Stock status of the dash-and-dot goatfish, *Parupeneus barberinus* (Lacepède, 1801) in Kenya's coastal marine waters

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Abstract

Demersal reef fisheries are important for the provision of food and livelihoods for the coastal communities. The fisheries are multispecies, exploited by artisanal fishers using a diverse range of gear types. Data collated from artisanal fishers along the Kenya coastline for the period 2017 to 2023 was used to assess the stock status of *Parupeneus barberinus* to inform the management of the fishery. Results revealed a higher proportion of *P. barberinus* caught were immature and large reproductive individuals were not conserved during the fishery. The fishing mortality estimate (F = 1.57 $year^{-1}$) and exploitation rate of 0.674, which is higher than the threshold of E = 0.5 $year^{-1}$ indicate overexploitation. We recommend management to enforce monitoring and surveillance to ensure that legal gears with the right mesh / hook sizes are used for the protection of juveniles and sustainability of the fishery. There is a need to disseminate findings from this study to the stakeholders for awareness creation to ease the implementation of regulations in place.

Keywords: stock status, selectivity, mortality rates, exploitation

Introduction

Small-scale fisheries comprise majority of the global fisheries and are crucial in providing food and nutrition security, livelihoods, income and tourism services to coastal communities (Donner and Potere, 2007; Newton *et al.,* 2007; McClanahan *et al.,* 2013). Small-scale fisheries support about 6,500 fishermen in the coastal communities, excluding those engaged in the fish processing and marketing sectors and are the main contributors, accounting for about 93 – 98% of the marine catches in the Western Indian Ocean (WIO) region. Small-scale fisheries in the tropics are multi-species, exploited by multi-gears, making the management of the fisheries difficult. (Peterman, 2004). The fisheries predominantly dwell in the seagrass meadows and among the coral reefs (Donner and Potere, 2007).

Despite their crucial contribution, current scientific information on small-scale fisheries is not available, coupled with limited financial and institutional support complicate the management of the small-scale fisheries, especially those in the developing countries (Mahon, 1997). Even with the limited information, compliance to the regulations in place is poor owing to the fact that the resources are open access (Donner and Potere, 2007; Newton *et al.*, 2007). Additionally, the small-scale fisheries are overexploited and their habitats are degraded by the use of destructive fishing gears and effects of climate change (McClanahan, 2008).

Kenya's marine fisheries lie within the 640 km long coastline which extends from 1.75-4.65°S to 39.18-41.22°E and includes a narrow continental (nearshore) shelf which extends to about 60 km offshore at the Northern part and the 200 km offshore Exclusive Economic Zone (EEZ). The nearshore is largely characterized by fringing reefs running parallel to the shoreline. There are numerous resources of conservation concern in the coastline which include marine fish, coral reefs, seagrass beds, mangrove forests and a lot of cultural heritage (Kimani *et al.,* 2018).

The small-scale fisheries are conducted in the nearshore zone and yield about 80% of the marine production annually, with the demersal finfish contributing 50% of the marine catches. The main artisanal fishing areas include the fishing grounds of the Lamu Archipelago, the Malindi-Ungwana Bay, North Kenya Bank and Malindi Bank. Artisanal fishing activities are conducted by local fishers whose capacity is debilitated by the small non-motorized vessels that cannot reach the deep waters. The demersal fish comprise of the Scaridae, Nemipteridae, Siganidae, Lethrinidae, Haemulidae and Lutjanidae.

The dash-and-dot goatfish, *Parupeneus barberinus* is one of the most abundant species of the *Parupenues* genus (Myers, 1999), with the adults occurring in solitary or small groups inhabiting large sand patches and rubble areas of reef flats and lagoon reefs at a depth of about 100 m. Additionally, the juveniles occur in small groups, mixed with other species in seagrass habitats (Kuiter and Tonozuka, 2001). In Kenya marine waters, *P. barberinus* is abundant in the shallow seagrass meadows, contributing about 2.9% of the total catches in abundance (Musembi *et al.,* 2019), coral reefs and along the rocky shores which are easily accessed by artisanal fishers.

The species exhibit diurnal a feeding pattern in which they forage on invertebrates such as polychaete worms and crustaceans (Randall, 2004). *Parupeneus barberinus* exhibits gonochorism, although some immature individuals of sizes between 16.1 and 22.5 cm, FL are bisexual (Longernecker *et al.,* 2017), with mature individuals migrating shoreward to feed or spawn (Hoese *et al.,* 2006). The peak spawning period occurs between May and August for males while the spawning period for females is between May and June (Wahbeh and Ajiad, 1985). The species utilizes multiple habitats, shifting from mangroves/ seagrasses to coral reefs (Honda *et al.,* 2013).

Globally, the species is distributed in Africa, Asia and Oceania continents, in 64 countries / islands as either an endemic, native or introduced species, where it occupies freshwater, salt water and sometimes brackish water (in the Indo-Pacific: Gulf of Aden and Oman, South on the East Coast of Africa to Mossel Bay, South Africa, East to the islands of Micronesia, Line Islands, Marquesas Islands, and Tuamotu Archipelago; and from Southern Japan to Australia and New Caledonia. The species has medium to high resilience and moderate vulnerability to fishing (Chueng *et al.,* 2005; Froese *et al.,* 2017). This study is meant to provide stock status information necessary for sustainable fishery of this species.

Stock status analysis can be done adopting the length-frequency approach to estimate mortality rates, which does not lead to misinterpretation of estimates, is easy to collect data and does not require complicated analytical tools (Pauly, 1983). Additionally, mortality estimates are indicators of fishing pressure in a locality for a specific fish stock. Length-frequency distribution is important for assessing the size structure of a particular fish population in nature and is used as the first gauge for gear selectivity (Bagenal, 1978). Size structure information is crucial for assessing the reproductive potential, growth, and stability of demersal reef fishes (Hixon *et al.,* 2014; Van Overzee and Rijnsdorp, 2015). The absence of smaller size classes is an indication of recruitment deficiency, while the lack of large size classes is an indication of high mortality of mature fish (Neumann and Allen, 2007). Length at first maturity (L_m) is also used to monitor whether representative juveniles in an exploited stock mature and spawn before they are caught (Beverton and Holt, 1959; Jennings *et al.,* 1998).

Population dynamics and the population's health status are proxies for providing information to guide the regulation of the fisheries. Many studies on small-scale fisheries focusing on various aspects have been conducted (Mwatha *et al.,* 1997; Fulanda *et al.,* 2009; Tuda *et al.,* 2018; Musembi *et al.,* 2019). However, there is no study on the stock status for *P. barberinus*. This study, therefore, seeks to provide baseline information on the stock status of *P. barberinus,* important for the management and regulation of its fishery. Specifically, to describe the size composition, estimating selectivity and assessing the stock status of *P. barberinus*.

