 3.6.1 for statistical computing (R Core Team, 2019). The probability density for normal distribution was performed to evaluate the goodness of fit between the observed TL and the theoretical normal distribution of TL, according to the 'dnorm (TL, mean, sd)' function from the R package 'stats'.

3. Results

A total of 2275 specimens belonging to 13 fish species and eight families were used for estimation of the size–frequency distribution and W–L relationship parameters (Table 1, Table A.1). All individuals of *Stolephorus indicus*, *Pomadasys kaakan* and *Mugil cephalus* were juveniles. For all species, the mean BH was estimated at 2.24 cm, ranging from 0.3 to 8.5 cm. Overall, the most individuals caught were recorded as juveniles with size below the L_{50} and above the mean BH (Figs. 2 and 3).

The W–L relationship equations estimated for each species were all highly significant (F-test, P < 0.001, Table A.2) with the coefficient of determination (r^2) explaining from 91 (*J. amblycephalus*) to 98% (*Oreochromis mossambicus, P. kaakan, M. cephalus* and *Otolithes ruber*) of the variance. The allometric coefficient b ranged from 2.728 (*S. indicus*) to 3.357 (*Johnius dussumieri*). All species exhibited positive allometric or isometric growth, with the exception of *S. indicus* that exhibited a negative allometric growth. Descriptive statistics, estimated parameters of the W–L relationships, 95% confidence limits for a and b, r^2 and the types of growth (allometry) are given in Table 1.

4. Discussion

Several factors may affect the fish length and weight, as well as the values of a and b from the W–L relationships. Among these factors are hydrodynamic patterns, food availability, fishing gears, sex, state of maturity, metabolic activity and habitat (Wootton, 1990; Froese, 2006; Nahdi et al., 2016). The values of b reported in the present study fall between the expected range from 2.5 to 3.5 (Carlander, 1969). Carlander (1977) demonstrated that the values of b < 2.5 or b > 3.5 are often derived from samples with narrow size ranges. This hypothesis has been lately confirmed by Froese (2006). Although the size of most specimens caught in the BSE fell below the L_{50}, their size–frequency distribution and b ranging between the expected values indicate that the sampled individuals had already obtained the adult body shape (Safran, 1992; Froese, 2006). Thus, species exhibiting isometric growth ($b = 3$), i.e. *H. kelee*, *S. albella*, *T. vitrirostris*, *M. cephalus*, *P. ditchela*, *J. amblycephalus* and *O. ruber*, indicate that these species increase in length and weight proportionately or at the same rate during ontogenic growth. On the other hand, the species with positive growth type (b>3) *O. niloticus*, *T. setirostris*, *P. kaakan*, *J. dussumieri* and *T. lepturus*, become relatively stouter or deeper-bodied as they increase in size (Le Cren, 1951; Froese and Tsikliras A. Stergiou, 2011). Only *S. indicus* showed negative allometric growth (b<3), which implies that this species becomes more slender as it grows (Froese, 2006; Froese and Tsikliras A. Stergiou, 2011). The use of the W–L relationship parameters for the species *S. indicus*, *P. kaakan* and *M. cephalus* should be used with caution because the large-sized individuals have not been caught in the BSE. Besides, for comparison purposes of the W–L relationship parameters by future studies, it is important to consider the size-range if the specimens were collected from the similar nursery ground estuarine ecosystems.

Indicators based on length-frequencies and other measures (BH) can be used to establish management measures for data-poor fisheries due to the relationship between fish BH and minimum mesh size of fishing gears (Froese, 2004; Froese and Pauly, 2017). According to the Mozambican Fisheries Law (Law 3/90 of 26 September 1990) and subsequent regulations for the fisheries sector, fishing gears with cod-end mesh size less than 3.8 cm are not allowed (Art.33, Decree 43/2003 of December 10th). The main objectives of the Art. 33 have been stated to contribute to fisheries management and species conservation, avoiding capture fish in larval and immature stages. Mesh size and gear restrictions have been pointed out among the most easily applied and widely used management regulations (Jul-Larsen et al., 2003). However, the present study has demonstrated that most individuals captured in BSE with BH larger than 3.8 cm were also in the immature stage, revealing that fishing gears used daily by the locals in the fishing communities are inappropriate for subsistence fisheries. All individuals caught are used as fresh, salted, dried or smoked food for local consumption and/or commercialization in the fishing communities.

Fishing gears are intrinsically associated with selectivity and have an impact on ecosystems, being an essential component of a management programmes (Jul-Larsen et al., 2003; Hicks and McClanahan, 2012). The gears used by artisanal fishers *Chicocota* and beach seine exhibit little selectivity, capturing mostly smaller fish (Bush et al., 2017; Short et al., 2018). The use of small mesh sizes (mosquito nets) in the cod-end of the beach seine and *Chicocota* is common in certain coastal and estuarine areas in Mozambique (Tietze et al., 2011). These nets are provided by the Ministry of Health (Mozambique) to prevent malaria and their use for fishing has been condemned as a threat to food security and biodiversity due to capture larvae and juveniles of several species of marine vertebrates and invertebrates (Tietze et al., 2011; Moon et al., 2016). Zambezia Province, where the BS estuary is located, has been considered as a high malaria prevalence region and, coincidentally, it is the Mozambican province, which has registered high use of mosquito nets for fishing with Chicocota representing 50% (1.933) of the total gears used in Zambezia province of Mozambique (IDPPE, 2013).

