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Original Article

Demographics of threatened Malabar mahseer, *Tor malabaricus* in a small-scale fisheries of Western Ghats hot spot in India

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Abstract: The Western Ghats region of India, a segment of the Western Ghats-Sril Lanka biodiversity hotspot, is renowned for its abundant fish diversity and endemism. *Tor malabaricus*, commonly known as Malabar mahseer, is a large growing, threatened cyprinid having restricted distribution in fast-flowing streams of the southern region of the Western Ghats. The absence of demographic and exploitation data regarding threatened freshwater fish in this region is a barrier to sustainably managing and conserving the species. This study focused on assessing the growth patterns, mortality rates, and the extent of exploitation faced by the Malabar mahseer from a small-scale fishery in Chalakudy River, WG, India, with the help of tribal fishers. The growth parameters for *T. malabaricus* were estimated as asymptotic length ($L\infty$) = 657.3 mm and growth rate (K) = 0.19 year^{-1}. The study revealed a potential longevity (t_{max}) of 15.78 years and a length at first capture (L_c) of 201.54 mm. The fishing mortality (F= 0.26 year^{-1}) of *T. malabaricus* was observed to exceed the natural mortality (M = 0.23 year^{-1}), indicating an unsustainable level of exploitation for the species within the study area. The current exploitation rate (E = 0.53) exceeding the E_{50} threshold indicates a potentially uncertain future for the stock under the current level of exploitation. Employing an integrative conservation approach such as fishing closures during spawning seasons, mesh size regulations, and establishing quota systems for local tribes and fishermen for fishing can effectively promote sustainable harvesting practices for the species within the Western Ghats hotspot.

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Introduction

The Western Ghats (part of the Western Ghats-Sri Lanka biodiversity hotspot), extending along the west coast of India, constitute a mountain range that stretches over 1600 km and covers an area of 180,000 km^2 (Divya et al., 2020). This mountain chain has been categorized into four distinct phytogeographic subregions, aligning with specific areas: the northern Western Ghats (from the Tapi River to Goa), the central Western Ghats (stretching from the Kali River to Coorg), the Nilgiris, and the southern Western Ghats covering the Anamalai, Palani, and Cardamom hills (Subramanyam and Nayar, 1974; Bharthi et al., 2021). The Western Ghats is one of the 36 globally recognized biodiversity hotspots and one of the four on the Indian subcontinent (Divya et al., 2020). Despite covering less than 6% of India's land area, the Western Ghats harbor nearly 30% of the country's biodiversity (Divya et al., 2020). This region is home to many endemic and threatened species, emphasizing its immense ecological importance and conservation significance (CEPF, 2016).

The freshwater ecosystems originating and flowing through the southern WG ecoregion in Southern India are home to 57 threatened fish species (Raghavan et al., 2013). These fish species are directly connected to the livelihoods of tribes and forest-dwelling communities in the area, serving as a food source and contributing to income generation (Raghavan et al., 2011). The increasing demand has driven the indiscriminate exploitation of threatened and endemic fish species, primarily through artisanal and open-access fisheries (Raghavan et al., 2011). This, coupled with a complex array of anthropogenic pressures like

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water pollution, habitat destruction, and the invasion of alien fish species, has significantly contributed to the decline in their populations (Renjithkumar et al., 2020a; Shanmughan et al., 2021).

Mahseers, belonging to the Cyprinidae family, are an iconic group of freshwater fishes distributed in Southeast Asia (Pinder et al., 2019) and globally praised as sport and table fish. They are classified as rheophilic or "flow-loving" fishes, showing a preference for habitats with cold, clear water and a substrate featuring stony, pebbly, and rocky bottoms. These specific environmental conditions are integral to their habitat selection and survival (Ng, 2004). Taxonomically, mahseers are categorized under three genera: *Naziritor, Neolissochilus*, and *Tor*. Among these, the genus *Tor*, considered the ‘true mahseer,’ consists of 16 species (Pinder et al., 2019). *Tor* species exhibit distinct potamodromous behaviours, specifically upstream spawning migrations essential to facilitate successful reproduction (Shrestha, 1997; Nautiyal et al., 2001, 2008). The high nutritional value of *Tor* mahseer and their ability to provide food security in regions with high poverty levels leads to their high exploitation (Pinder et al., 2019). In recent years, constructing numerous reservoirs and other human-induced activities, including invading alien fish species, has imposed unprecedented population pressures on *Tor* mahseer species. (Dudgeon, 2011; Grumbine and Pandit, 2013). Despite their status as one of the most endangered freshwater fish groups in the Western Ghats, significant knowledge gaps remain regarding their life-history traits (Renjithkumar et al., 2020b).