Materials and methods

Study area

The study was conducted within the Kenya coastline which extends from 1°30′ S at the Somalia border to 5°25′ S at the Tanzania border (Fig. 1). The marine coastal area has an extensive cover of mangroves and an intertidal zone covered with seagrass meadows and coral reefs (McClanahan and Mangi, 2000). The marine environment is characterized by warm tropical conditions, with sea surface temperatures (SSTs) ranging between 24°C in August and 30°C in February (McClanahan, 1988; Obura, 2001). The Kenya coastal waters are influenced by the Inter-Tropical Convergence Zone (ITCZ) movement that acts on the waters to create the northeast monsoon (NEM) and southeast monsoon (SEM) seasons which prevail from November to March and April to October, respectively (McClanahan, 1988). The monsoon seasons influence fishing activities in the Kenya coast (Ochiewo, 2004).

Data collection and analysis

Fishery data

Data was collected between 2017 and 2023 from 18 fish landing sites distributed along the entire coastline through the catch assessment program conducted in the five coastal counties. Extractive method associated with fishing gears was used for data collection as it allows for direct measurement of the catch to give accurate size structure data for the artisanal catches (Weerarathne *et al.,* 2021). However, the method cannot be used for protected fisheries (Mallet and Pelletier, 2014). Data enumerators identified landed catches to species level and recorded the number, size (total length in cm), gear used, landing site, and date. Although all sampling was conducted during daylight hours, these include catches attributed to night-time fishing activities as data enumerators also intercepted fishers returning from their overnight fishing.

Data analysis

Size structure

The size composition of P. barberinus was assessed using bar plots and determining the mean sizes of the length frequencies of the fish sampled during the 2017-2023 fishing period in Minitab ® software (Minitab, 2021). To assess the size structure of the individuals caught during the fishing period, the lengths were compared with length at first maturity (L_m) and asymptotic length (L_∞) values obtained from Fishbase (Froese *et al.,* 2017).

The optimal size of capture, a level where highest yield from a cohort for each species is obtained was determined as the proportion of the catch between $0.9L_{opt}$ and $1.1L_{opt}$, then the proportion of all the catch with lengths greater than $1.1L_{opt}$ were

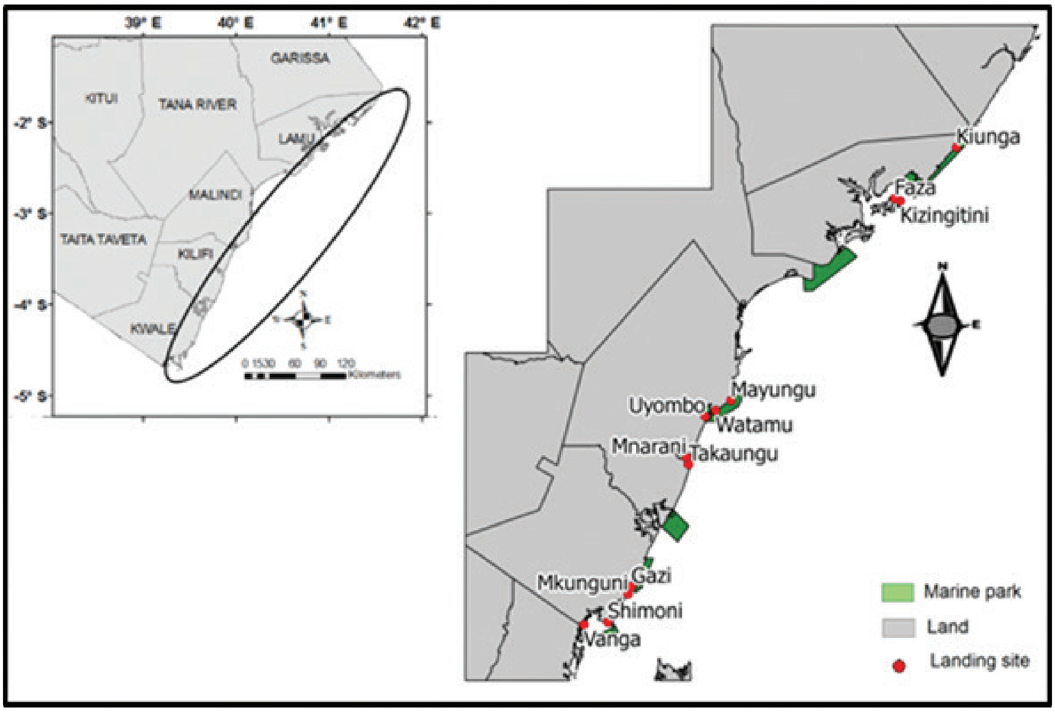

Figure 1. Map of Kenya showing some of the artisanal fisheries landing sites at the Kenya coast (Source: Authors).

considered as "mega-spawners" (P_{mega}) which indicate future recruitment and sustainability of the fishery. The "mega-spawners" should be allowed to live to have a sustainable fishery (Froese, 2004).

Historical length-weight relationship (LWR) parameters, a = 3.5 * 10^{-5} and b = 2.7 (Ontomwa *et al.,* 2018) for *P. barberinus* were input in the ELEFAN, LBI and LBSPR tools in Tropfish R to determine the stock status, mortality rates, spawning potential rate and conservation indicators.

Stock status

Growth parameters mortality and exploitation rates

The *Parupeneus barberinus* fishery was assessed using the length-based stock assessment TropFishR (Tropical fisheries analysis) package (version 1.6.3). The length-based stock assessment with TropfishR is based on the routine outlined by FAO (1998), which was compiled into R by Mildenberger *et al.* (2017). The assumptions of TropFishR are that: the data used is a representative of the whole catch; and the routine assumes a sigmoid selectivity commonly applicable for trawl-like fishing gears including gillnets and hook-based methods with various mesh and hook sizes, respectively. Further, the routine assume that there is constant recruitment, fishing and natural mortality, somatic growth and maturation over time, the density is independent on maturity and somatic growth, growth parameters (L_∞ and K) are predictors of natural mortality, somatic growth follows the logistic von Bertlanffy growth (VBG) function and that the stock under study is closed with no immigration or migration taking place. All these assumptions may limit the results of this study.

Prior to the assessment, the length data was organized into length-frequency clusters in Microsoft Excel® software and converted to comma-separated values (CSV) text file format, before uploading in TropFfishR. Length-frequency data was generated at an optimal bin size (OBS) determined from the maximum body size as: OBS = $0.23*L_{max}^{0.6}$ according to Wang *et al.* (2020). Then growth parameters (K, L_∞, and t_a), natural (M), total (Z) and fishing (F) mortality rates, and stock status were assessed using the ELectronic LEngth Frequency ANalysis with genetic algorithm (ELEFAN_GA) in TropFishR package (Mildenberger *et al.,* 2017). The TropFish package allows for the analysis of length-frequency data for data-poor fisheries and the ELEFAN_GA method allows for optimization hence reducing search (Mildenberger *et al.,* 2017).

The most important growth parameters considered in this study were the asymptotic length (L_∞), condition factor, K and t_a. Asymptotic length also referred to as L infinity (L_{inf}) is the length a fish would reach if they are allowed to grow indefinitely. K is the growth coefficient which expresses the rate at which asymptotic length is approached.

Length-frequency data was pooled by quarter then ELEFAN method was applied to estimate L_∞, K and t_a by restructuring and fitting growth curves through restructured data (Pauly, 1980). This method assumes that the length-frequency data are representative of the population, growth parameters are repeated each year, all samples have the same growth parameters and length frequency data obtained usually contain modes pertaining to one of two major cohorts per year.

