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Research Article

Fishery, Growth, and Mortality of Threatened Asian Sunfish, *Horabagrus brachysoma* (Günther 1864) in Five Rivers of Western Ghats Hotspot, India

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ABSTRACT

Community-based data monitoring (CBM) systems play a vital role in small-scale inland fisheries, offering valuable insights into the catch patterns of various fish species over extended periods. This study adopted a participatory approach to investigate the fishery, demography, and exploitation patterns of the 'Vulnerable' Catfish (*Horabagrus brachysoma*) in five river systems within the Western Ghats biodiversity hotspot of India. The catches of this species from various landing centres across the Western Ghats' rivers varied between 0.73 t to 3.15 t annually. These fish typically measured between 11.00 and 41.10 cm in Total Length (TL) and weighed between 26.00 g to 470.00 g in Total Weight (TW). Analysis of annual length frequency data provided by local fishers, the estimated growth parameters of *H. brachysoma* are estimated as; asymptotic length ($L\infty$) between 316.05 and 421.05 mm, growth coefficient (*K*) between 0.58 yr^{-1} and 1.10 yr^{-1} from different rivers. The total mortality (*Z*) was calculated to range between 1.25 yr^{-1} and 2.91 yr^{-1} while the fishing mortality (*F*) was estimated between 0.62 yr^{-1} and 2.09 yr^{-1}. The estimated fishing mortality rate of *H. brachysoma* in the Periyar River, at 2.09 yr^{-1}, is alarmingly high and among the highest recorded for this species. The calculated exploitation rate (*E*) ranging from 0.49 to 0.72 yr^{-1} exceeds the anticipated optimum exploitation levels (0.5). This suggests that the populations of *H. brachysoma* in the river systems of the Western Ghats are experiencing overexploitation. Various conservation measures such as fishing closures during spawning seasons, restrictions on mesh sizes, non-fishing zones and quota systems should be implemented.

Keywords: Yellow catfish, Western Ghats, Vulnerable, Fishery, mortality, conservation

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INTRODUCTION

According to the Food and Agriculture Organization (FAO, 2010), a staggering 90% of the world's exploited fish stocks remain unassessed, leaving many in the 'uncertain risk' category (Costello et al., 2012). Unassessed fish stocks, often supporting artisanal and subsistence inland fisheries, play a vital role in providing livelihoods and employment opportunities for rural communities, who depend on these resources for their well-being and food security (Lynch et al., 2016; Smith et al., 2005). Inland fish and fisheries are a crucial component of global food security, providing local and affordable sources of essential nutrients, including protein, fatty acids, oils, and micronutrients, to hundreds of millions of people worldwide, particularly in developing countries (Funge-Smith & Bennett, 2019). Inland fisheries are often marked by small-scale, household-level, and subsistence-oriented practices, where fishing is conducted on a local scale to meet the basic needs of the community (Youn et al., 2014). In developing countries, inland fisheries play a vital role in supporting the livelihoods of over 60 million people, serving as a critical source of both food security and income (Cooke et al., 2016). Global inland fisheries face a myriad of threats, posing significant risks to the livelihoods and well-being of millions of people worldwide (Smith et al., 2005). Collecting precise data on inland fisheries production poses challenges due to the dispersed nature of most inland fisheries activities, often leading to underreporting or no reporting at all to government agencies (Allan et al., 2005). Despite the important contributions, inland fish and fisheries generally remain economically and socially undervalued and biologically underappreciated because accurate information about these small scale highly dispersed fisheries is inherently difficult to acquire (Youn et al., 2014).