Tor malabaricus (Jerdon, 1849), commonly known as ‘Malabar mahseer,’ is a large-growing *Tor* species endemic to the Western Ghats river systems of Karnataka, Kerala, and Tamil Nadu states (Pinder et al., 2019). It prefers mainly deep pools in fast-flowing streams with rocky substrates (Arunachalam et al., 2000). Adult fishes play a significant role in contributing to the food supply of tribal communities, whereas the young ones are traded as aquarium pets (Raghavan and Ali, 2013). In the Chalakudy and Chaliyar rivers of Kerala state, *T. malabaricus* are known to coexist with introduced populations of *T. khudree* (Raghavan and Ali, 2013; Ambili et al., 2014). The population of *T. malabaricus* is declining due to anthropogenic stressors in their habitats, including habitat loss due to hydropower dams and reservoirs, pollution from multiple sources, biological invasions, destructive fishing practices, and sand mining; the species has been assessed as Endangered as per IUCN criteria (Pinder et al., 2019).

The lack of scientific evidence regarding the stock status of mahseer species is primarily attributed to various factors. These include remoteness of fishing areas, lack of manpower for monitoring fish landings, and the complex jurisdictional control over freshwater fishing sites within the Western Ghats such as some fishing sites are under the authority of the Forest and Wildlife Department, Department of Irrigation and Department of Electricity (Rajeev et al., 2011). The most dependable approach to gathering fish catch data involves collaborating with local tribes and forest-dwelling communities in these regions. Hence, this paper adopts a participatory approach to evaluate the demographics and exploitation rates of *T. malabaricus*, exploited in small-scale fisheries. The study utilizes length-frequency data gathered from local fishers in a tropical reservoir in Southern peninsular India. The significance of this data lies in its potential contribution to future conservation and management strategies for the species.

Materials and Methods

Study area and fish sampling: This study was carried out at Poringalkuthu Reservoir, situated upstream of River Chalakudy (10°10’0” and 10°33’30”N and 76°17’0” and 77°4’0” E) originating from Southern Western Ghats (SWG) of India. The reservoir has an area of 285 ha and was built in 1957 by the Kerala State Electricity Board (KSEB), Government of Kerala, to facilitate hydroelectric power production and support irrigation activities. Small-scale fishery activities conducted in the reservoir have reported a total of 11 fish species, including two alien species (Roshni et al., 2016).

244 specimens of *T. malabaricus* ranging from

153-635 mm were collected monthly from Poringalkuthu Reservoir, Chalakudy River, from April 2019 to March 2020 from tribal fishers. The local tribes in this area use gill nets ranging from 20 to 80 mm and hook and lines as their primary fishing methods. After collection, the total length (TL) was measured using a digital vernier caliper with precision up to the nearest millimetre (0.01mm), and total body weight (BW) was recorded using a digital weighting balance with an accuracy of up to the nearest gram (0.01 gr).

Data analyses: 244 samples were utilized to examine the demographics of *T. malabaricus* and the data were organized into a length frequency table featuring 25 mm class intervals. Length-frequency distributions were employed to examine growth patterns, mortality rates, and the level of exploitation. The growth of *T. malabaricus* was represented using the von Bertalanffy growth function (VBGF) (von Bertalanffy, 1938) formula:

$$L_t = L_\infty\ [1-\exp^{-K(t-t_0)}]$$

Where L_t is the expected or mean length at age t, L_∞ is the asymptotic length, K is the growth coefficient, t is the age of fish, and t_0 is the theoretical age at length zero.

The Electronic Length Frequency Analysis I (ELEFAN I) routines integrated into the FAO-ICLARM Stock Assessment Tools II (FiSAT II) software were used to fit growth curves to the restructured length-frequency data (Gayanilo et al., 2005). t_0 were determined using the empirical equation (Pauly, 1984) using the formula of $\log_{10}(-t_0) = -0.3922-0.275 \log_{10} L_\infty -1.038 \log_{10} k$.