Estuarine habitats play an important role for fishes, as feeding, nursery and refuge areas, as well as migration routes for species living and growing in either freshwaters or the sea, supporting high densities of larvae and juveniles of several fish species (Dolbeth et al., 2008; Blaber, 2013; Fonseca et al., 2015; Wolanski and Elliott, 2016). Thus, the frequent presence of juveniles

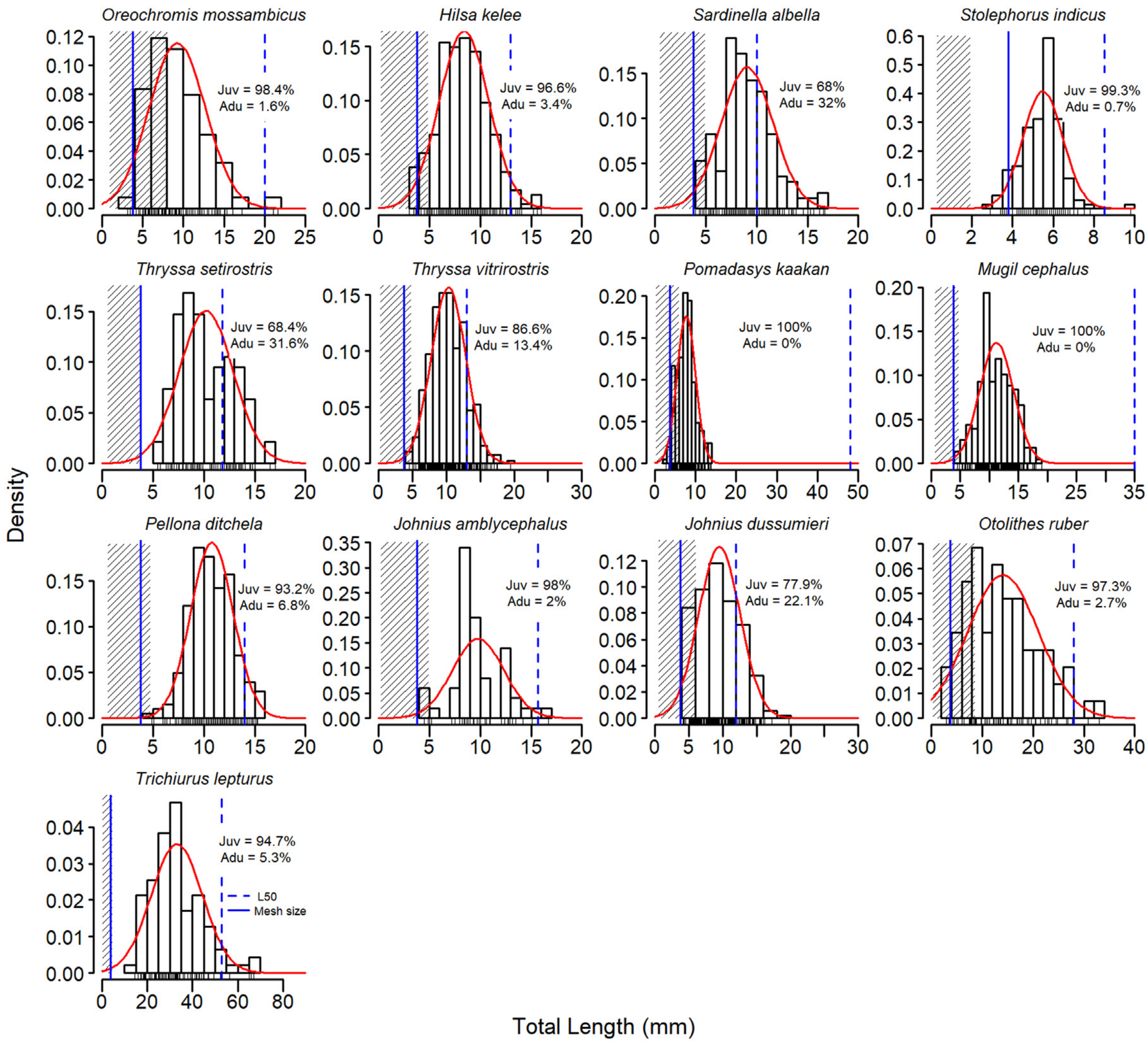

Fig. 3. Length–frequency distribution for fish species from the Bons Sinais estuary, Mozambique. In the figure legend, L_{50} represents the size at first maturity and minimum mesh size (3.8 cm) for fisheries in Mozambican waters. Vertical strip area indicates body height variation (minimum and maximum values). Probability density for the normal distribution is represented on the *y*-axis in the histograms. TL = total length. Juv= juveniles (percentages of individuals below the L_{50}), Adu= adults (percentage of individuals above the L_{50}).