Effective management of freshwater fish population is crucial for both food security and minimizing biodiversity loss (Tickner et al., 2020). This may be done by the management of exploitation (reduction of bycatch, minimizing fishing effort and size limits regulation), management of fish habitat (river flow regulation and management of aquatic vegetation) and the use of fisheries enhancements (river ranching and use of artificial reefs) (Lorenzen et al., 2016). Fish stock assessment models are invaluable tools for fishery managers providing critical insights into the dynamics of fish population and their response to various external pressures, including commercial fishing, predation and environmental changes (Hilborn et al., 2020; Sun et al., 2020). Accurate data for length-based stock assessments can be obtained through targeted sampling at commercial fish landing sites or fisheries-cruise surveys, eliminating the need for complete removals from the target stock (Shephard et al., 2021). This approach enables researchers to gather essential information on fish populations, such as size distribution and abundance, without causing unnecessary harm to the stock or disrupting the ecosystem, thereby supporting sustainable fisheries management. However, in inland habitats where local knowledge of fishers is essential, researchers and fisheries managers may find it difficult to obtain and validate data for stock assessment (Valbo-Jørgensen & Poulsen, 2000). Community-based data monitoring (CBM) systems offer an alternate approach in such small-scale and artisanal fisheries, which are playing an increasingly important role in sustaining local food supply and food security (Lam et al., 2019; Oviedo & Bursztyn, 2017). Local communities frequently monitor fish catch patterns in their fishing practises throughout the year, and this knowledge can be captured as quantitative indicators (Shephard et al., 2021).

Despite their importance, the growth patterns and exploitation dynamics of threatened freshwater species harvested from the Western Ghats have received limited research attention, with only a few studies addressing these critical aspects (Prasad et al., 2012; Raghavan et al., 2018; Renjithkumar et al., 2020; Shanmughan et al., 2021). The freshwater fisheries of the Western Ghats region in India are inextricably linked to the well-being of local communities residing along rivers and reservoirs because it provides a source of food and livelihood for local community (Prasad et al., 2012; Rajeev et al., 2011). The freshwater fisheries in this region are facing unprecedented threats due to "open-access" nature of the fisheries, the use of destructive fishing gears, overfishing of resources and poor enforcement of rules and regulations (Raghavan et al., 2011). The Asian Sun catfish or the yellow catfish, *Horabagrus brachysoma* (Gu¨nther 1864) belongs to the family Horabagridae and is an important food fish exploited by traditional fishers from rivers, lakes, backwaters, and associated inland canal systems in the Western Ghats region of Kerala, Karnataka, and Maharashtra states (Raghavan et al., 2016). The species is a nocturnal, opportunistic, omnivorous feeder that adapts its diet based on prey availability (Padmakumar et al., 2009; Prasad & Ali, 2008; Sreeraj et al., 2006). Its peak breeding season occurs from June to July, coincides with the south-west monsoon in peninsular India (Bindu et al. 2012; Chandran & Prasad, 2014). It is an important food fish widely harvested across its range by traditional fishers using gill nets operated from dugout canoes, as well as cast nets, drag nets, stake nets, and hook-and-line (Bindu, 2006; Prasad et al., 2012; Sreeraj et al., 2007). The fishery for *H. brachysoma* appears to be unsustainable in many rivers of the Western Ghats due to overexploitation of stock and habitat destruction (Raghavan et al., 2016) and the IUCN has classed the species as 'Vulnerable' due to an overall population drop (Raghavan & Ali, 2013). It has been suggested that without effective management plans, excessive fishing effort and subsequent overexploitation in certain rivers (Prasad et al., 2012; Prasad, 2008) could lead to the collapse of the fishery. Management of the fishery of yellow catfish is hindered due to the lack of successful fisheries management programmes in Kerala's WG waters, where the largest share of exploitation takes place (Prasad et al., 2012). A study on the population dynamics of *H. brachysoma* in the River Periyar suggests several management strategies to protect the species such as restricting gear (minimum mesh size of 160–180 mm for gill nets), enforcing a minimum size limit (200 mm) and implementing closed seasons from May to August. (Prasad et al., 2012). There are no reliable estimates of the *H. brachysoma* fishery, growth, mortality, and exploitation in its native ranges in the Western Ghats except from Prasad et al. (2012) studied the population characteristic of the species from a single river system in Southern India. The current study examines the fishery, growth, and exploitation status of vulnerable *H. brachysoma* exploited from different river systems (Pampa, Achenkovil, Muvattupuzha, Periyar, and Chalakudy Rivers) in the Southern Western Ghats of India.