Then the growth performance coefficient, *phi'*, which provides a metric for the correlation of L_∞ and K and essential for the comparison of growth parameters among species or analyses was estimated using the formula: $phi' = \log_{10}K + 2\log_{10} L_\infty$

Total mortality (Z) was deduced from the length "converted catch curves" derived by Ricker (1975). The assumptions made are that Z is same in all age groups used in the plot, all age groups used in the plot were recruited with the same, small and random abundance fluctuations, all age groups used in the plot are equally vulnerable to the fishing gear (s) used for fishing and the sample used is large and lengths cover enough age groups to effectively represent the average population structure for the fishing period.

Using L_∞, total mortality, was also estimated as: $Z = K*(L_{inf} * L_{mean}) / (L_{mean} * L_c)$, where L_{mean} is the mean length of all fishes caught at sizes equal or larger than L_c which is the smallest size in the catch in the life history Fishbase tool. Both L_{mean} and L_c were estimated from length-frequency data using the LBI tool in TropFishR. Exploitation ratio (E), a fraction of the number caught versus the total number of individuals dying as a result of fishing and other causes (Pauly, 1984), set at E = 0.5 as the default (Gullad, 1971). Exploitation rate was calculated from mortality rates as: $E = F / (F+M)$; where M is the natural mortality rate and F the rate of fishing mortality.

Then the F and E estimates were compared with those at maximum sustainable yield (F_{msy}, E_{msy}) estimated from L_c in Fishbase. However, E_{msy} tends to be unrealistically high especially for small fishes with high natural mortality, necessitating the use of another value which is slightly lower than E_{msy}, which is the exploitation giving the highest yield (E_{opt}). The exploitation giving the highest yield, E_{opt} corresponds to a point on the yield-per-recruit curve where the slope is $1/10^{th}$ of the value at the origin of the curve.

Natural mortality (M), the instantaneous rate at which juveniles and adults die due to other causes other than fishing, was computed by the equation: $M = -0.0152 - 0.279 \ln L\infty + 0.6543 \ln K + 0.463 \ln T$ (Pauly, 1980), where, L_∞ and K are growth parameters and T is the annual mean water temperature in which the stocks live. Fishing mortality (F) was calculated by subtracting natural mortality from total mortality, $F = Z - M$ (Beverton and Holt, 1956).

Conservation indicators

Conservation indicator points for *P. barberinus* fishery were estimated using the length-based indicator (LBI) tool in TropfishR and compared with the reference indicator reference points to assess the status of the fishery. Length based indicators provide information reflecting the conservation of large, mature fish with high fecundity (mega-spawners), and immature individuals and provide a size at which highest yield (MSY) is expected. These metrics are indicators of how the stock is performing in terms of yield optimization and conservation goals. The LBIs estimated were length at first capture (L_c), the average length of the first 25% of the catches ($L_{25\%}$), mean length of largest 5% of the catches ($L_{max5\%}$), optimal length (L_{opt}), mean length of largest 5% of the catches ($L_{max5\%}$), optimal length (L_{opt}), mean length of individuals with lengths greater than Lc (L_{mean}), length class with maximum biomass in the catch (L_{maxy}), length at which fishing mortality (F) equals natural mortality ($L_{F=M}$) and 95^{th} percentile of the lengths ($L_{95\%}$). Then the indicators relative to their reference points were used to derive the stock status of the fishery.

To assess whether the conservation of large individuals was achieved, the following expressions were employed: $L_{max5\%} / L_{inf}$, $L_{95\%} / L_{inf}$, and L_{opt} + 10% (P_{mega}). On the other hand, the conservation of immature *P. barberinus* individuals was assessed using the following formulae: $L_{25\%} / L_{mat}$ and L_c / L_{mat}. To establish whether optimal yield was achieved during the fishery calculated using the following expressions were used; L_{mean} / L_{opt} and L_{maxy} / L_{opt}. Lastly, the sustainability (MSY) of *P. barberinus* fishery during the fishing period was assessed from the following expression: $L_{mean} / L_{F=M}$.

The LBI methods assume that the dataset is representative of the length distributions of the whole catch, that recruitment and natural mortality, somatic growth and maturation over time were constant within and over all the years of fishing when data was collected, density is independent maturity and somatic growth, that the natural mortality is equal for all length classes, the growth of individuals in length follows the logistic von Bertlanffy growth (VBG) function and that the stock (population) under study is closed (Cope and Punt 2009; ICES, 2018).

Relative yield per recruit (Y'/R) and spawning potential ratio (SPR)

Relative yield-per-recruit was estimated from the mean length at first capture (L_c), L_{inf}, M, K and E (Beverton and Holt, 1964). Spawning potential ratio (SPR), a proportion of the total reproductive production at equilibrium for a given level of fishing mortality divided by the productive production in the unfished state (Goodyear, 1993; Mace and Sissenwine, 1993), was assessed using the length-based spawning potential ratio (LB-SPR) tool in TropFishR package. The tool requires M/K and L_m/L_∞ ratios for the estimation of SPR. The length-frequency data was input in the tool and the target SPR was set at 40% a level considered as a conservative proxy for attaining maximum sustainable yield (Hordyk *et al.,* 2015). Additionally, the lower limit is set at 20%, a point when recruitment rates are compromised (Mace and Sissenwine, 1993; Prince *et al.,* 2015).

Results

Size structure

A total of 1,276 fish were sampled during the 2017- 2023 fishing period and were caught by ten different fishing gears. The gears include basket traps, beach seine, cast net, gill net, hand line, harpoons, ring net, rapala, reef seine and spear gun. Most of the *P. barberinus* individuals representing 68.9% and 14.5% of the total fish sampled were caught by basket traps and gillnet, respectively (Fig. 2). Length at first maturity (L_m) and asymptotic length (L_∞) for *P. barberinus* are 19.2 cm and 32.8 cm, TL (Froese *et al.,* 2017) respectively. Comparatively, the size of most of the *P. barberinus* individuals caught by majority of the gears were greater than L_m. However, majority of the *P. barberinus* individuals had sizes less than L_{inf} (Fig. 2).

Based on the pooled data across the years, 72.6% of the *P. barberinus* individuals were caught between September and January, with the later having the highest proportion accounting for 27.7% of the total fish sampled. Most of the *P. barberinus* caught during all the months had sizes greater than L_m with most of the fish having sizes less than L_{inf} except in December (Fig. 3).

Generally, the mean sizes of the individuals caught was 28.2 ± 7.7 cm, TL, with about 75.4% of the fish caught having sizes greater than L_{50} (23.0 cm, TL). A higher proportion accounting 48.1% of the fish were immature with sizes less than L_{mat}, while few individuals caught had optimal sizes. About 20.9% of the fish caught were mega-spawners and 29.8% of the individuals had the optimal size of capture (Fig. 4).

The annual mean sizes of *P. barberinus* ranged between 25.6 ± 4.1 cm, TL in 2020 and 30.5 ± 1.1 cm, TL in 2022 (Fig. 5). There was no significant variation in the mean size of fish caught during the 2017-2023 fishing period. The small variation in mean sizes is a reflection of the fish size composition in the fishing grounds.