Table A.1
Number of fish sampled (sampling size) by year, season, tide, sampling station, fishing gear and fishing event. Fishing event are given between brackets.

Species	Year	Season	Tide	Sampling station	Fishing gear (n)	
					Chicocota	beach seine
	2017	Dry[a]	Spring high	Lower	57 (2)	
		Dry	Spring high	Middle	69 (2)	
		Dry	Spring high	Upper	8 (2)	
	2018	Dry	Neap low, neap high, spring low, spring high	Lower	97 (6)	253 (4)
		Dry	Neap high, spring low, spring high	Middle	322 (2)	170 (6)
		Dry	Neap low, spring low, spring high	Upper	77 (6)	
		Wet[b]	Spring low, spring high	Lower	160 (4)	
		Wet	Spring high	Middle	166 (4)	
		Wet	Spring high	Upper	27 (3)	
	2019	Dry	Spring low, spring high	Lower	131 (2)	206 (3)
		Dry	Spring low, spring high	Middle	69 (3)	35 (5)
		Dry	Spring low, spring high	Upper	40 (2)	
		Wet	Neap high, spring low,	Lower	63 (3)	111 (2)
		Wet	Neap low, spring low, spring high	Middle	128 (1)	86 (3)

[a]The dry season corresponds to the period which ranged from May to October.
[b]The wet season corresponds to the period which ranged from November to April.

in estuarine ecosystems, associated with less selective fishing gears used by subsistence fishers, can explain the number of individuals below the L_{50} and the high frequency of small fish in the size–frequency distributions recorded at BSE. *Stolephorus indicus*, *Pomadasys kaakan* and *Mugil cephalus* adults were absent from sampling. The absence of adults of the latter species is

Table A.2
F-test output performed to evaluate the Weight–length relationships.

Species	*F*- test	*df*	*P*
Oreochromis mossambicus	7316	124	<0.001
Hilsa kelee	5534	238	<0.001
Sardinella albella	6524	171	<0.001
Stolephorus indicus	428.6	147	<0.001
Thryssa setirostris	3261	101	<0.001
T. vitrirostris	4982	381	<0.001
Pomadasys kaakan	8518	209	<0.001
Mugil cephalus	9053	286	<0.001
Pellona ditchela	2866	208	<0.001
Johnius amblycephalus	514.3	48	<0.001
J. dussumieri	12740	286	<0.001
Otolithes ruber	4324	71	<0.001
Trichiurus lepturus	2563	94	<0.001

Table A.3
T-test output performed to test whether the slope (*b*) depart significantly from isometric value of 3.

Species	*t*- *test*	df	*P*
Oreochromis mossambicus	2.48	124	<0.05
Hilsa kelee	0.37	238	>0.05
Sardinella albella	−0.07	171	>0.05
Stolephorus indicus	−2.15	147	<0.05
Thryssa setirostris	3.23	101	<0.05
T. vitrirostris	1.56	381	>0.05
Pomadasys kaakan	3.21	209	<0.05
Mugil cephalus	0.03	286	>0.05
Pellona ditchela	−1.84	208	>0.05
Johnius amblycephalus	−1.03	48	>0.05
J. dussumieri	11.94	286	<0.05
Otolithes ruber	−1.05	71	>0.05
Trichiurus lepturus	5.06	94	<0.05

associated with species life cycle. So, it remains unknown how the larvae of these species ingress into the estuary if adults are not found along the year in the BSE. Nevertheless, a mismatch between IIP L_{50} and L_{50} values in the literature for *S. indicus* and *Stolephorus* spp. pointed out that L_{50} might be overestimated by local IIP studies (Froese and Pauly, 2017). Therefore, for this species results regarding adult/juvenile presence in BSE should be interpreted with caution and size of their first maturity deserves further investigations.

5. Conclusions

In this study, a large number of species were juveniles or young of the year fish. Such information on lower size classes' morphometric and length size distribution is vital for understanding exploitation patterns of subsistence fisheries at BSE. No information currently exists on the length–frequency distribution and W–L relationships of fish species from the BSE, mainly for those species exploited daily for livelihood and with local economic importance. The allometric coefficient estimated and information on BH can be used to adjust mesh sizes at L_{50} and for subsistence unreported catches estimations based on W–L relationships. The results on the biological aspects of 13 species from BSE provide importantly novel information for fishery managers and conservation of data-poor subsistence fisheries.

CRediT authorship contribution statement

Eudriano F.S. Costa: Software, Formal analysis, Methodology, Data curation, Writing - original draft. **Jeremias Mocuba:** Conceptualization, Methodology, Data curation, Investigation, Writing - review & Editing. **Daniel Oliveira:** Investigation, Resources. **Maria Alexandra Teodósio:** Supervision, Resources. **Francisco Leitão:** Validation, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

See Tables A.1–A.3.

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