MATERIALS AND METHODS

Study area

The study was conducted at the major fish landing centres along five major rivers in central Kerala, India: Periyar (244 km), Chalakudy (146 km), Pampa (176 km), Muvattupuzha (121 km), and Achenkovil (128 km) Rivers, which are located in the central region of Kerala state. The five fish landing sites were strategically selected due to the high occurrence of *H. brachysoma* in the daily catches of local fishers. Bhoothanthankettu, Periyar (10°08′12.75″ N; 76°39′51.27″ E); Pulikakadavu, Chalakudy (10°14′28.53″ N; 76°19′50.27″ E); Mulakulam, Muvatupuzha (09°51′15.00″ N; 76°29′19.12″ E); Prayikkara, Achenkovil (09°15′44.04″ N; 76°32′28.72″ E) and Edatuva, Pampa (09°21′53.29″ N; 76°28′35.05″ E) (Fig. 1) were the landing centres selected for the study.

Data collection

For data collection, we selected 10 fishers (two fishers from each of rivers) and provided training in essential fisheries data collection methods. This training covered procedures for measuring and re-

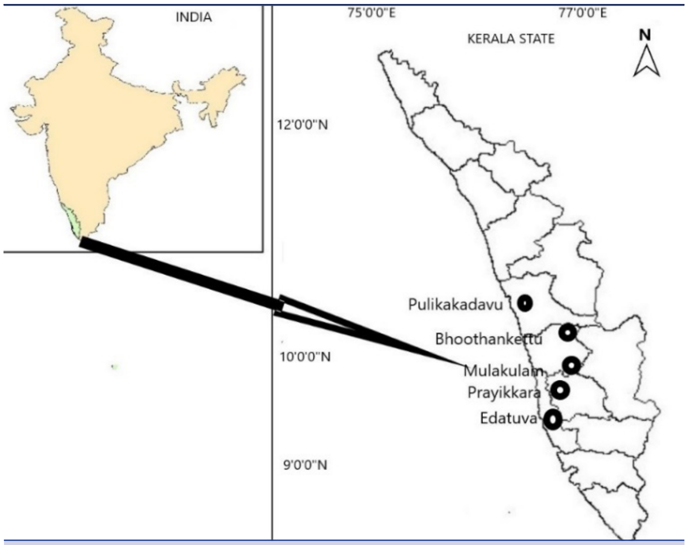

Figure 1. Map showing the landing centre of different rivers of Western Ghats were *H. brachysoma* collected.

cording fish length and weight. Total length (TL) was measured to the nearest 0.1 mm using a digital sliding calliper, and total body weight (BW) was measured to the nearest 0.1 g using an electronic weighted scale. These 10 local fishers served as data assistants for a year (April 2020 to March 2021), providing monthly data on the length and weight of *H. brachysoma* specimens. Monthly catch data of *H. brachysoma* harvested at the five rivers were also recorded with assistance from the data collectors. The total catch (kg) from each haul of gill nets and hook & lines from each river were recorded by the data team. To ensure data accuracy, the authors conducted random monthly visits to each of the five rivers. These visits validated the fishers' data collection techniques, evaluated the quality of data entries and provided technical assistance as needed. At the end of the study, we consolidated the data recorded by the data collectors in datasheets and logbooks.

The primary fishing gears used for catching yellow catfish were gill nets, as well as hook and lines. Gill nets used for fishing typically ranged in length from 75 to 150 metres, with mesh sizes varying from 30 to 60 mm. Daily landings from each type of gears were calculated using the formula: W = (w/n) x N, as described by Kurup et al. (1993), where: W = total weight of fish landed, w = total weight of fish from sampling gear, n = number of gears sampled, N = total number of similar gears operated. The monthly catch was estimated by multiplying daily catch by the total number of fishing days in a month, assumed to be 25 days. To calculate the annual exploited quantity, the monthly landings were summed over a 12-month period, providing a comprehensive estimate of the total annual catch.

