



Characterising different artisanal fishing gears catches that operate in distinct habitats to assess ichthyofauna assemblages in Bons Sinais estuary, Mozambique

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ABSTRACT

Monitoring the ichthyofauna is crucial to detect changes in aquatic communities for fisheries management and conservation. This study aimed to identify the most effective gear for ichthyofauna studies in the estuary. Thus, the performance of the beach seine (active gear) and chicocota (fixed gear), common fishing gears used by artisanal fishers in the Bons Sinais estuary (BSE), were used to characterise fish assemblage structure. Monthly surveys were conducted at two fixed sample points of the BSE to assess the composition of the fish assemblage. The analysis revealed statistical differences in abundance, biomass, and the presence/absence of different species between gears regardless sampling months. At ecological level, differences among gears were explained by different modus operandi, technological features and also different sampling habitats where gears operate; beach seine is catching bottom-bound and littoral fish while Chicocota is sampling the pelagic assemblage of the mid-channels. The frequency of occurrence of the 13 most abundant species differed between gears. Both gears showed little size-selectivity, with the mean total length and mean body height of these species statistically differing between gears. A total of 92 fish species were identified. No statistical differences were observed among gears for species richness, diversity and evenness. Both fishing gears captured several local socio-economically important species in the BSE. In particular, 13 of the most important species accounted for more than 54% and 60% of the total abundance and biomass in beach seine and chicocota, respectively. The complementary use of fixed and active fishing gears for studying fish community structure in estuaries is recommended. This multi-gear sampling approach enhances the capacity to detect changes in fish communities and provides valuable data for fisheries management and conservation efforts.

1. Introduction

Regular fish community assessment is a crucial tool to improve the management and conservation of fisheries resources. This approach is based on assessing fish assemblages, considering their abundance, richness and diversity, age and size distribution, and trophic ecology (Fausch et al., 1990; Whitfield and Elliott, 2002; Raposa et al., 2003; Rueda and Defeo, 2003). In addition, fish community data can be used to estimate ecological indicators for assessing the environmental and ecological status of the ecosystems and detecting changes attributed to

human-induced factors (Fausch et al., 1990; Whitfield and Elliott, 2002).

Fisheries in Eastern African countries face many challenges, including the need for monitoring programmes and scientific data collection. This critical lack of data on catch sizes, species composition, and bycatch severely constrains effective fisheries management, potentially increasing the risk of overfishing key species (Pinto and Lopes, 2001; Van der Elst et al., 2005; Pierce et al., 2008; Jacquet et al., 2010). Unsustainable fishing methods, characterised by high efficiency and low selectivity, exacerbate these challenges and are commonly

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employed in artisanal and subsistence fisheries (Van der Elst et al., 2005; Short et al., 2018; Costa et al., 2020; Mugabe et al., 2021).

Mozambique's small-scale fisheries significantly contribute to the country's overall marine fish landings (Jacquet et al., 2010; Doherty et al., 2015), but a critical knowledge gap persists, similar to other eastern African nations (Jacquet et al., 2010). This gap highlights the need for more fisheries assessments in Mozambique's coastal zones, particularly estuaries, where artisanal and subsistence fisheries are vital for the livelihoods of local communities. Existing studies primarily focus on commercially valuable fish and invertebrate species, addressing specific biological aspects (Mugabe et al., 2021), estimating catches and assessing stocks (Bilika et al., 2019; Cardinale et al., 2014; Inácio and Barros, 2012; Mugabe et al., 2021; Samoilys et al., 2019; Vølstad et al., 2014), and exploring management challenges (Darkey and Turatsinze, 2014; Gervásio and Lopes, 2003). However, there is a clear need for more research on the entire estuarine fish community structure.

The choice of fishing gear is a critical factor in estuarine

ichthyofauna assessment programs. Gear selection must be associated with catch efficiency for the target species and habitats, as well as for the overall objectives of the study (Rozas and Minello, 1997). Despite the importance of the combination of fishing gears to study fish community structure in estuaries, the comparisons of results from different sampling methods are scarce (Butcher et al., 2005; Gray et al., 2005; Boswell et al., 2010; Wasserman and Strydom, 2011; Pasquaud et al., 2012; Rotherham et al., 2012).

The two types of fishing gear mainly used at Bons Sinai's estuary (BSE) in Mozambique are beach seine and chicocota nets (Mugabe et al., 2021; Manhice et al., 2022), active and fixed gear, respectively. Beach seine nets are deployed from small boats in the channel, where estuarine or migrating marine juveniles of demersal and pelagic fish (some schooling) can be encircled (Hahn et al., 2007). These fishing gears capture juveniles that feed on submerged vegetation or are sheltered in turbid waters (Rozas and Minello, 1997). Chicocota nets, on the other hand, are deployed in the shallow water channel and are primarily used