The mean size (mean ± SD, cm) of *P. barberinus* individuals caught by the ten gear types used by the small-scale fishers during the fishing period is shown in Fig. 6. The mean sizes of *P. barberinus* caught using beach seine (a banned gear), cast net, and ring net during the 2017-2023 fishing period were lower than length at first maturity (L_m).

Stock status

Growth parameters

In ELEFAN, the length-frequency data was restructured by scoring the length bins based on their deviation from a moving average (MA)

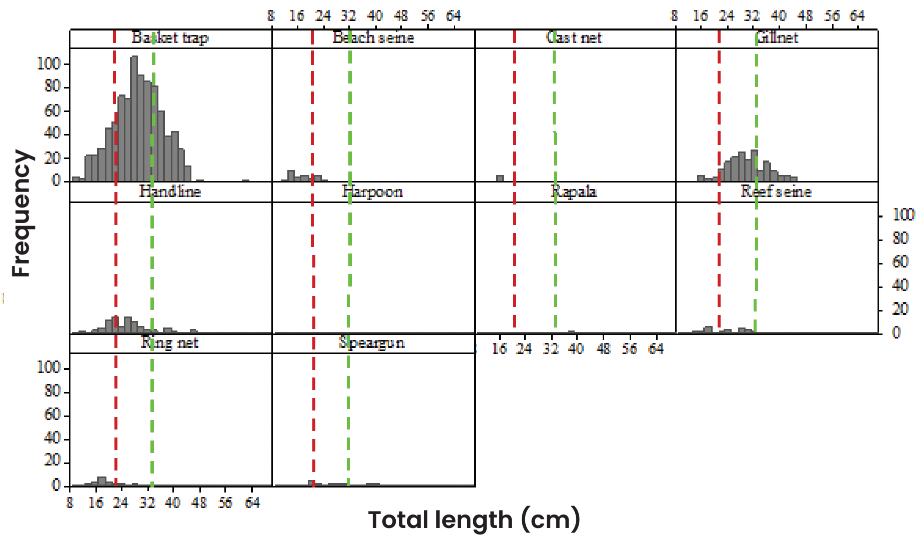

Figure 2. Size composition of the fish caught by basket traps, beach sein, cast nets, gillnet, handline, harpoon, rapala, reef seine, ring net and spear gun during 2017-2023 fishing period (red dashed line= length at first maturity, green-dashed line = asymptotic length).

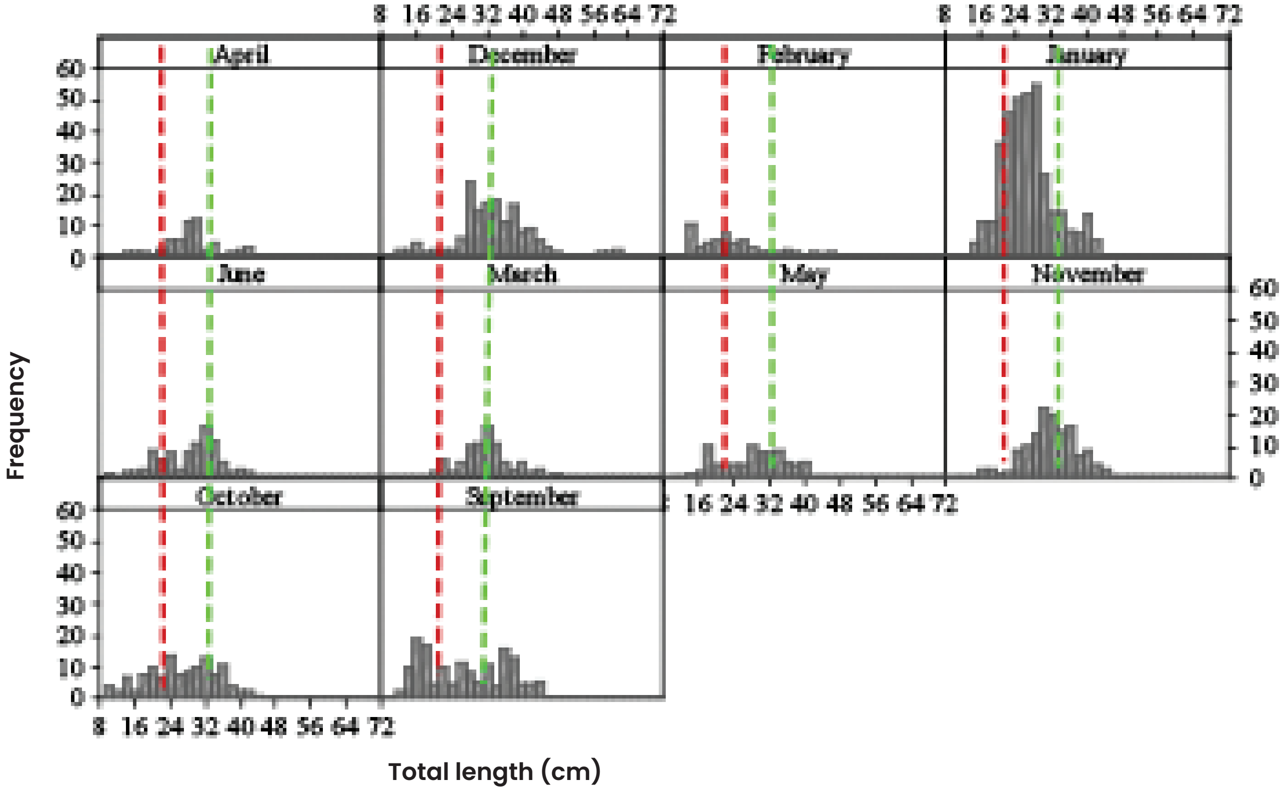

Figure 3. Size composition of the fish caught in different months during 2017-2023 fishing period (red dashed line= length at first maturity, green dashed line = asymptotic length).

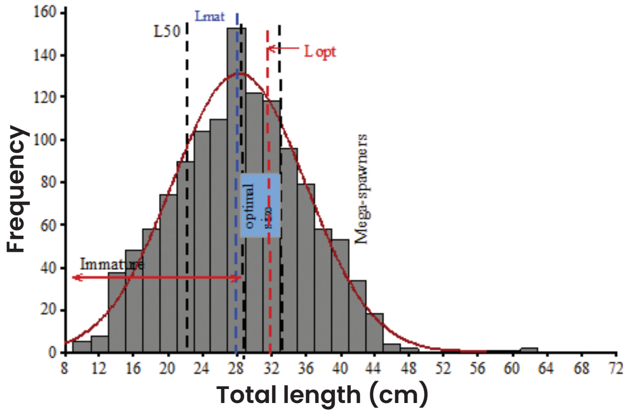

Figure 4. Size structure with the length at first maturity (L_{mat}), optimal length (L_{opt}), L_{50} and optimal size of *P. barberinus* caught during the 2017-2023 fishing period.

across neighboring bins. The improved ELEFAN fit in terms of the average and best score value (fitness value) of the genetic algorithm used in ELEFAN_GA over the number of iterations (generations) is as shown in Annex 1. The estimated von Bertlanffy growth parameters (L_∞, *K*, *ta*), the growth performance coefficient

phi' = log10 *K* + 2 log10 L_∞, and the best score value (*Rn*) are shown in Table 1. The asymptotic length the fish can reach in an unfished situation is 55.5 cm.