1938 samples of *H. brachysoma* were collected from Periyar (n=383), Chalakudy (n=407), Pampa (n=448), Muvatupuzha (n=351), and Achenkovil (n=349) Rivers for demographic analysis. The length frequency data were categorized into 25 mm class intervals.

Growth, mortality and exploitation

Length frequency distributions were used to estimate the growth, mortality and exploitation pattern of *H. brachysoma*. The von Bertalanffy growth function parameters including asymptotic length (L_∞) and growth coefficient (*K*) were estimated with the ELEFAN-1 (electronic length frequency analysis) module in FiSAT-II (FAO-ICLARM Stock Assessment Tools II) software (Gayanilo et al., 2005). The growth parameters were obtained by von Bertalanffy growth formula (VBGF) was fitted using $L_t = L_\infty [1- \exp^{-K(t-t_0)}]$, where L_t is the growth at time 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 age at zero length (t_0) was calculated from Pauly's (1983) equation: $\text{Log}(-t_0) = -0.392 - 0.275 \text{ Log } L_\infty - 1.038\ K$. Longevity ($t_{max}$) of the population was determined as $t_{max}=3/K$ (Pauly 1984), and growth performance index (phi prime,φ) was estimated using the equation $\log K + 2 \log L\infty$ (Moreau et al. 1986). Growth performance equation can be utilized to compare growth rates among species and assess growth performance potential under different environmental stresses (Pauly 1994). Total mortality (*Z*) was estimated from the length-converted catch curve method (Pauly 1984) and natural mortality (*M*) was determined using Pauly (1980) empirical equation: $\ln M = -0.0152 - 0.279 \text{ Log } L_\infty + 0.6543 \log K + 0.463 \text{ Log } T$, where, L_∞ is the asymptotic length in mm, *K* is the growth constant in year^{-1} and *T* is the mean annual temperature (26-30°C). Fishing mortality (*F*) was derived from the equation *F=Z-M* (Ricker 1975) and exploitation rate (*E*) was calculated as *E=F/Z*. The probability of capture was determined by backward extrapolating the descending limb of the length-converted catch curve using the FiSAT II software package (Gayanilo et al., 2005). The probabilities of capture obtained from the catch curve analysis were used to estimate the length at first capture (L_{50}%) through a logit function (Pauly 1984). Recruitment pattern was assessed by reconstructing the recruitment pulses from a time series of length-frequency data (Gayanilo et al., 2005). A length-structured virtual population analysis (VPA) was carried out to estimate survivors, natural mortality and fishing mortality in each length group. The relative yield per recruit (*Y/R*) and relative biomass per recruit (*B/R*) analysis were estimated using knife selected method given by Beverton & Holt (1966), which help to understand whether populations are overexploited, E_{max} (exploitation rate with maximum yield) and E_{50} (exploitation that retains 50% of the biomass).

RESULTS AND DISCUSSION

The annual exploited fishery of *H. brachysoma* from the five rivers of Southern WG was estimated to be 7.17 t. High landing was observed in Pampa River (3.15±0.099 t) and low landing in Muvatupuzha (0.57±0.013 kg) (Fig. 2). Monsoon season (June – September) contributed the bulk of landing (3.26±0.097 t) followed by post

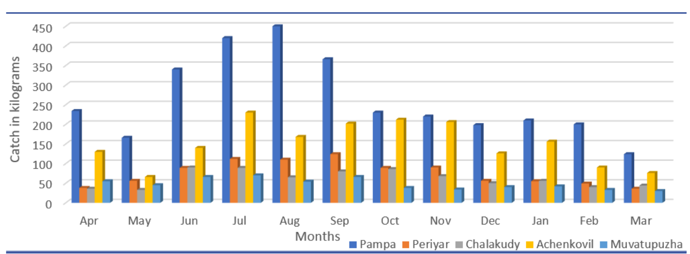

Figure 2. Monthly variations in the landing of *H. brachysoma* from different river systems of Western Ghats.