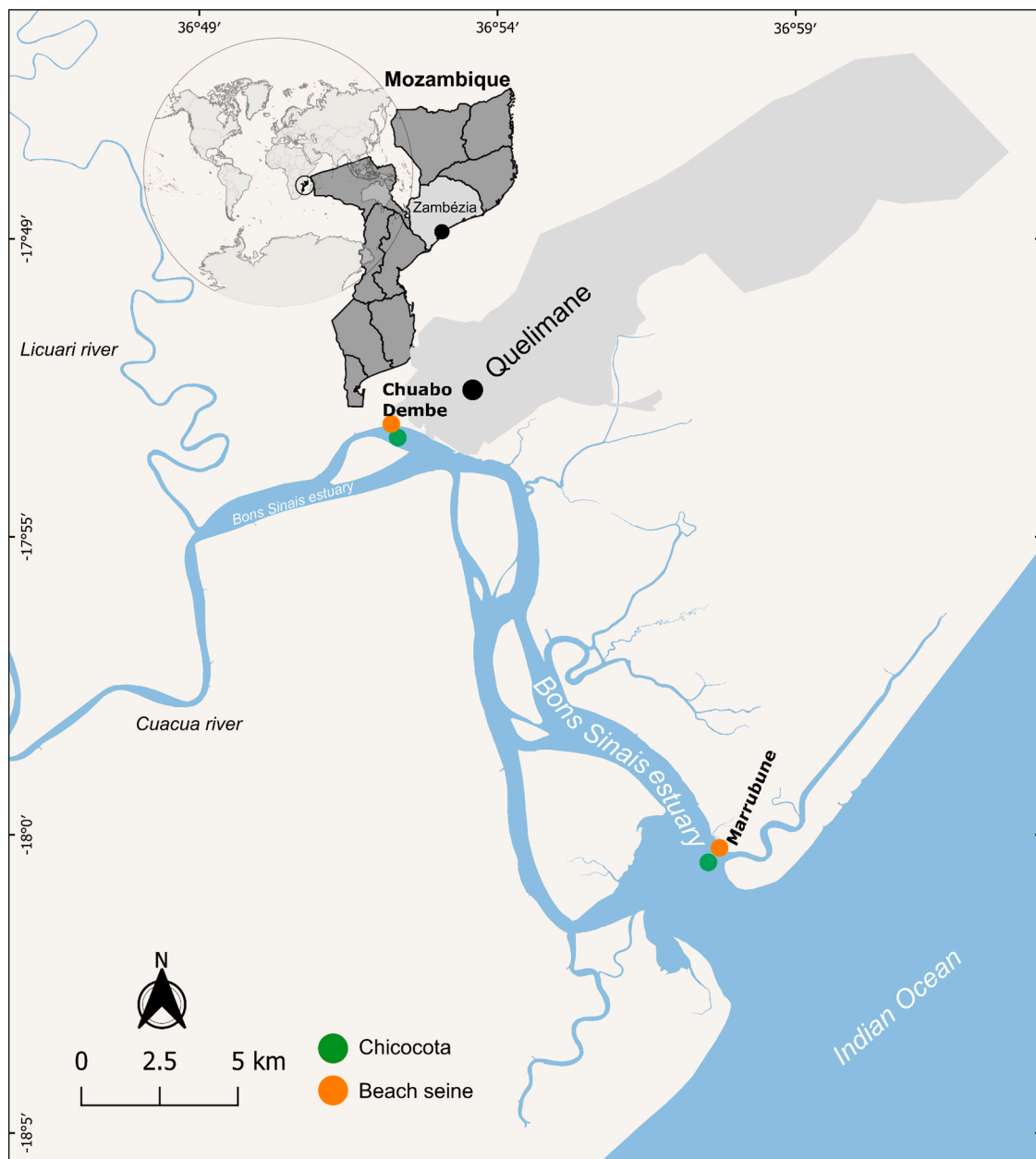


Fig. 1. Locations of fish sampling stations in the Bons Sinais estuary, Quelimane, Mozambique.

during spring tides. The net obstructs the fish movement in the channel, allowing it to capture juveniles of diadromous and estuarine fish that use the estuary as a migratory route. Both types of fishing gear are reported as being highly efficient and have very little selectivity (Mugabe et al., 2021). Chicocota and beach seine nets tend to have small meshes, and the frequent use of mosquito nets in the fish collecting bags yields substantial catches of juvenile specimens from diverse fish and invertebrate species (Benkenstein, 2013; Darkey and Turatsinze, 2014; Costa et al., 2020). Such gears can collect samples and provide scientific data on species composition and size structure of local fish and invertebrate communities' composition.

Thus, the present study aimed to analyse the performance of beach seine and chicocota nets used by artisanal fishers in BSE. It aims to compare data related to community structure, ecological indices (species richness, diversity and evenness), abundance, biomass, and species size. It is here discussed about the most suitable gear for collecting long-term data aiming to detect possible changes in the estuarine ichthyofauna community.

2. Material and methods

2.1. Biological sampling

To collect reliable data on fish assemblage, the fishing gears must be consistently deployed over space and time (Rozas and Minello, 1997; Boswell et al., 2010; Lipsky et al., 2019). Therefore, monthly sampling was conducted in the Bons Sinais estuary (BSE) in January 2020 and then from July 2020 to June 2021 at two fixed and easily logistic accessible stations (Fig. 1). The first sampling station was situated in the lower estuary (18° 0'20.29"S 36°58'14.40"E), in the Marrubune fishing village, while the second station (17°52'42.74"S 36°51'36.18"E) was located in the middle estuary (Mazzilli, 2015; Mocuba et al., 2023), in the Chuabo Dembe fishing community. Both locations are accessible by land and boat from the town of Quelimane. Three replicate samples were taken monthly for each fishing gear at each station, comprising 156 samples (78 samples for each fishing gear in the whole sampling period). The selection of sampling locations benefited from close collaboration with the local fishermen community. This ensured that the sampling sites represented traditional fishing grounds commonly exploited throughout the estuary, providing valuable insights into typical fishing practices. Our sampling stations were positioned near fishing villages where fish and invertebrates are caught with local fishing gears. The standard local logistic daily procedures used for each gear in BSE are described below.

The beach seine utilised in this study measured 200 m in length and had a height of 3.0 m. It featured a 7-meter-long conical bag (codend) designed to retain catches. The lateral mesh panel was 3 cm, while the mesh size of the bag was 5 mm. In the BSE, the beach seine net is typically deployed during the transition period from flood to ebb tides in shallow waters and with low currents. In this study, eight fishers pulled the net from the estuarine channel to the margin for an average period of 30 min. Broadhurst et al. (2007) studied beach seine configurations for fish size selectivity and explained the operation in the Clarence River estuary, similar to the situation observed in BSE.

The chicocota net, a stow net, is a stationary gear in the form of a cone placed according to the direction and strength of the tide current. Pereira et al., (2008) provided a comprehensive characterisation of the chicocota, the background of its introduction in coastal zones of Mozambique, and the impacts of its use in the ecosystems. In this study, the chicocota net was 15 m long, extending from the mouth to the codend, with a mouth width of 10 m and a height of 5 m. The body mesh size was 2.3 cm, while the codend had a mesh size of 1.2 mm. The chicocota net is moored to two wooden poles deeply embedded in the middle of the channel. Anchoring the net to trunks on the margins are rigid cables on both sides of the net opening. Buoys keep the net afloat and signal its location (Mugabe et al., 2021; Pravin et al., 2011).

When the current carrying the fish goes through the chicocota net, fish are collected in the codend (Pravin et al., 2011; Boopendranath, 2012). The BSE has semi-diurnal strong tidal currents, reaching a height of 4 m during spring tides, which classifies it as a meso- to macro-tidal system (Mazzilli, 2015). In these hydrodynamic conditions, fishers deploy chicocota nets for around 6-hour periods, day or night. At the end of this period, the net is hauled, fish are collected from the codend, and the net is turned in the opposite direction for fishing during the next tide (flood or ebb).

All specimens were identified at the species level using the taxonomic guides by Bell-Cross (1972), Fischer et al., (1990), Skelton (1993), and Smith and Heemstra (2012). In all species, fishes were counted, and the total weight was determined (g). For size comparisons between fishing gears, we measured the total length (cm) and body height (cm) of each individual belonging to any of the 13 preselected species because of their socio-economic relevance (*Oreochromis mossambicus*, *Hilsa kelee*, *Sardinella albella*, *Stolephorus indicus*, *Thryssa setirostris*, *Thryssa vitrirostris*, *Pomadasy kaakan*, *Mugil cephalus*, *Pellona ditchela*, *Johnius dussumieri*, *Otolithes ruber*, *Sillago sihama* and *Trichiurus lepturus*) (Doherty et al., 2015; Costa et al., 2020; and Mugabe et al., 2021).