The growth performance index was calculated based on (Pauly and Munro, 1984) using the formula of $\phi = \text{Log}_{10}\ k + 2\text{Log}_{10}\ L\infty$. The potential longevity (t_{max}- $3/K$) was computed using the empirical equations of Pauly (1984). The length-converted catch curve was utilized to calculate the total mortality (Z) (Pauly, 1984). Natural mortality (M) was determined using Pauly's empirical equation, designed explicitly for tropical fishes as follows: $\text{Log10}\ M= 0.0066-0.279 \log 10\ L_\infty + 0.6543 \log 10\ K+0.4634 \log 10\ T$, where, L_∞ is the asymptotic length in mm, K is the growth constant in year^{-1} and T is the average annual temperature (23°C of the current study area) (Pauly, 1980).

Fishing mortality (F) was derived by subtracting the natural mortality (M) from the total mortality (Z) ($F=Z-M$). The current level of exploitation rate (E) was obtained from F/Z (Gulland, 1970). The length at first capture (Lc) was estimated using the length-converted catch curve method applied to the length frequency dataset (Pauly, 1984). The recruitment pattern offers insights into the frequency of pulses per year and the comparative strength of each pulse. It was established by reconstructing the recruitment pulses from a time series of length-frequency data (Gayanilo et al., 2005). Growth and mortality parameters were employed in modelling virtual population analysis (VPA) to estimate the species' exploitation level. The relative yield per recruit (Y/R) and relative biomass per recruit (B/R) analysis were estimated using knife selected method, which helps to understand whether populations are overexploited (E_{max} exploitation rate with maximum yield) and E_{50} (exploitation that retains 50% of the biomass) (Beverton and Holt, 1966).

Results

The sampled population of *T. malabaricus* from Poringalkuthu Reservoir represents the individuals in the 153-635 mm size range. The frequency distribution of different length-class across months indicated the occurrence of the smallest individual in June and the largest individual in May. The asymptotic length (L_∞) and growth coefficient (K) (growth parameters) were estimated as 657.3 mm and 0.19 yr^{-1}, respectively (Table 1). The growth performance index (ϕ) and the life span (t_{max}) were estimated as 4.91 and 15.78 years, respectively. The growth curve showed that the population of *T. malabaricus* comprised a single cohort from April to May (Fig. 1).

The total mortality (Z), natural mortality (M), and fishing mortality (F) were 0.49 yr^{-1}, 0.23 yr^{-1} and 0.26 yr^{-1}, respectively based on length converted catch curve analysis (Fig. 2). The estimated length values for *T. malabaricus* capture probabilities of 25% (L_{25}),

Table 1. Growth and mortality parameters of *Tor malabaricus* from Poringalkuthu Reservoir, Chalakudy River, India.

Population parameter	Value
Asymptotic length (L_∞, mm)	657.3
Growth coefficient (K; year^{-1})	0.19
Growth performance index (ϕ)	4.91
Longevity (t_{max}; years)	15.78
Total mortality rate (Z)	0.49
Natural mortality rate (M)	0.23
Fishing mortality rate (F)	0.26
Length at first capture (Lc; mm)	201.54
Annual exploitation (E)	0.53
E_{50}	0.45
E_{max}	1.00

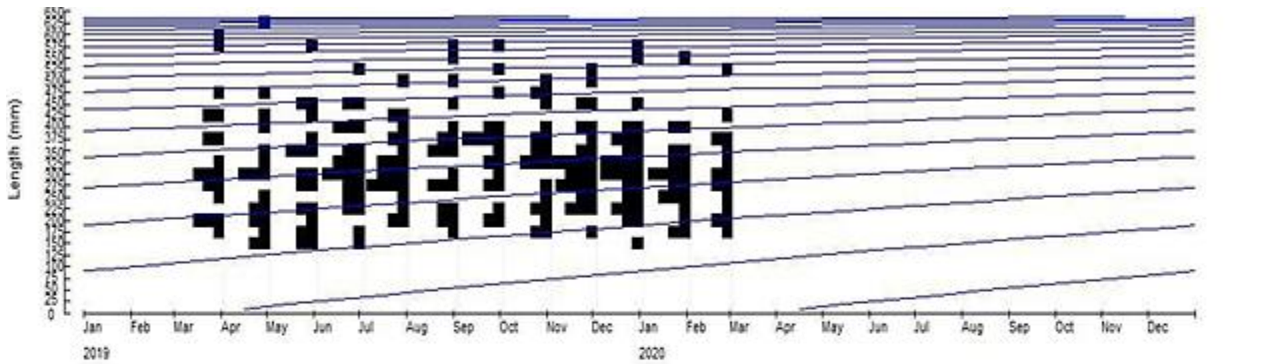

Figure 1. Growth curves fitted by ELEFAN I to length-frequency of *Tor malabaricus* from Poringalkuthu Reservoir, Chalakudy River, India, where peaks or positive points (black bars) and trough or negative points (white bars) are shown. The points were computed and used to identify the growth curve which passes through the largest number of positive points by avoiding negative points.