monsoon season (October- January) with 2.26±0.074. *Horabagrus brachysoma* is an important food fish, is extensively exploited from Western Ghats rivers by traditional fishers (Bindu, 2006; Sreeraj et al., 2007; Renjithkumar et al., 2011, 2016). Gill nets and hook and lines are the main gears used for catching. Depending on the net size, about 3-6 gill nets and 1-2 hook and lines are actively engaged in yellow cat fishing in each landing centre of the rivers. During the monsoon season, the floodplain fishery (locally known as *Oothapiditham*) yields a significant catch of mature *H. brachysoma*, with approximately 100 kg harvested weekly using traditional fishing traps, gill nets, and electric fishing methods (Shaji & Laladhas, 2013). The landing of the species from Kerala state rivers ranges from 3.67 t to 17.1 t (Renjithkumar et al. 2011, 2016) whereas annual landings in Vembanad Lake ranged between 2 and 439 t (Bindu, 2006; Kurup et al., 1995; Sreeraj et al., 2007). The fishery of this species in many rivers seems unsustainable due to excessive fishing effort with over fishing such as growth fishing (capturing individuals before they reach a size significant enough to contribute to the spawning stock) and recruitment fishing (exploiting the spawning stock itself) (Prasad et al., 2012; Raghavan & Ali, 2013; Raghavan et al., 2016).

The frequency distribution of length groups showed considerable variation in the length range of *H. brachysoma* exploited from various rivers of Western Ghats region (Fig 3). Although this species can reach a maximum length of 420 cm (Bindu & Padmakumar, 2019), individuals of this size were not encountered in the present study. The largest specimen recorded in this investigation was 410 mm, significantly smaller than the reported maximum length. The length range of *H. brachysoma* populations in Chalakudy and Muvatupuzha Rivers are much smaller than other rivers. In Chalakudy and Muvatupuzha Rivers the maximum length of fishes was recorded in the size class 330 mm and 308 mm respectively. The highest length of *H. brachysoma* in Pampa was 406 mm, while the maximum lengths in Achenkovil and Periyar River were 384 mm and 350 mm, respectively. Although only 29% of the exploited *H. brachysoma* in the River Pampa were < 200 mm TL, the proportions increased to 31% in the River Achenkovil, 42% in the River Periyar, and > 50% in the Rivers Chalakudy and Muvatupuzha. The size at first maturity for the *H. brachysoma* is known to be 175 mm and 188 mm TL in males, and 168 mm and 185 mm TL in females (Bindu et al., 2012; Chandran & Prasad, 2014). Length-frequency analysis reveals that a significant proportion of yellow catfish are being caught in small-scale fisheries before they reach sexual maturity, indicating a potential threat to the sustainability of the population. Harvesting small fish before they reach maturity leads to a slow population recovery and reduced fish catches and decreased profits (Isaac & Ruffino, 1996; Myers & Mertz, 1998).

Restructured form of the length frequency data of exploited *H. brachysoma* populations from five river presented as output of ELEFAN I shows that the growth curves for different populations differ considerably (Fig.4). The asymptotic length ($L\infty$) ranged from 316.05 mm in Achenkovil to 421.05 mm in Pampa, while the growth coefficient (*K*) ranged from 0.58 y^{-1} in Chalakudy to 1.10 y^{-1} in Muvatupuzha (Table 1 and Fig. 5). The demographic characteristics of *H. brachysoma* have been understudied, with only a few investigations, including Prasad et al. (2012) in the Periyar River, therefore the comparison between geographic populations becomes difficult. The growth coefficient (*K*) values for the *H. brachysoma* population in the five rivers were significantly lower compared to the Periyar River population (4.60 y^{-1}) in the Southern Western Ghats (Prasad et al., 2012). The variations in differences in growth parameters of *H. brachysoma* observed across different rivers can be attributed to a combination of factors including stock variances, ecological conditions of the habitat, feeding habits, and environmental parameters. The high growth coefficient (*K*) and low longevity were recorded in Periyar and Muvatupuzha Rivers when compared to Chalakudy, Pampa and Achenkovil Rivers. It indicated that Periyar and Muvatupuzha Rivers yellow catfish populations acquired asymptotic length ($L\infty$) quickly which agree with Pauly & Munro (1984), that species having shorter life have higher '*K*' values and reach their $L\infty$ within one or three years of life history. Potential longevity of *H. brachysoma* was the highest (5.17) in Chalakudy and lowest in lowest (3.3) in Muvatupuzha (Table 1). Estimates of growth performance index (φ) recorded in this study (4.29 to 4.52) were lower (4.99) than those observed for Periyar River (Prasad et al., 2012).