2.2. Data analysis

The differences between chicocota and beach seine nets were compared regarding ecological indices, fish assemblage composition, and fish size structure.

2.2.1. Ecological analyses

Species richness, diversity and evenness were estimated from the samples of each fishing gear. Species richness refers to the number of species and species diversity to Shannon–Wiener's (H') index and the evenness to Pielou's evenness index (J') (Strong, 2016). The statistical differences between chicocota and beach seine for ecological indices were assessed using the Wilcoxon Mann–Whitney rank sum test (Zar, 2010). The frequency of occurrence (FO) for each species was estimated as the percentage of samples where the species was caught compared to the total sample number.

2.2.2. Fish assemblage composition

We used an nMDS analysis on a Bray–Curtis similarity matrix derived from standardised and fourth-root transformed abundance data to display similarities among fish samples between fishing gears. Standardising the data (relative abundances) eliminates the absolute difference in abundance and biomass values, while transformation reduces the influence of highly abundant species. Additionally, we created a separate presence-absence similarity matrix to examine the species selectivity of the gears. To determine whether there are differences in community structure (abundance, biomass, and species presence) between fishing gears and months, we conducted a two-way PERMANOVA with 9,999 permutations (Legendre and Legendre, 2012; Anderson, 2017). The PERMANOVA involved comparing fish assemblages between fishing gears throughout all months to evaluate both within-month variability and between-month differences. After obtaining significant PERMANOVA results, we conducted a SIMPER analysis to identify the key species contributing to the dissimilarity between fishing gear types (Clarke, 1993). The statistical analyses were performed in R (version 3.6.1) using the 'vegan,' 'dplyr,' 'ggplot2,' and 'tidyverse' packages (Wickham, 2016; Anderson, 2017; R Core Team, 2019)

2.2.3. Size composition

Differences in size class distribution (cm class) between gears of 13 preselected socio-economically important species were assessed by the Kolmogorov–Smirnov two-sample test (Zar, 2010). Additionally, we used two-sided t-tests to compare the mean total length of each species between fishing gears.

In meshed gear, fish are retained by their body height. The body height is the maximum vertical distance between the dorsal and ventral margin of the fish body. The fish body height data allows the design of gear with more selective mesh sizes, minimising the capture of

undersized fish (Rudershausen et al., 2016). The relationship between body height (dependent variable) and total length (explanatory variable) was determined in this study using a simple linear regression equation: $Y = a + bX$, where Y is the body height, X is the total length, a

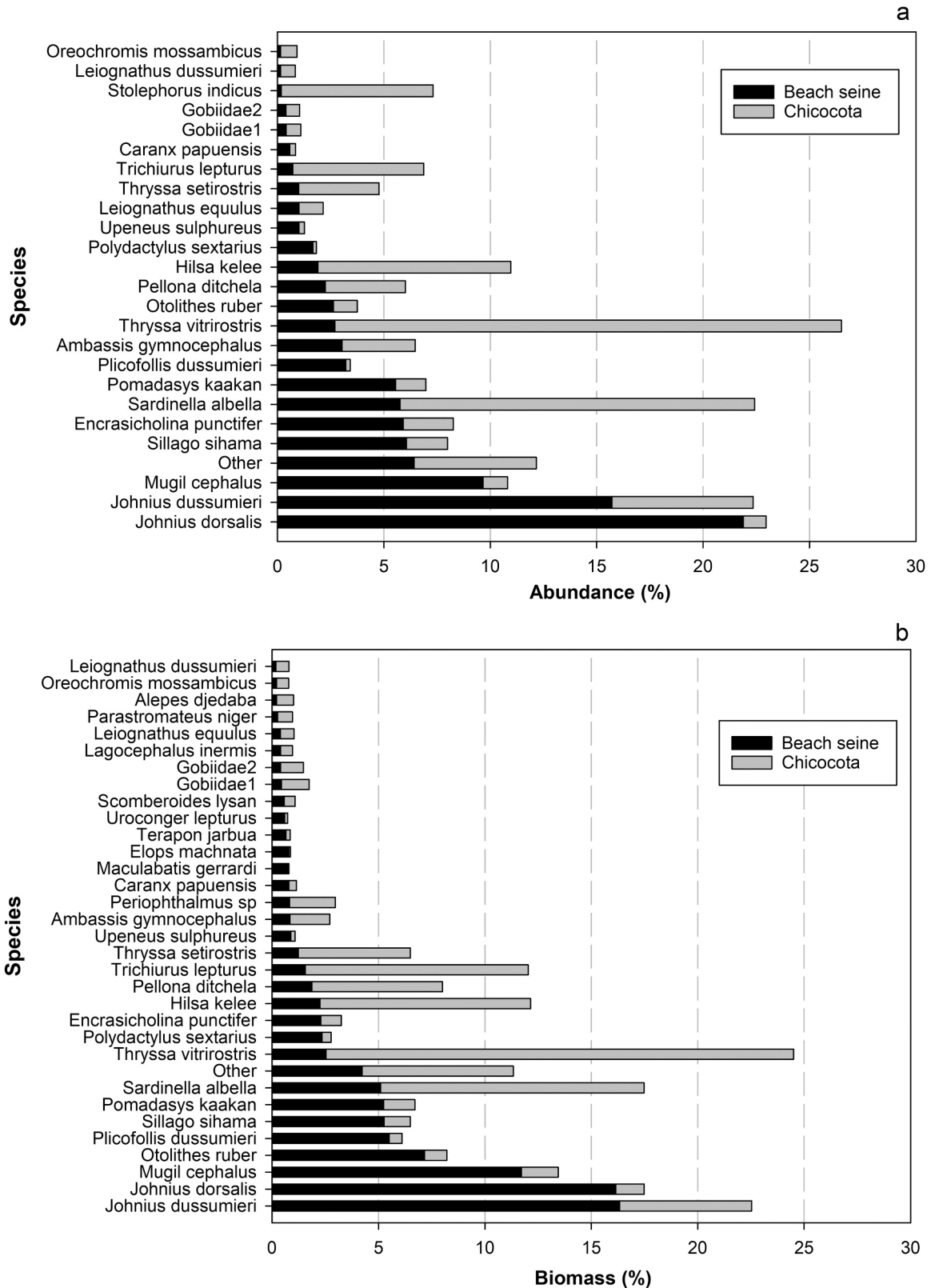


Fig. 2. Fish taxa relative abundance (a) and biomass (b) by fishing gears (chicocota and beach seine nets) in the Bons Sinais estuary, Mozambique. Only species exceeding 0.5% abundance or biomass are shown. The Appendix shows a complete list of fish species and the percentages of abundance and biomass (Table A.1).

is the proportionality constant and b is the regression coefficient. This species-specific equation was used to calculate H50 (Alam et al., 2013), that is, the body height (H) at which 50% of the fish species specimens are mature, by replacing the total length (X) with the size at first maturity (L50) provided in the bibliography (Willing and Pender, 1993; Al-Husaini et al., 2002; Di Dario and Williams, 2017; Whitfield, 2019; Froese and Pauly, 2021). We used L50 values from existing literature to estimate H50 for the chosen species due to the scarce published data on the Mozambican coast. The H50 estimated value for each species was compared with the mesh size of each fishing gear. If the mesh size of the gear is below the H50, there is a higher probability of capturing undersized specimens.