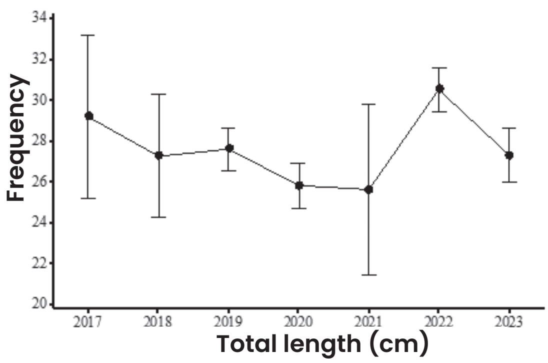

Figure 5. Annual mean size ± standard deviation (SD, cm) of the fish caught during the 2017-2023 fishing period.

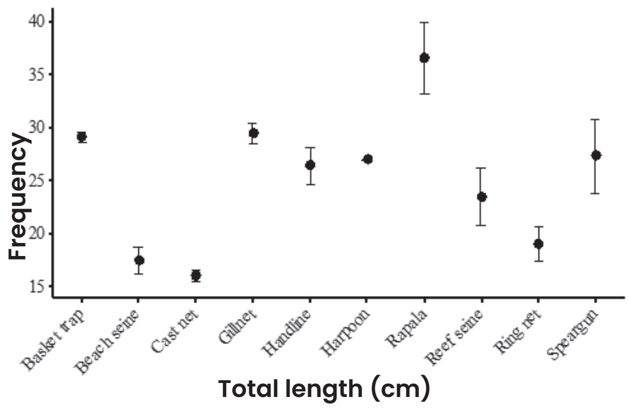

Figure 6. Mean size ± standard deviation (SD, cm) of the fish caught during the 2017-2023 fishing period by gear type.

Table 1. Growth parameters estimates obtained from ELEFAN.

L_{inf}	K	t_a	R_n	*phi'*
55.5	0.606	0.871	3.27	0.234

Mortality and exploitation rates

Estimated fishing mortality (F) was 1.57 $year^{-1}$ representing 67.4% (E =0.674 $year^{-1}$) of the total mortality estimate (Z = 2.33 $year^{-1}$), while natural mortality estimate was 0.759 yr^{-1}. The fishing mortality is concentrated at sizes between 18.0 and 35.0 cm, TL (Fig. 7). Catch per length interval against the relative age is shown in Annex 1.

The estimated current fishing mortality (F = 1.57 $year^{-1}$) is slightly lower than the fishing mortality leading to maximum yield per recruit (F_{max} = 1.62 $year^{-1}$). However, the estimated F was higher than the fishing mortality at which yield per recruit equals 10% of the slope ($F_{0.1}$ =0.71 $year^{-1}$), representing a more conservative reference point than F_{max}. Additionally, the estimated fishing mortality was higher than fishing mortality where biomass equals to 50% of the unexploited biomass ($F_{0.5}$) estimate of 0.54 $year^{-1}$ (Fig. 8 and Table 2).

Table 2. Mortality, exploitation and selectivity estimates for *Parupenues barberinus* fishery.

Z	M	F	E	L_{s50}	L_{s75}	F_{max}	$F_{0.1}$	$F_{0.5}$
2.33	0.759	1.57	0.674	27	30	1.62	0.71	0.54

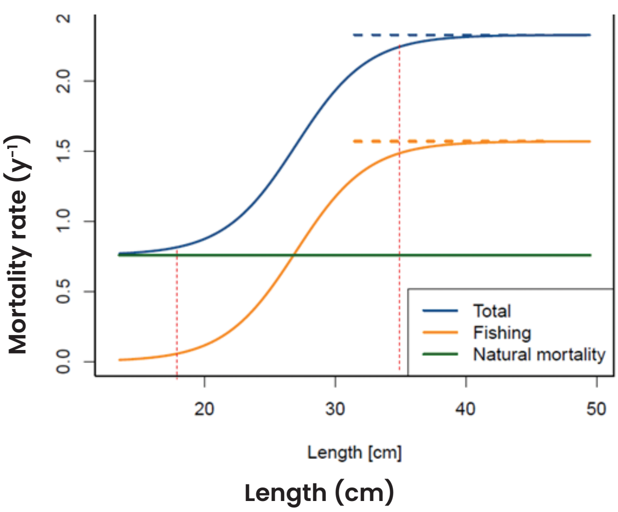

Figure 7. Estimated (total, fishing, and natural) mortality rates by length class (solid lines) and average levels for main exploited length classes (dashed lines).

The exploitation rates estimated from the life history tool are as shown in Table 3. The mortality estimates derived from the life history tool were too low compared to those obtained from the ELEFAN TropFishR tool. On the other hand, the exploitation rate (E = 0.674 $year^{-1}$) was slightly higher than the average exploitation where the maximum sustainable yield can be achieved (E_{MSY} = 0.71 $year^{-1}$) but lower than the exploitation where optimal yield can be achieved (E_{opt} = 0.628 $year^{-1}$).

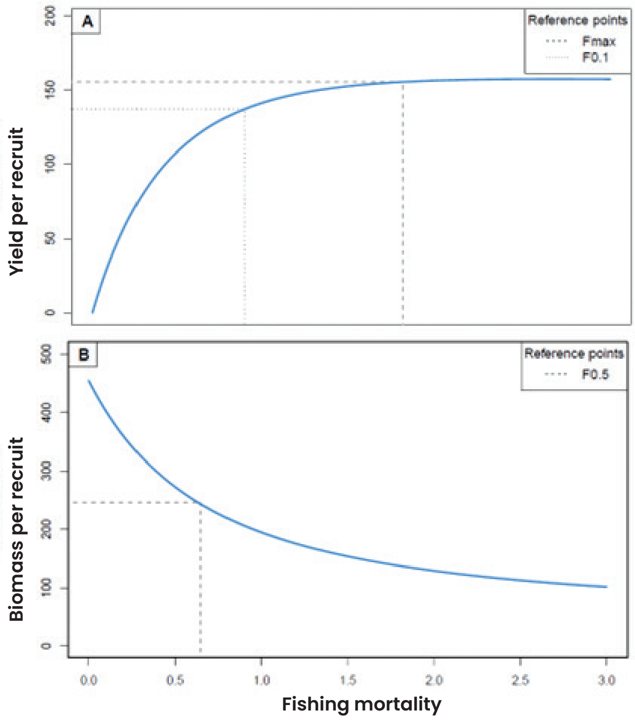

Figure 8. Yield per recruit (panel A) and biomass per recruit (panel B) against fishing mortality rates.

Conservation indicators for the fishery

The estimated LBIs are as represented in Table 4. The estimates varied across the years but L_{opt} was constant at 39.2 cm. The respective length-based estimated indicator ratios indicating the stock status generated as traffic light model is as shown in Table 5 with the green and red colors indicating how the stock performs for different properties. The indicator ratios reflect whether the conservation of large individuals and highly reproductive individuals mega-spawners (P_{mega}) and immature individuals, was achieved. The estimated LBIs for the conservation of large individuals and mega-spawners were below the expected reference values in the all years except in 2018 and 2022 when the $L_{max5\%}$ / L_{inf} was above the target level. The conservation of immature individuals was only achieved in 2022 when the esti-

Table 3. Exploitation and yield per recruit (Y'/R) estimates.