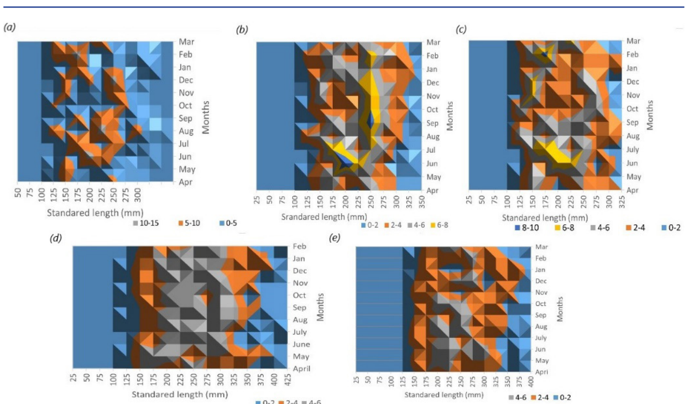

Figure 3. Distribution of length frequencies of *H. brachysoma* across five rivers in the Western Ghats (a) Chalakudy (b) Periyar (c) Muvatupuzha (d) Pampa (e) Achenkovil.

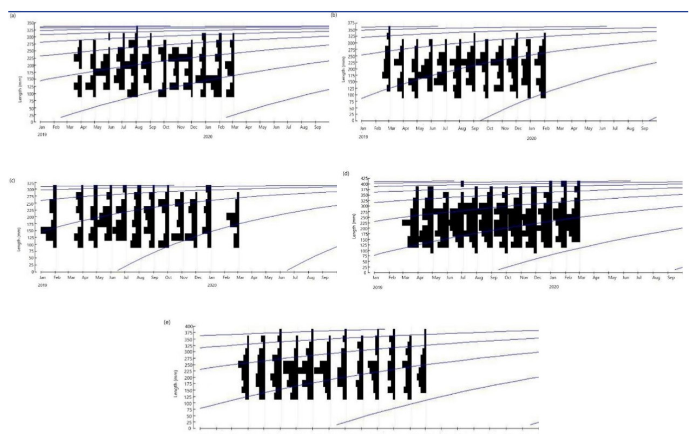

Figure 4. von-Bertalanffy growth curves for *H. brachysoma* from different rivers on the Western Ghats (a) Chalakudy (b) Periyar (c) Muvatupuzha (d) Pampa (e) Achenkovil.

The decrease in the fish population size can be attributed to by two primary factors: natural mortality (*M*) (disease, predation, pollution and other environmental stressors) and fishing pressure (*F*). Fishing mortality (*F*) was highest in Periyar (2.09 y^{-1}) and lowest in Achenkovil (0.62 y^{-1}), whereas natural mortality (*M*) was lowest in Pampa (0.62 y^{-1}) and highest in Muvatupuzha (0.99 y^{-1}) Rivers (Table 2). The fishing mortality rate of *H. brachysoma* was higher than the natural mortality rate in four rivers (Periyar, Muvatupuzha, Chalakudy and Pampa) indicating a rather significant fishing pressure on the species. The mortality rate of species is crucial for developing exploitation strategies to harvest and manage the fishery resources optimally. The ratio of total mortality (*Z*) to growth coefficient (*K*) is a key indicator of population dynamics. A ratio greater than 1.0 ($Z/K > 1.0$) suggests a mortality-dominated population, where deaths exceed growth, leading to a declining population. In contrast, a ratio less than 1.0 ($Z/K < 1.0$) indicates a growth-dominated population, where growth outpaces mortality, resulting in an increasing population (Etim et al., 1999). *H. brachysoma* populations in all the rivers studied were dominated by mortality (Z/K = 1.88–3.58). This is a highly alarming situation where overfishing gradually reduce recruitment, resulting in severe population losses in the near future (Rajeev et al., 2018). In an ideally managed fishery, the fishing mortality rate (*F*) should be balanced with the natural mortality rate (*M*), resulting in an exploitation rate (*E*) of approximately 0.5 y^{-1} (Gulland, 1970).