3. Results

3.1. Ecological indexes

A total of 92 species belonging to 45 families were caught during the study. For beach seine nets, 81 species from 43 families were caught, with an average species richness of 13.95 ± 4.6 per sample. Chicocota nets captured 77 species belonging to 37 families, with an average

species richness of 14.97 ± 5.8 per sample. Notably, some species were exclusive to either one of the two fishing gears. For instance, 15 species (Fig. 2, Table 1) were exclusively found in beach seine catches, such as *Anguilla marmorata*, *Brycinus imberi*, *Lutjanus ehrenbergii*, and *Sardinops ocellatus*. Conversely, 11 species were caught only using chicocota nets, including *Acanthurus blochii*, *A. bicolor*, *Encrasicholina heteroloba*, and *Pegusa nasuta*.

The catch composition, relative abundance, and biomass varied between fishing gears, particularly at the species level. For chicocota nets, nine species dominated the catch, accounting for 80.40% of the total abundance. The top five species with the highest abundance were *T. vitrirostris* (23.79%), *S. albella* (16.67%), *H. kelee* (9.06%), *S. indicus* (7.13%) and *J. dussumieri* (6.63%; Fig. 2a). For the beach seine catches, nine species accounted for 76.78% of the total abundance. The top five species with the highest abundance were *Johnius dorsalis* (21.89%), *J. dussumieri* (15.72%), *M. cephalus* (9.66%), *S. sihama* (6.06%) and *Encrasicholina punctifer* (5.91%) (Fig. 2a, Table A.1). Fish species caught exclusively by beach seine comprises less than 1% to the total abundance and 1.56% to the total biomass. Species caught exclusively by chicocota net comprised also less than 1% of the abundance and less than 1% of the biomass (Table A.1). The species that most contributed to

Table 1
Frequency of occurrence of fish species caught by two traditional fishing gears in the Bons Sinais estuary, Mozambique.

Species	Chicocota	Beach seine	Species	Chicocota	Beach seine
	Fo (%)	Fo (%)		Fo (%)	Fo (%)
<i>Acanthopagrus berda</i>	0	<20	<i>Monodactylus falciformis</i>	<20	<20
<i>Acanthurus blochii</i>	<20	0	<i>Mugil cephalus</i>	20–50	50–80
<i>Alectis indica</i>	<20	<20	<i>Muraenesox bagio</i>	<20	<20
<i>Alepes djedaba</i>	20–50	<20	<i>Nettastoma parviceps</i>	<20	<20
<i>Ambassis gymnocephalus</i>	50–80	50–80	<i>Ophisurus serpens</i>	<20	<20
<i>Anguilla bicolor</i>	<20	0	<i>Oreochromis mortimeri</i>	<20	0
<i>Anguilla marmorata</i>	0	<20	<i>Oreochromis mossambicus</i>	<20	<20
<i>Johnius dorsalis</i>	20–50	50–80	<i>Oreochromis placidus</i>	<20	0
<i>Arothron hispidus</i>	0	<20	<i>Otolithes ruber</i>	20–50	20–50
<i>Brycinus imberi</i>	0	<20	<i>Parastromateus niger</i>	20–50	<20
<i>Carangoides malabaricus</i>	<20	<20	<i>Paratrypauchen microcephalus</i>	<20	<20
<i>Caranx papuensis</i>	<20	<20	<i>Pegusa nasuta</i>	<20	0
<i>Caranx sexfasciatus</i>	<20	<20	<i>Pellona ditcheila</i>	> 80	20–50
<i>Carcharhinus falciformis</i>	<20	<20	<i>Periophthalmus sp</i>	20–50	<20
<i>Chelon richardsonii</i>	<20	0	<i>Plicofollis dussumieri</i>	20–50	20–50
<i>Conger wilsoni</i>	<20	<20	<i>Polydactylus sextarius</i>	20–50	50–80
<i>Crenidens crenidens</i>	<20	<20	<i>Pomadasys kaakan</i>	50–80	>80
<i>Ctenopoma multispine</i>	0	<20	<i>Pomadasys maculatus</i>	<20	<20
<i>Cynoglossus lida</i>	20–50	20–50	<i>Sardinella albella</i>	> 80	20–50
<i>Drepane longimana</i>	<20	<20	<i>Sardinella melanura</i>	<20	0
<i>Drombus triangularis</i>	<20	0	<i>Sardinops ocellatus</i>	0	<20
<i>Elops machnata</i>	<20	<20	<i>Scatophagus tetracanthus</i>	<20	<20
<i>Encrasicholina heteroloba</i>	<20	0	<i>Scomberoides commersonianus</i>	<20	0
<i>Encrasicholina punctifer</i>	20–50	20–50	<i>Scomberoides lysan</i>	20–50	<20
<i>Epinephelus coioides</i>	0	<20	<i>Scomberoides tol</i>	<20	<20
<i>Epinephelus malabaricus</i>	0	<20	<i>Scomberomorus plurilineatus</i>	<20	<20
<i>Gazza minuta</i>	<20	<20	<i>Secutor insidiator</i>	<20	<20
<i>Gerres filamentosus</i>	<20	<20	<i>Seriola dumerili</i>	<20	<20
<i>Gerres longirostris</i>	<20	<20	<i>Sillago sihama</i>	20–50	>80
<i>Gerres oyena</i>	<20	<20	<i>Sphyraena flavicauda</i>	<20	<20
<i>Glossogobius giuris</i>	<20	<20	<i>Stolephorus indicus</i>	20–50	<20
Gobiidae1	20–50	20–50	<i>Strongylura leitura</i>	0	<20
Gobiidae2	20–50	20–50	<i>Taenioides esquivel</i>	<20	<20
Gobiidae3	<20	<20	<i>Terapon jarbua</i>	<20	20–50
<i>Hilsa kelee</i>	50–80	20–50	<i>Terapon puta</i>	<20	<20
<i>Johnius amblycephalus</i>	<20	<20	<i>Thryssa setirostris</i>	50–80	20–50
<i>Johnius dussumieri</i>	50–80	50–80	<i>Thryssa vitrirostris</i>	> 80	20–50
<i>Laeops nigromaculatus</i>	<20	<20	<i>Thysanophrys chiltonae</i>	0	<20
<i>Lagocephalus inermis</i>	20–50	20–50	<i>Trichiurus lepturus</i>	50–80	20–50
<i>Karalla dussumieri</i>	<20	<20	<i>Umbrina ronchus</i>	<20	<20
<i>Leiognathus equulus</i>	50–80	20–50	<i>Upeneus sulphureus</i>	20–50	20–50
<i>Lobotes surinamensis</i>	0	<20	<i>Upeneus taeniopterus</i>	0	<20
<i>Lutjanus ehrenbergii</i>	0	<20	<i>Upeneus vittatus</i>	<20	<20
<i>Lutjanus russellii</i>	0	<20	<i>Uroconger lepturus</i>	<20	20–50
<i>Maculabatis gerrardi</i>	0	<20	<i>Yirkkala lumbricoides</i>	<20	<20
<i>Megalaspis cordyla</i>	<20	0			
<i>Megalops cyprinoides</i>	<20	<20			