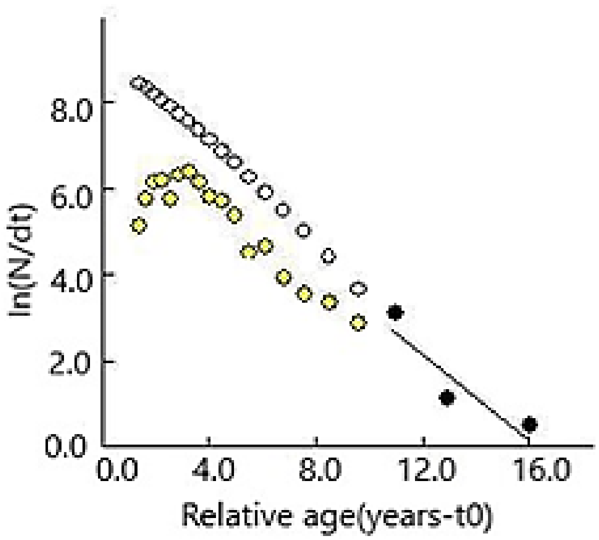

Figure 2. Length converted catch curve for the estimation of mortality of *Tor malabaricus* from Poringalkuthu Reservoir, Chalakudy River, India (Regression line is based on dark circles, the yellow circle is excluded point and the empty circle is extrapolated point; Black dots were used for total mortality (Z) calculation (i.e. the slope) using least squares line regression. The empty circle dots represent the fish that would have been caught if fully recruited. The yellow dots are the not fully recruited points discarded from the calculation)

50% (L_{50}) and 75% (L_{75}) were 164.12, 201.54 and 252.06 mm, respectively. Virtual population analysis (VPA) indicated that high natural mortality was noticed up to 275 mm for the species, though the fishery principally targeted comparatively larger-sized individuals (>276 mm) (Fig. 3).

Exploitation levels estimated using relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) analysis using knife-edge selection were found to be 0.43 (E_{50}) and 1.00 (E_{max}), respectively (Fig. 4). The current level of exploitation (E=0.53) was found to be almost 53% of the maximum exploitation (E_{max}). The recruitment pattern of *T. malabaricus* revealed two major recruitment pulses from April to June and October to January. The major peak recorded 14.20% recruitment in October.

Discussions

Freshwater fishes are intricately linked to the livelihoods of local tribes and forest-dwelling

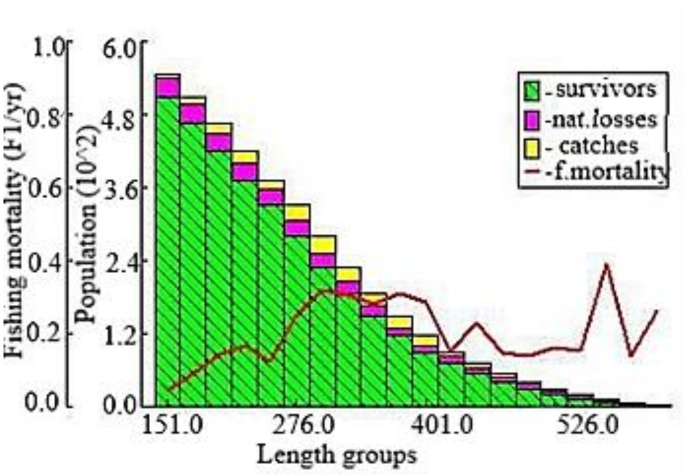

Figure 3. Length-structured virtual population analysis (VPA) of *Tor malabaricus* from Poringalkuthu Reservoir, Chalakudy River, India.

communities living around streams, rivers, and reservoirs of the Western Ghats region of India because they provide a source of food and income generation for local people (Raghavan et al., 2011). Freshwater fisheries in this region are, however, believed to be under increasing pressure due to the "open-access" nature of the fisheries, frequent use of destructive fishing techniques, over-exploitation of resources, and poor enforcement of laws and regulations (Raghavan et al., 2011). Conservation of endemic and threatened fish populations exploited through small-scale fisheries is an important social and biological challenge (Mace and Reynolds, 2001). However, a major research gap exists between the impacts of fishery resource utilization and freshwater biodiversity, which requires critical attention, especially for poorly known freshwater fishes.