	Exploitation			Y'/R (/year)			
Year	Z	F	E	E_{MSY}	E_{opt}	F_{MSY}	F_{opt}
2018	0.21	-0.02	-0.1	0.65	0.56	0.43	0.3
2019	0.34	0.11	0.32	0.87	0.75	1.54	0.68
2020	0.35	0.12	0.34	0.75	0.66	0.69	0.44
2022	0.24	0.01	0.04	-	0.67	-	1.25
2023	0.17	-0.06	-0.35	0.57	0.5	0.3	0.23
Average	0.262	0.032	0.05	0.71	0.628	0.74	0.58

mated indicator values were above the expected target. The indicator values show that the sizes of fish caught cannot give the optimal yield for the fishery hence the stock is not sustainable (Table 5). Most of the indicator ratios were further from the target values, indicating there is more over-exploitation of the fishery (Fig. 9).

Selectivity and Spawning potential ratio (SPR)

Selectivity of the fishery during the fishing period is shown in Fig. 10. Fish caught in all the years measured less than length at first maturity with about 75% of the fish vulnerable to the fishing gears (caught) having lengths ranging from 20-30 cm. 50% of the catches had sizes less than 25 cm (Fig. 10).

Table 4. Estimated length based indicators (cm) for the years whose data was analyzed.

Year	L_c	$L_{25\%}$	L_{maxy}	$L_{F=M}$	L_{mean}	L_{opt}	$L_{95\%}$	$L_{max5\%}$
2018	19.5	22.5	34.5	29.8	29.5	39.2	43.5	45.1
2019	25.5	25.5	31.5	34.1	31.2	39.2	40.5	41.7
2020	22.5	22.5	28.5	31.9	28.7	39.2	37.5	41.1
2022	28.5	28.5	34.5	36.2	35.3	39.2	43.5	45.3
2023	16.5	22.5	34.5	27.6	29.0	39.2	40.5	43.4

Table 5. Annual length-based indicators (LBIs) relative to specific reference values (in parenthesis) for the conservation of large and immature individuals and obtaining optimal yield and maximum sustainable yield (MSY), (green and red cells indicate value is above or below reference value, respectively).

Conservation of large individuals				Conservation of immature individuals		Optimal yield		MSY
Year	$L_{max5\%}/L_\infty$ (>0.8)	$L_{95\%}/L_\infty$ (>0.8)	P_{mega} (>0.3)	$L_{25\%}/L_{mat}$ (>1)	L_c/L_{mat} (>1)	L_{mean}/L_{opt} (≈1)	L_{maxy}/L_{opt} (≈1)	$L_{mean}/L_{F=M}$ (≤1)
2018	0.81	0.78	0.07	0.83	0.72	0.75	0.88	0.99
2019	0.75	0.73	0.02	0.94	0.94	0.8	0.8	0.91
2020	0.74	0.68	0.02	0.83	0.83	0.73	0.73	0.9
2022	0.82	0.78	0.1	1.06	1.06	0.9	0.88	0.98
2023	0.78	0.73	0.05	0.83	0.61	0.74	0.88	1.05

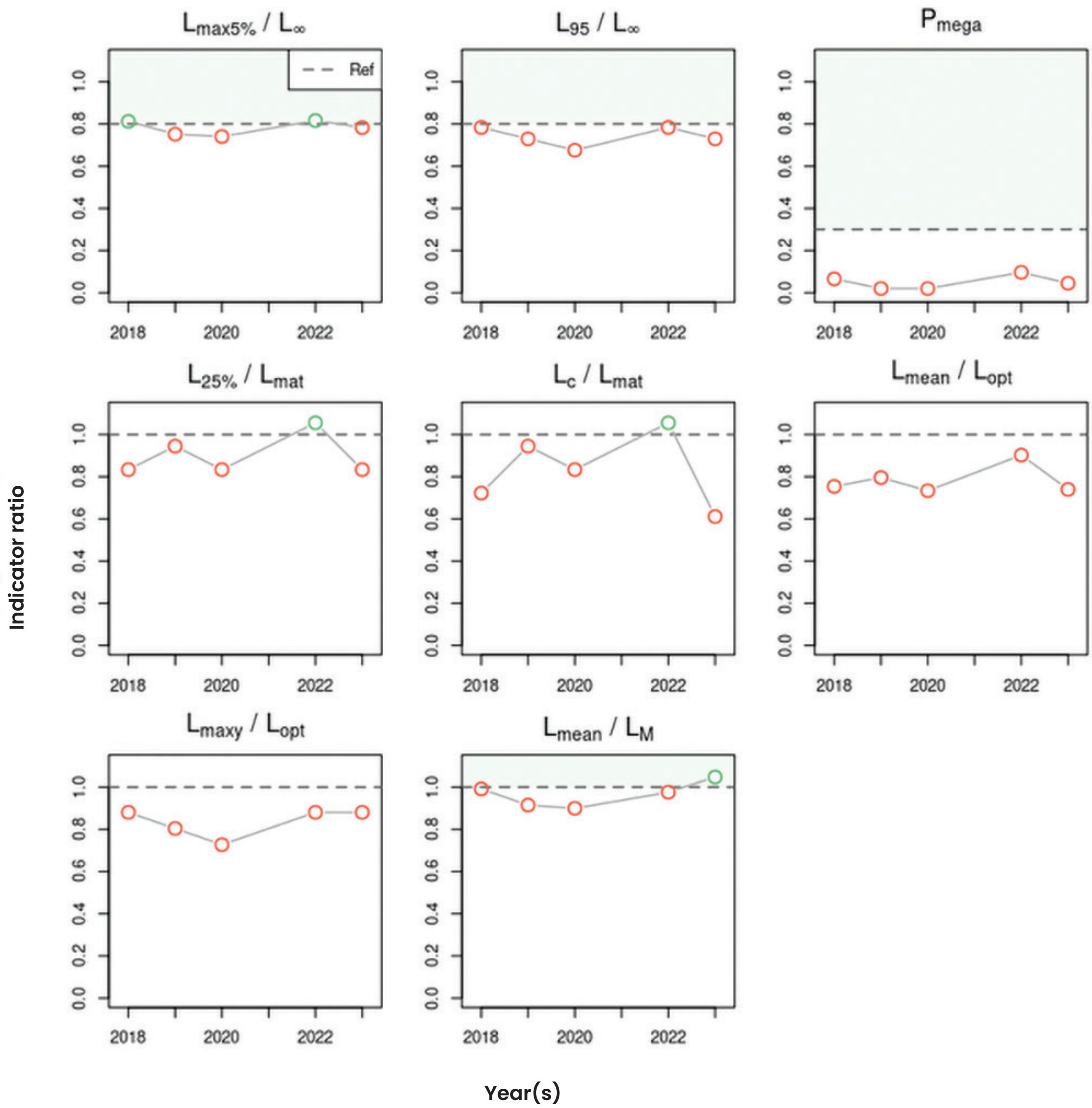

Figure 9. Graphical presentation of the indicator ratios over time, the reference point is represented by a horizontal dashed line. The further the points/lines are from the expected values the more evidence of overfishing, any value above the limit reference point is considered desirable.