differences in biomass between gears showed a similar pattern to that observed for abundance data (Fig. 2b). Overall, the abundance and biomass of 13 socio-economically important selected species caught using chicocota and beach seine nets showed substantial variation except for *O. mossambicus* (Table A.1).

Few fish species had the same frequency of occurrence (FO) in chicocota and beach seine nets. For the interval 20%–50%, the similarity was observed in *Cynoglossus lida*, *E. punctifer*, Gobidae1, Gobidae2, *Lagocephalus inermis*, *Plicofollis dussumieri* and *Upeneus sulphureus*. Fish species with FO greater than 50% differed between gears, except for *J. dussumieri* and *Ambassis gymnocephalus* (Table 1). In chicocota nets, *P. ditchela*, *S. albella* and *T. vitrirostris* were the most frequently caught species (FO > 80%). Conversely, *P. kaakan* and *S. sihama* were the most frequent species in the beach seine nets, with FO values exceeding 80%. Most species caught by chicocota (N = 50 species) and beach seine (N = 58 species) nets comprised less than 20% FO (Table 1) of the catch. Species exclusively captured by chicocota or beach seine nets exhibited less than 50% FO.

The species richness, diversity and evenness did not differ significantly between fishing gears (Fig. 3, Table A.2).

3.2. Fish assemblage structure

The nMDS ordination for presence/absence, abundance and biomass data showed that fish assemblage structures are grouped accordingly gears (Fig. 4). Additionally, the results of the PERMANOVA analysis indicate statistical differences in the ichthyofaunal assemblages based on the type of fishing gear and the month (Table 2). The interaction between month and gear ($p = 0.0001$) suggests that the composition of fish communities among gears varied across months. In fact, the pairwise comparisons showed that there were consistently statistical differences ($p < 0.001$) between the two types of gear in all months (refer to Table A.3). On average, the monthly similarity in fish communities between the two types of gear was less than 50% throughout the year.

According to the SIMPER analysis, 25 species have the most contribution (70.50%) on the dissimilarity in species presence between two gears. The top five contributors to this dissimilarity were *P. sextarius*, *S. sihama*, *T. setirostris*, *P. ditchela*, and *S. albella*, which account for a dissimilarity of 17.47%. The dissimilarity in abundance and biomass is even higher, with an average of 76.99% and 77.54%, respectively. The top five contributors for abundance and biomass dissimilarity were

T. vitrirostris, *J. dorsalis*, *S. albella*, *J. dussumieri*, and *H. kelee*, which explain a cumulative dissimilarity of 36.08% and 32.71%, respectively.

3.3. Size structure

Statistically significant differences in mean total length (TL) were observed between fish caught with chicocota and beach seine for eight species: *H. kelee*, *J. dussumieri*, *O. ruber*, *P. kaakan*, *S. sihama*, *T. lepturus*, *S. indicus*, and *S. albella* (Fig. 5a, Table A.5). No statistically significant differences in TL were found for *M. cephalus*, *O. mossambicus*, *P. ditchela*, *T. setirostris*, and *T. vitrirostris* between the two gear types. Similarly, body height showed statistically significant differences between chicocota and beach seine for *H. kelee*, *J. dussumieri*, *O. ruber*, *P. kaakan*, *S. sihama*, *S. indicus*, and *T. lepturus* (Fig. 5b, Table A.6). No statistically significant differences were detected in body height for *M. cephalus*, *O. mossambicus*, *P. ditchela*, *S. albella*, *T. vitrirostris*, and *T. setirostris*. The H50 values of the selected species, estimated from the TL data and the L50, were larger than the codend mesh sizes of the two gears (1.2 mm for chicocota and 5 mm for beach seine). Furthermore, the H50 values were larger than the body net mesh sizes (2.3 cm for chicocota and 3 cm for beach seine) except for *S. indicus*, *S. albella*, *T. setirostris* and *T. vitrirostris* (Table A.6).

4. Discussion

The findings from the present study highlight the variability in the assessment of fish assemblage structure in the BSE when using different sampling gears. The results emphasise the need for multiple fishing gears to capture ecological data on fish assemblages in estuarine environments comprehensively. Using multiple gears is advantageous because it takes into account various factors, such as fish behaviour, fish size, gear deployment, gear dimensions, and habitat characteristics, all of which influence the effectiveness of a specific gear (Harrison and Whitfield, 1995; Butcher et al., 2005; Lowry et al., 2012; French et al., 2021; Mehdi et al., 2021).

Tropical artisanal fisheries are complex due to the variety of species targeted by different gears and the diversity of landing locations (Batista et al., 2014). Studies using a multiple-gear approach can significantly improve the reliability of local and national catch estimates while providing a complete picture of species diversity and tracking community changes. For example, a study in four permanently open Eastern