Information on the growth, mortality rates, exploitation levels, and the intricate link between these items are required to understand better and effectively manage freshwater fisheries (Raghavan et al., 2013). Only a few studies have focused on the demographic pattern of freshwater fishes exploited from small-scale fisheries of the Western Ghats regions of India (Raghavan et al., 2011, 2018; Prasad et al., 2012; Renjithkumar et al., 2020b; Shanmughan et al., 2021). In this regard, a detailed investigation of the population dynamics of threatened fish species exploited from the Western Ghats region is an

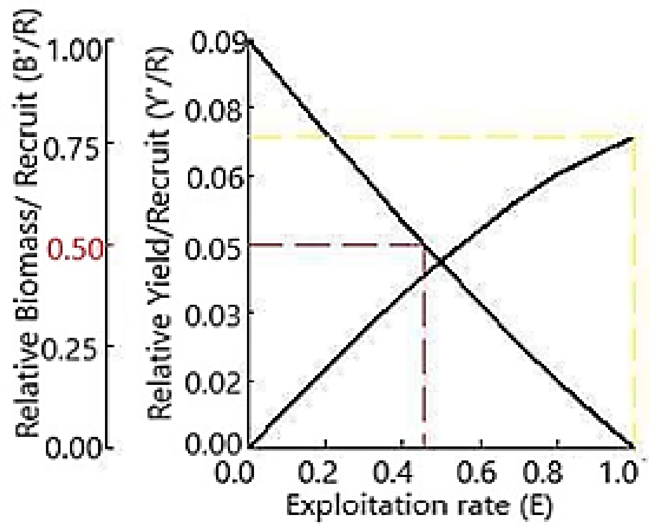

Figure 4. Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) plots of *Tor malabaricus* from Poringalkuthu Reservoir, Chalakudy River, India (Emax -maximum yield per recruit, E10- exploitation that retains 10% of the biomass, E50 -exploitation that retains 50% of the biomass).

important aspect of their conservation and management. The present study provides the first information on the population dynamics of Malabar mahseer, *T. malabaricus*, and highlights the need for conservation action for this threatened species.

The present study extends the maximum length of malabar mahseer to 635 mm from the previously recorded value of 530 mm by Renjithkumar et al. (2022). In natural ecosystems (rivers and reservoirs), Mahseer is highly endangered, experiencing a rapid and alarming decline in its population. In the absence of published information on the demographic pattern of *T. malabaricus*, our results have been compared with those of other Mahseer species occurring in India. *Tor malabaricus* has a higher growth coefficient (K = 0.19) and lower asymptotic length ($L\infty$ = 657.3 mm) compared to its congener Deccan mahseer, *T. khudree* (K = 0.12 and $L\infty$ = 1202.25 mm) (Raghavan et al., 2011) in the Chalakduy river system of Kerala state. Tor *malabaricus* has a higher growth coefficient and lower asymptotic length compared to the Golden/Himalayan Mahseer, *Tor putitora* (K = 0.035-0.041; mean of 0.038) ($L\infty$ = 2160-2720 mm; mean of 2440 mm), and a lower growth coefficient and a lower asymptotic length compared to the Tor Mahseer, *Tor tor* (K = 0.50-0.78; mean of 0.64) ($L\infty$ =

787–946 mm; mean of 866.5 mm) (Nautiyal et al., 2008). The lower growth coefficient (*K*) value indicated that *T. malabaricus* attained asymptotic length (L_∞) slowly, which is in agreement with Pauly and Munro (1984), that species having high life span have low '*K*' value and reach their $L\infty$ slowly.

The total mortality rate of *T. malabaricus* (Z=0.49 years^{-1}) is lower than that of *T. khudree* (Z=0.35-0.95 year^{-1}; mean of 0.67 years^{-1}) in Chalakudy River. However, *T. malabaricus* has a comparable total mortality rate to *T. putitora* (Z = 0.366-0.58 years^{-1}; mean of 0.473 years^{-1}), but lower than that of *T. tor* (Z = 4.08–5.57 years^{-1}; mean of 4.825 years^{-1}) (Nautiyal et al., 2008). *Tor malabaricus* has a comparable natural mortality rate (M = 0.23 years^{-1}) to *T. khudree* (M = 0.15-0.27 years^{-1}; mean of 0.22 years^{-1}) (Ragavan et al., 2011) but lower than that of *T. putitora* (F = 0.312–0.517 years^{-1}; mean of 0.414 years^{-1}) (Nautiyal et al., 2008).