The estimated LB-SPR, selectivity parameters (L_{s50} and L_{s95}) and the ratio of fishing relative to natural mortality is shown in Fig. 11. Selectivity at L_{s50} ranged between 19.3 cm in 2018 and 36.64 cm in 2022 while that at L_{s95} ranged between 25.9 cm and 53.7 cm for the same period. The SPR ranged between 10% in 2020 and 24% in 2023, however the target $SPR_{40\%}$ was not reached in all the years of the fishery.

Discussion

This study provides information on the stock status of *P. barberinus* caught by small-scale fishers during the 2017-2023 fishing period. Information provided on size composition, conservation indicators, mortality rates, selectivity and SPR are important for the regulation and management of the *P. barberinus* fishery. Most of the *P. barberinus* caught were immature and very few had optimal sizes indicating growth overfishing is prominent for the fishery.

The size structure results indicate there are very few mega-spawners and this indicate that older fish have been completely fished due to over-fishing, leading to the occurrence of small sized fish, hence the fishery will not be sustainable in the near future (Mangi and Roberts, 2006). The observed high level of immature *P. barberinus* individuals could be associated with the functional role of the seagrass habitats as a breeding ground, where the artisanal fishers capture fish (Musembi *et al.,* 2019). Additionally, from the LBI assessment estimates, the conservation of mega-spawners was not achieved during the fishing period, indicating the future of *P. barberinus* fishery is at threat of extinction. The immature fish were not conserved as the estimated indicators for the conservation of immature fish were below the expected threshold (>1). This is evident that growth over-fishing is taking place for the fishery. The conservation of immature *P. barberinus* individuals was not achieved during the fishing period. This is an indication that the main gears, i.e. basket traps and gillnets could be capturing immature fish. The length based asymptotic length obtained for this fishery, L_{inf} = 55.5 is lower than the value recorded in Fishbase, Froese *et al.* (2017), justifying the analytical tools and methodology used in this study.

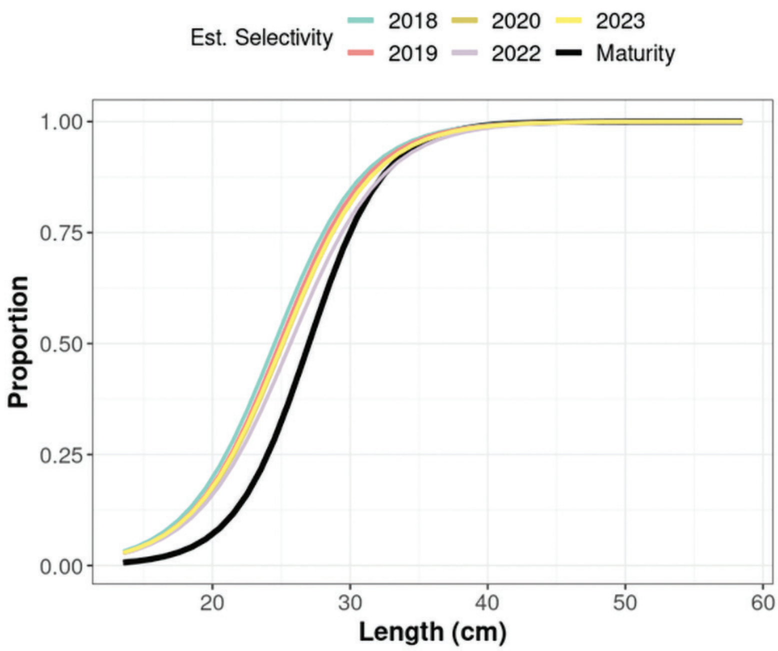

Figure 10. Estimated selectivity (coloured lines) and provided maturity (black line), curves indicate the proportion of the stock vulnerable to the gear (y-axis) at a given length (x-axis).

In any fishery which is optimally fished, the fishing mortality equals or closely approaches natural mortality, (E = 0.5 year^{-1}). The estimated current exploitation rate (E =0.674 year^{-1}) is much higher than the threshold value (E = 0.5 year^{-1}), an indication overex-

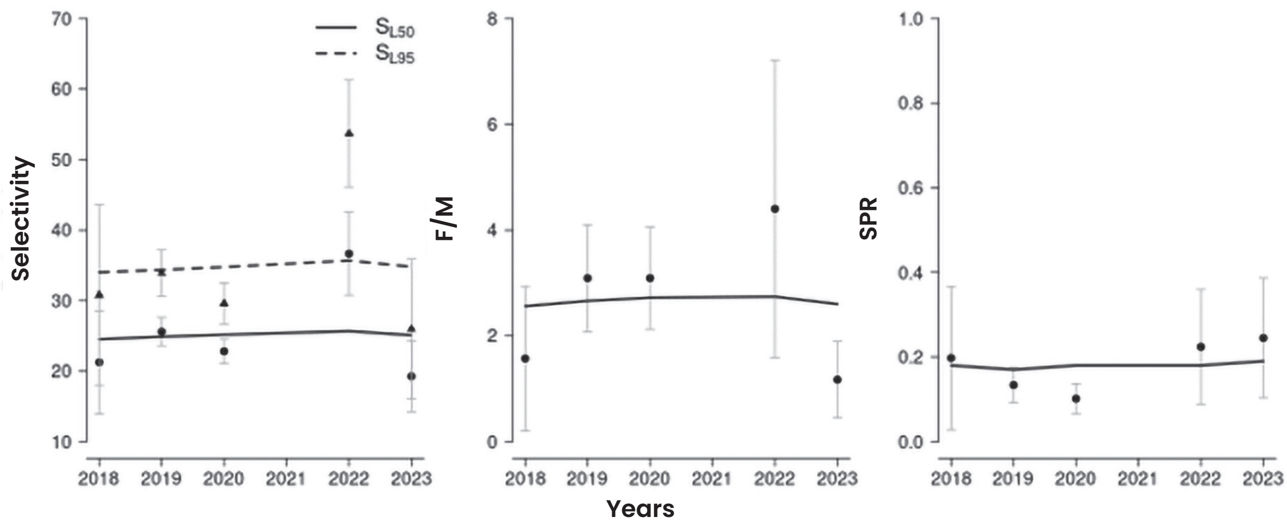

Figure 11. Annual selectivity parameters, fishing mortality relative to natural mortality and spawning potential ratio (SPR).

ploitation. However, the fact that the fishery was exploited using different gears with varying selectivity and sampling was not uniform across gears may influence the exploitation estimates (Tuda 2019).

The estimated fishing mortality relative to the fishing mortality estimate where biomass equals to 50% of the unexploited biomass ($F/F_{0.5}$ = 2.51 year^{-1}) and that of F/F_{max} was 0.969 indicating high fishing pressure on the *P. barberinus* fishery which may lead to a reduction in the population size and size at first maturity (Froese and Binohlan, 2000).