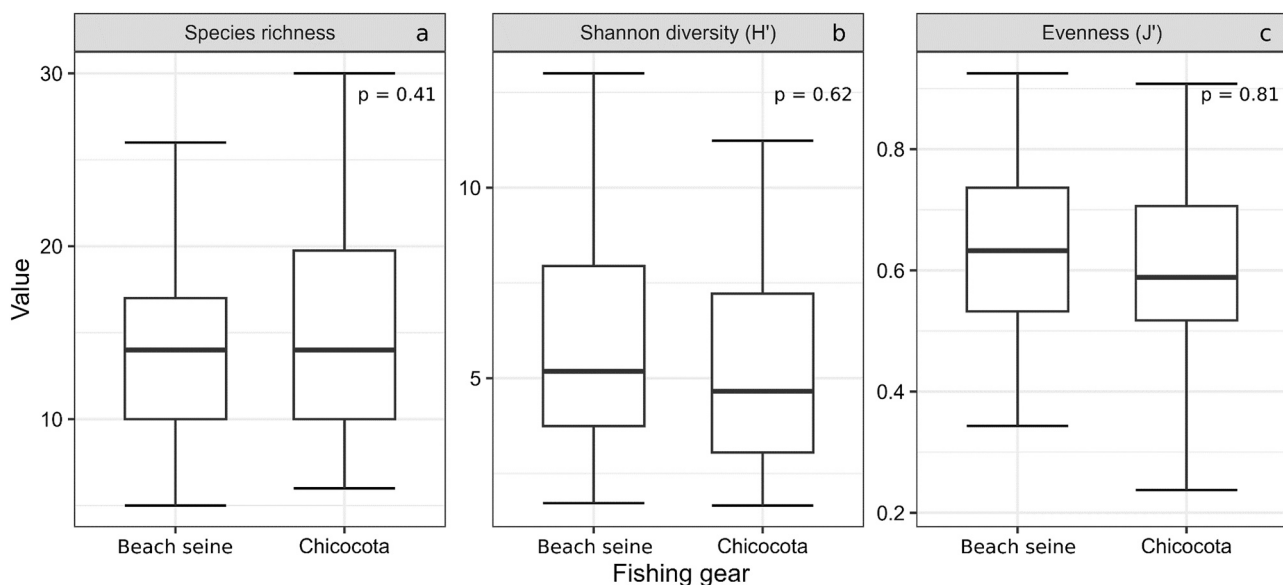


Fig. 3. Box plots of species richness (a), diversity (b) and evenness (c) of fish assemblages caught by two different fishing gears (beach seine and chicocota nets) in the Bons Sinais estuary, Mozambique. Statistical comparisons were evaluated between gears (p -value).

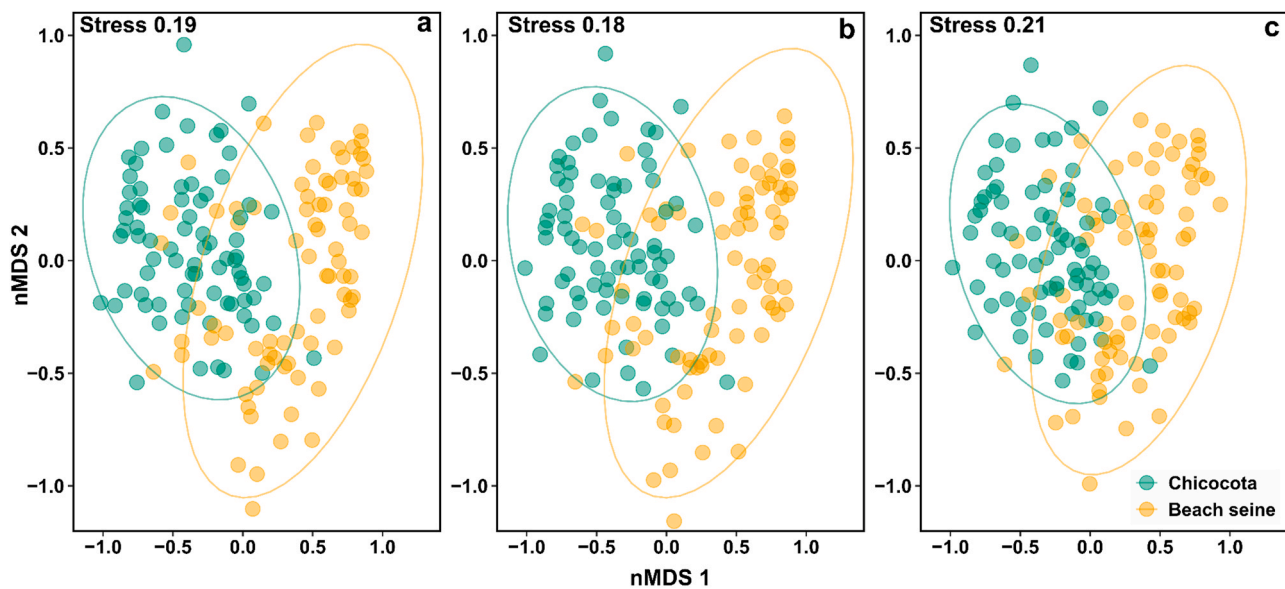


Fig. 4. Non-metric MDS of fish assemblages caught by chicocota and beach seine gears using different data: abundance (a), biomass (b) and presence and absence (c). Distances were calculated with Bray-Curtis’s dissimilarity metrics on the fourth root transformed for abundance and biomass data. Ellipses represent 95% confidence intervals.

Table 2

Results of Two-way PERMANOVA testing for differences in fish assemblages between fishing gears and months, using abundance, biomass, and presence/absence data. df= degrees of freedom, MS= mean square, F= F statistics, RS = residuals.

Data	df	MS	F	p-value
Abundance				
Factor				
Gear	1	76742	45.995	0.0001
Month	11	6327	3.7922	0.0001
Gear x Month	11	3442	2.0628	0.0001
Residual	132	1669		
Biomass				
Factor				
Gear	1	80429	45.522	0.0001
Month	11	5364	3.036	0.0001
Gear x Month	11	3218	1.8211	0.0001
Residual	132	1767		
Presence/ absence				
Factor				
Gear	1	53674	41.202	0.0001
Month	11	4630	3.5541	0.0001
Gear x Month	11	2493	1.914	0.0001
Residual	132	1303		

Cape, South Africa estuaries utilised fixed and active gears to examine fish utilisation of headwater environments, revealing variations in fish assemblage between net types (Wasserman and Strydom, 2011). Other studies in Mozambique (Mugabe et al., 2021; Samoilys et al., 2019) and Kenya (Manyenze et al., 2021; Musembi et al., 2019) also highlighted the importance of using a multiple-gear approach to analyse catches and size distributions in artisanal fisheries.

Despite variations in the number of species caught by each fishing gear, the diversity indices in the BSE did not exhibit statistically significant differences between the fishing gears. The unique presence of some species in each gear and the abundance differences in many corroborates the idea of the importance of using multiple gears for studying and assessing estuarine ichthyofauna. The outcomes of multivariate analyses further support this point and reveal that the composition of catches differed between the two gears across all analysed aspects, including abundance, biomass, and presence/absence. While presence/absence data are predominantly associated with selectivity

characteristics linked to gear operation and the sampled habitats, the relative abundance and biomass data provide insights into the ecological contributions of species to the overall fish assemblage composition.

The differences observed between gears are associated with the critical factors that affect gear efficiency to catch species of different ecological niches in specific habitats (Mehdi et al., 2021). For example, beach seine nets are effective in sandy and gravelly beach areas with no obstructions (Rozas and Minello, 1997; Desmond et al., 2002; Lipsky et al., 2019). These areas correspond to shallow waters near the river-bank. However, beach seine nets have been reported to have low catch efficiency in estuarine habitats, such as emergent marsh and seagrass (Clark et al., 1996; Huxham et al., 2004). Fixed nets, such as chicocota, effectively collect data for studies of the age structure, reproductive aspects and migratory patterns of fish (Rozas and Minello, 1997; Hubert et al., 2012). However, fixed nets have practical inconveniences as sampling depends on the tidal energy that carries fish into the net. Moreover, density or biomass per unit area cannot be estimated through fixed gear sampling as they accumulate fish samples over time and space, making it challenging to relate samples to specific times or habitats (Kneib, 1991; Faunce and Serafy, 2006; Hubert et al., 2012).