The fishing mortality of *T. malabaricus* exceeded the natural mortality, suggesting that this species is undergoing fishing pressure. Information about the mortality rate of fish species is vital in developing strategies to responsibly harvest and manage fishery resources at their most efficient and sustainable levels. A ratio between total mortality and growth coefficient (*Z/K*) of < 1.0 indicates a growth-dominated population, whereas a ratio of > 1.0 indicates a mortality-dominated population (Etim et al., 1999). The population of *T. malabaricus* in the Chalakudy River was dominated by mortality (Z/K = 2.57). Our findings suggest that the overexploitation of fish could lead to a gradual decline in their recruitment and development, potentially causing a severe reduction in stock in the near future, unless effective management interventions are introduced. The length at first capture (L_c) for the population was estimated to be 201.54 mm. In the absence of published information on any aspects of reproductive biology, it is challenging to determine whether individuals who have not yet reached maturity are being exploited. Capturing individuals only after they have reached a size greater than their first maturity ensures each one can reproduce at least once, contributing to the long-term preservation of the stock (Santos et al., 2024).

Virtual population analysis (VPA) hints there is a high natural mortality in younger individuals (to 275 mm), and a high fishing mortality was noticed from 275 mm length. Such high natural mortality of younger ones could be due to various factors such as predation, disease, pollution, etc (Raghavan et al., 2018). High mortality levels, particularly in immature juveniles, could lead to severe recruitment failure and drive local populations to extinction. The relative *Y'/R* and relative *B'/R* analysis using knife-edge selection of *T. malabaricus* suggest that exploitation rates are E_{50} = 0.45, E_{max} = 1.00. The present level of exploitation (E = 0.53) is almost 53%, which gives the maximum level of exploitation (E_{max} = 1.00) and is higher than E_{50} (0.45), which maintains 50% of the spawning biomass. For the conservation of the species in the study area, it is necessary to maintain at least 50% of the spawning stock and reduce the current level of exploitation from 0.53 to 0.45. For an exploited, optimally utilized fish stock, the rate of fishing mortality (*F*) should be equal to the rate of natural mortality (M), giving an exploitation rate (*E*) of 0.5 (Gulland, 1970). The recruitment pattern of *T. malabaricus* revealed two recruitment peaks from April to June and October to January, indicating two spawning periods per year. The recruitment peaks are observed during rainy periods (Southeast and Northeast monsoon, Kerala state, India). This suggests that the abundance of food during rainy seasons favors the recruitment of juveniles into the population. Detailed investigation of various reproductive characteristics such as maturity stages, spawning season, length at first maturity, and fecundity is suggested.

Tor malabaricus stock in the reservoir is under intense fishing pressure and is at risk of imminent collapse; there is a need for urgent implementation of effective management measures. Implementing regulations on the total harvest could be a crucial management strategy for protecting this fish stocks. A combination of conservation strategies, including mesh size regulation, closed fishing season and areas, awareness programs through videos and booklets, and a quota system for fishing will be the key to managing the *T. malabaricus* fishery in the Western Ghats. To enable juvenile *T. malabaricus* to reach sexual maturity, it is imperative to rigorously enforce a minimum size limit set at above 300 mm. This measure aims to protect and allow the younger individuals to reach the stage of sexual maturity, contributing to the sustainable conservation of the species. Setting up minimum size limits for catch should also implemented with restrictions on the mesh size of the gill nets in the reservoir. There is also a need to prohibit fishing *T. malabaricus* during monsoon seasons in Kerala state when the species is known to breed in the waters of the Western Ghats (per. observe). Educating local tribes and fishers about the current status of this species through informative videos and booklets is vital. Developing catch quotas in consultation with government agencies and fishermen cooperative societies can be an effective approach.

Conclusions

Insufficient data regarding the demographics of many threatened and exploited fish populations poses a significant obstacle in formulating suitable conservation plans for fisheries. *Tor malabaricus* is a slow-growing species with a *K* value of 0.19 and a lengthy life span that may be completing its life cycle of about 15.78 years. Our result suggests that the stock of *T. malabaricus* is vulnerable to overexploitation in subsistence fisheries unless management interventions are implemented. This study serves as a basic resource for scientists and conservation managers, enabling the management and sustainable harvesting not just of this species but also other lesser-known and threatened species in the Western Ghats, which are exploited through unregulated small-scale fisheries.

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