Selectivity results indicate the fishery capture immature individuals, an indication of unsustainability. The increased selectivity length in 2022 compared to other years could be due to improved monitoring and surveillance or as a result of high level of compliance to the gear restrictions in place during this period. The estimated F to M ratio was exceptionally higher SPR estimates indicating the exploitation rate does not have effect on the stock status os *P. barberinus*. The LB-SPR estimates of less than the reference limit (20%) and not reaching the target reference (40%) indicate the fishery is experiencing both growth and recruitment overfishing.

Conclusion and recommendations

This study describes the stock status of *P. barberinus* exploited by artisanal fishers in the Kenya marine waters, providing information on size structure, growth parameters, mortality and exploitation rates and assessment on the conservation of the fishery for its sustainability. The findings form a preliminary baseline of the fishery as there is no prior stock status study conducted for the specific fishery.

The results obtained were based on data not consistently collected, hence using data-poor methods to assess the status of the fishery. There is a need therefore, for data collection consistently over a long period to allow for the application of other assessment methods and comparison of the results. Beach seine and spear gun, which are banned gears, are still used in the *P. barberinus* fishery, where the mean sizes of individuals caught is lower than L_m. Additionally, the estimated LBIs for the conservation of immature individuals were not achieved for most of the years, indicating that immature fish are caught during the artisanal fishing. Therefore, we recommend management to enforce monitoring and surveillance to ensure illegal gears are not used for the protection of juveniles (Hicks and McClanahan, 2012). There is a need to disseminate findings from this study to the stakeholders for awareness creation to ease the implementation of regulations in place.

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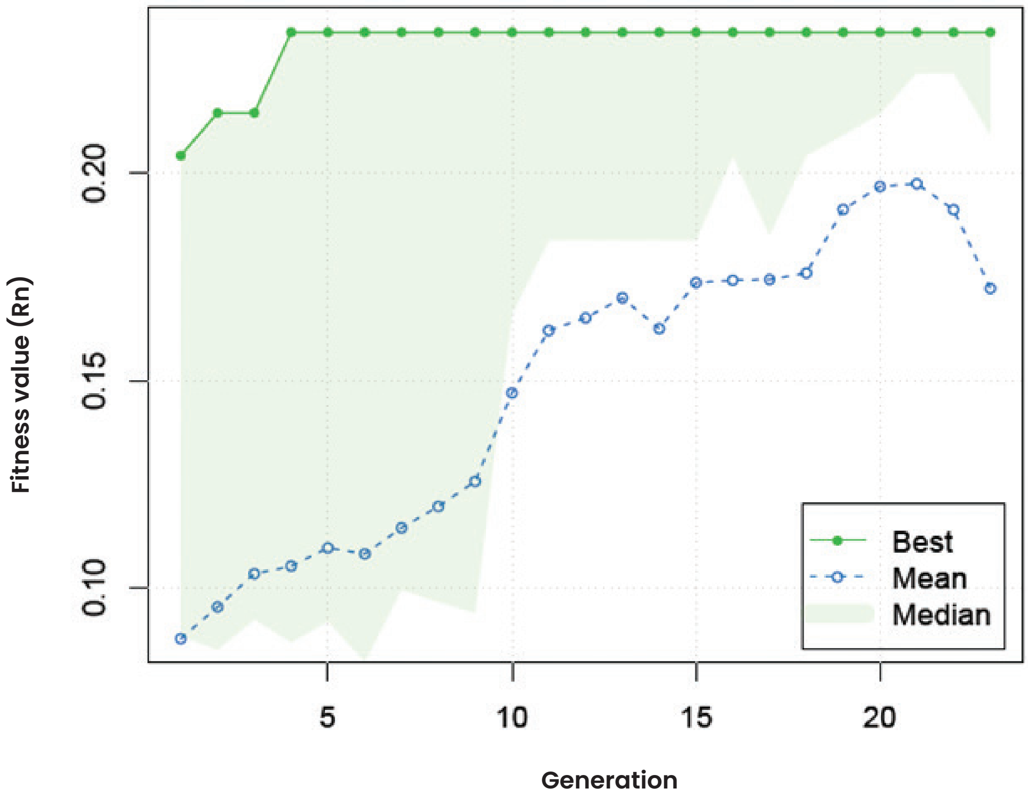
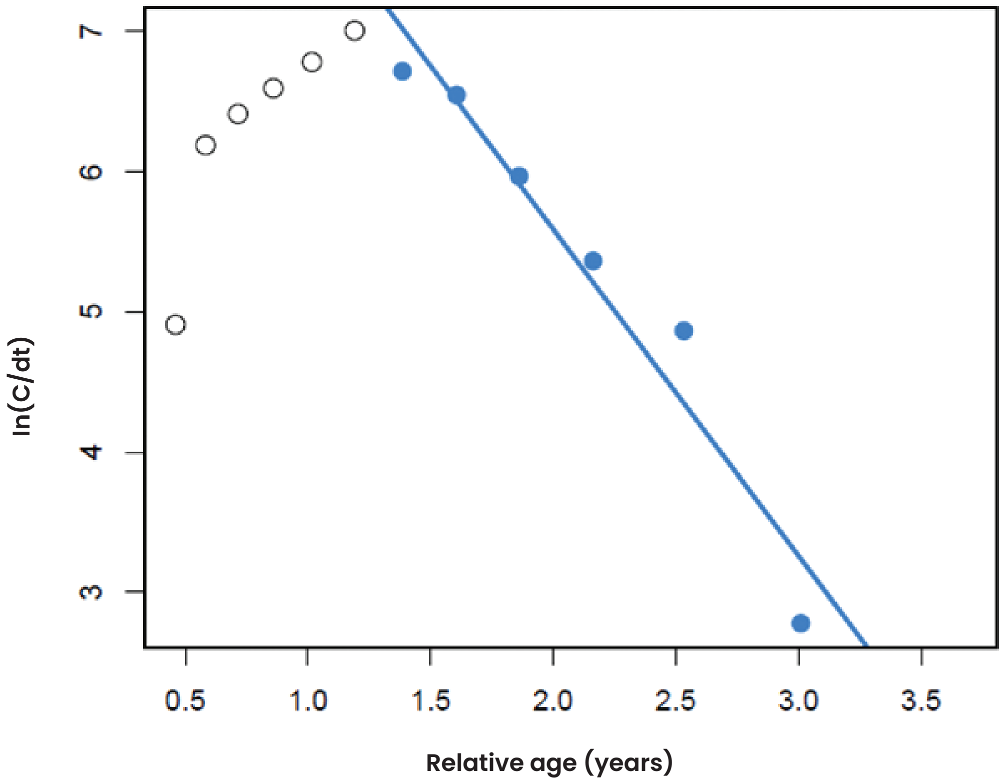


Annex 1. Score graph of ELEFAN with genetic algorithm. Fitness value (y axis) corresponds here to the score value of ELEFAN (Rn) and in the lingo of genetic algorithm 'Generation' (x axis) refers to the iteration.



Annex 2. Logarithm of catch per length interval against relative age. Blue points correspond to points used in the regression analysis (blue line) of the catch curve for the estimation of total mortality (Z), which corresponds to the slope of the displayed regression line.