Among the most abundant species, *P. ditchela*, *S. albella* and *T. vitrirostris* showed the FO, relative abundance and biomass greater in chicocota nets than in beach seine nets. However, *M. cephalus*, *O. ruber*, *P. kaakan* and *S. sihama* exhibited FO, relative abundance and biomass greater in beach seine nets than in chicocota nets. Most of the species exclusively sampled in chicocota nets are pelagic, with a few being demersal, namely, *A. bicolor*, *C. richardsonii*, *D. triangularis* and *P. nasuta* (Whitfield, 2019; Froese and Pauly, 2021). Conversely, those exclusively found in beach nets are mostly demersal, with a few being pelagic, namely *A. hispidus*, *C. multispine*, *L. surinamensis* and *S. ocellatus* (Whitfield, 2019; Froese and Pauly, 2021). This finding also reveals that sampling strategies using a combination of gears allow capturing fishes belonging to different functional groups from different habitat types across the ecosystem, as documented in other estuarine studies (Chong and Sasekumar, 2002; Franco et al., 2012).

Upon analysing the total length (TL) and body height (H) of the 13 socio-economically important species, it is evident that chicocota and beach seine gears are catching many juvenile fish. However, it is crucial to address the interpretation of the H50 results cautiously, as these values are derived from L50 values in the literature that may not directly

Table 3

SIMPER analysis: 70% cut off for low contribution of fish species responsible for the dissimilarity between fishing gears (chicocota and beach seine nets).

Species	Abundance (76.99%)			Species	Biomass (77.54%)		
	Avg.	Cont. (%)	Cum. (%)		Avg.	Cont. (%)	Cum. (%)
<i>T. vitirostris</i>	6.95	9.03	9.03	<i>T. vitirostris</i>	6.52	8.41	8.41
<i>J. dorsalis</i>	6.19	8.04	17.07	<i>J. dorsalis</i>	5.02	6.48	14.89
<i>S. albella</i>	5.70	7.41	24.47	<i>J. dussumieri</i>	4.96	6.39	21.28
<i>J. dussumieri</i>	5.04	6.55	31.02	<i>S. albella</i>	4.82	6.22	27.50
<i>H. kelee</i>	3.89	5.06	36.08	<i>H. kelee</i>	4.04	5.21	32.71
<i>M. cephalus</i>	3.54	4.6	40.68	<i>T. lepturus</i>	4.00	5.16	37.87
<i>S. sihama</i>	3.27	4.24	44.92	<i>M. cephalus</i>	3.98	5.13	43.00
<i>P. kaakan</i>	2.9	3.77	48.69	<i>P. ditchela</i>	3.37	4.35	47.35
<i>E. punctifer</i>	2.88	3.74	52.43	<i>O. ruber</i>	3.14	4.05	51.41
<i>S. indicus</i>	2.82	3.66	56.10	<i>S. sihama</i>	2.88	3.71	55.12
<i>P. ditchela</i>	2.82	3.66	59.75	<i>T. setirostris</i>	2.75	3.54	58.66
<i>T. lepturus</i>	2.81	3.65	63.4	<i>P. kaakan</i>	2.71	3.49	62.15
<i>A. gymnocephalus</i>	2.51	3.26	66.66	<i>P. dussumieri</i>	2.23	2.87	65.03
<i>T. setirostris</i>	2.24	2.91	69.57	<i>P. sextarius</i>	1.88	2.42	67.44
–	–	–	–	<i>E. punctifer</i>	1.62	2.09	69.54

Notes: Avg. = average dissimilarity, Cont. = percentage of contribution to differences, Cum. = cumulative percentage of contribution to differences. The overall average dissimilarity is given between brackets. Full species names are in Table 1.

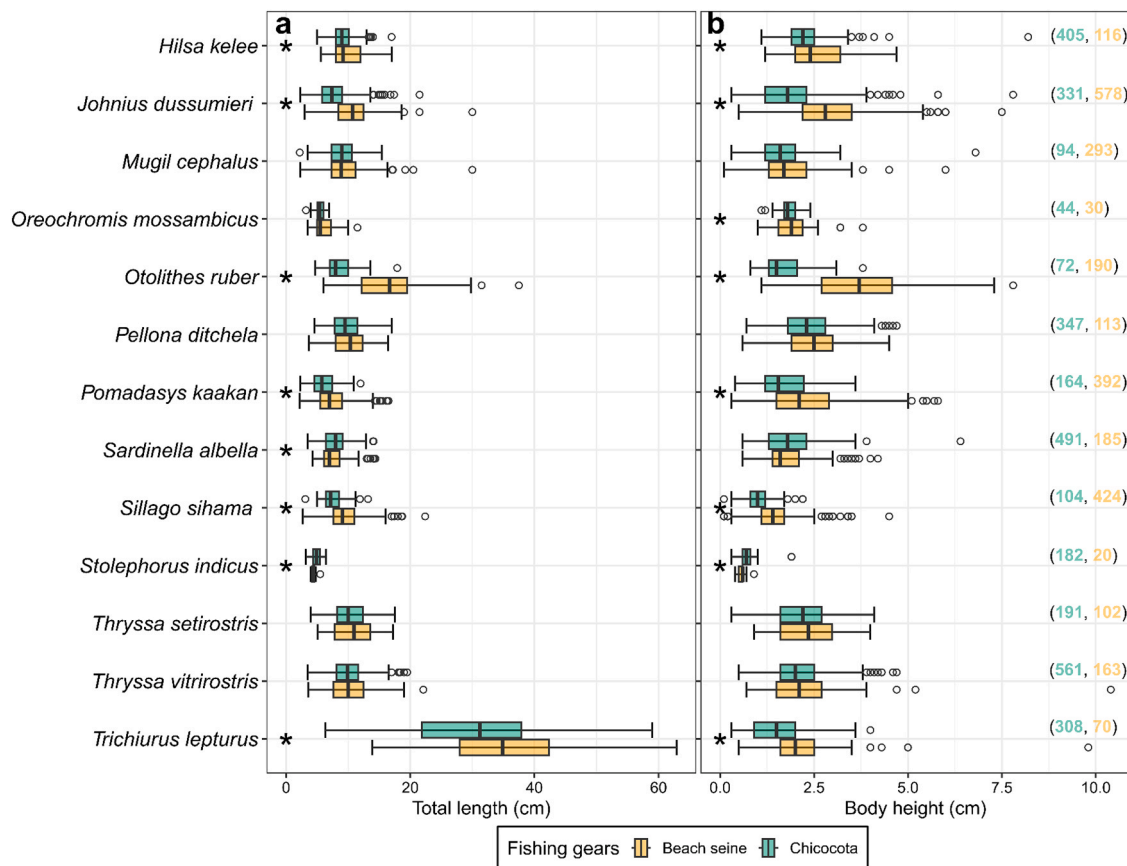


Fig. 5. Boxplots of the total length (a) and body height (b) of 13 fish species caught by chicocota and beach seine gears in the Bons Sinais estuary, Mozambique. * indicate statistically significant differences between the two gears at the 0.05 level. The numbers in parentheses are the sample sizes for chicocota and beach seine.

apply to the Sofala Bank population of the same species. The study demonstrated TL and body height differences between chicocota and beach seine for *H. kelee*, *J. dussumieri*, *O. ruber*, *P. kaakan*, *S. sihama*, and *T. lepturus*. In addition, two species, *S. albella* and *S. indicus*, differed uniquely in TL between the two fishing gears. Therefore, combining gears can enhance knowledge related to the population dynamics of species with commercial interest. In particular, fixed gears have been used to sample juvenile fish in some estuaries (Vidy et al., 2004; Patrick and Strydom, 2014; Sloterdijk et al., 2017; Simier et al., 2019; Costa et al., 2020).

Fisheries authorities discourage using these two types of fishing gear nationwide because of the low selectivity and, therefore, high efficiency in catching multiple species and collecting high numbers of juveniles of both fish and invertebrates (Mugabe et al., 2021). However, and only from the perspective of collecting scientific data, these characteristics are favourable to sampling as they increase the probability of capturing the species that inhabit the estuary and because they are easy to use by the local fishers. Sampling of juveniles allows for covering a large range of small fish sizes, information that is a major asset for studying community demographic structure (e.g., juvenile/adult ratio) and

recruitment potential. However, the intense catching of immature fish raises concerns for fisheries management (Tuda et al., 2016; Costa et al., 2020; Mugabe et al., 2021). Intensive use of small unselective mesh sizes in the estuary raises concerns about significant impacts on fish and invertebrate recruitment within the BE and the adjacent marine waters (Palha De Sousa et al., 2016). Zambézia province, where the BSE is located, holds approximately 50% of all 2000 Mozambique's chicocota gears. Notably, the estuaries have the highest number of fishing gears compared to other coastal and inland ecosystems (IDPPE, 2012). The increased use of less selective fishing gear might be driven by labour and economic factors of fishery operations (Groeneveld et al., 2021), and coastal communities rely on direct natural resource exploitation for subsistence (Francisco et al., 2021; Furaca et al., 2021; Manhice et al., 2022).

Tropical small-scale fisheries can achieve sustainability through the balanced harvest (BH) approach, which recommends harvesting all species, stocks, and sizes proportionally to their natural productivity to maintain the relative size and species composition and reduce the overfishing of large fish (Burgess et al., 2016; Pelage et al., 2021). BH contrasts with the size regulations that protect juveniles from fishing (Jacobsen et al., 2014). While the BH might be easier to implement in developing countries where small-scale fisheries are crucial for food security and provide mainly small fish at lower prices (Pelage et al., 2021), it requires deep biological knowledge of each ecological group and coordinated fishing efforts to prevent overfishing (Burgess et al., 2016).

The results of this study showed that the estimated H50 height values in all selected species were larger than the codend mesh sizes of the two gears. In addition, except for *S. indicus*, *S. albella*, *T. setirostris* and *T. vitrirostris*, the selected species had the H50 larger than the body net mesh sizes, indicating a high catch of undersized fish as denoted by the TL analyses. Mesh selectivity occurs mainly through the net section of a fishing gear through which fish can escape. In both gears, the selection is provided by the body height and behaviour rather than the TL (Stewart and Ferrell, 2003), which is used for selectivity analyses due to its positive correlation with body height and easier to measure than body (Mitchell and Baxter, 2021). Thus, selectivity studies are required to determine multi-species mesh sizes to minimise juvenile retention that would adversely affect the role of BSE as a nursery for fish species with socio-economic relevance.

Therefore, the study's results can be used to set up fishing gears to achieve specific selectivity for sampling in fish Biology studies and mesh size regulation. Biological and ecological data collected during assessment surveys can provide data on species morphometric traits, reproductive seasons, size at maturity, fish assemblage, and ecological structure variability over time and space. It can also be crucial to assess the role of the estuary as a nursery area, functional groups and life strategies (Whitfield et al., 2022), which must be improved in the BSE. Overall, this study demonstrated that using complementary fishing gears that operate over different habitats can enhance fish assessments of the estuary's resources, such as species composition and size distribution, allowing better estuarine ecological and demographic characterisation.

The sampling approach employed in this study was consistently applied across both time and space, with fixed sampling sites during the entire study duration. These sites were strategically chosen in collaboration with the local fishers as they are traditional fishing grounds along the estuary and had been used as the main points for data collection in previous studies on artisanal fisheries (Mugabe et al., 2021; Manhice et al., 2022). This approach offers several technical and logistical advantages (Rozas and Minello, 1997). Notably, the fishing gears used in this study do not require specialised training, making them accessible and practical for data collection. Moreover, this methodology presents an excellent opportunity for collaboration with artisanal fishers, contributing to the concept of citizen science aimed at supporting fisheries assessment (Bonney et al., 2021). However, scientific sampling

gear does not necessarily have to be commercial fishing gear. In the present study, we propose utilising local alternatives as a matter of convenience, as, due to local circumstances, they have the potential to achieve significant success in long-term monitoring initiatives.

5. Conclusions

The study showed that beach seine and chicocota are effective gears for gathering data on fish community structure and size distribution. However, data on fish community structure, abundance and size of the individuals were strongly affected by the features of fishing gear used to collect the data. The study demonstrated that a combination of fixed and active gears, each with distinct operating characteristics in the BSE, are complementary methods that can generate a long-term database for ichthyofauna community structure assessment. This approach can track changes in fish structure and demographic aspects over time. Given the importance of BSE in biodiversity and as a source of income and subsistence for local fishing communities, the systematic assessment of the ichthyofauna should be a high priority. Furthermore, size structure data showed that both fishing gear mesh sizes could exert significant pressure on the fish community because of the use of net mesh sizes below the maturation size of fish (H50).

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CRedit authorship contribution statement

Jeremias Mocuba: Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Eudriano Costa:** Writing – review & editing, Writing – original draft, Visualization, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Daniel Mualeque:** Writing – review & editing, Resources, Investigation. **Maria Alexandra Teodósio:** Writing – review & editing, Supervision, Resources, Funding acquisition. **Francisco Leitão:** Writing – review & editing, 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.

Data availability

The data that has been used is confidential.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.risma.2024.103592](https://doi.org/10.1016/j.risma.2024.103592).

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