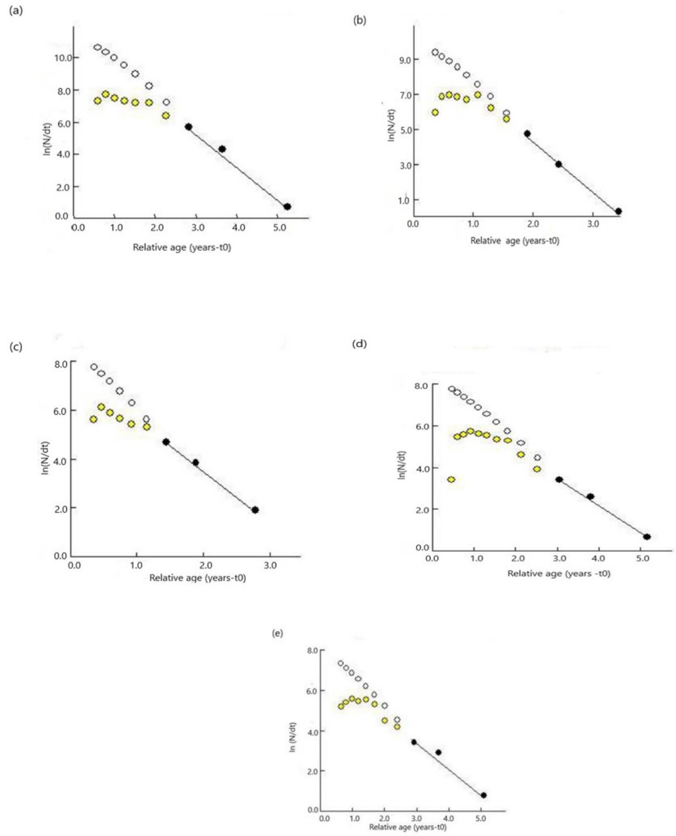

Figure 5. Length converted catch curve for the estimation of mortality of *H. brachysoma* from different rivers on the Western Ghats (a) Chalakudy (b) Periyar (c) Muvatupuzha (d) Pampa (e) Achenkovil.

The exploitation rates (*E*) of yellow catfish in four rivers (Chalakudy, Pampa, Periyar, and Muvatupuzha) are greater than sustainable threshold of 0.5, whereas the exploitation level in the Achenkovil River nearly equals to $E_{0.5}$, indicating uncertain future for native yellow cat fish population if management attention is not taken. Yellow catfish exploitation level (*E*) in the Chalakudy, Periyar, Muvatupuzha and Pampa were higher (0.70, 0.72, 0.52 and 0.53) than the expected optimal exploitation level (E_{50}), indicating that these populations are overexploited. When compared to the Muvatupuzha and Pampa Rivers, populations of *H. brachysosma* in the Chalakudy and Periyar Rivers had higher levels of exploitation and fishing mortality. The size at first capture (*Lc*) calculated from the probability of capture was 197.86 mm –288.22 mm (Table 3). *Lc* was 78% of *L*∞ in Rivers Chalakudy and Periyar, but it was it was 61– 63.5% of *L*∞ in the Muvatupuzha, Pampa and Achenkovil. The harvest of smaller individu-

Table 1. Growth parameters of *Horabagrus brachysoma* from different rivers on the Western Ghats.

Rivers	Asymptotic length (*L*∞, mm)	Growth coefficient (*K*) year^{-1}	Growth performance index (ϕ)	Longevity (3/*K*) years
Chalakudy	342.30	0.580	4.29	5.17
Periyar	368.55	0.890	4.52	3.70
Muvatupuzha	316.05	1.100	4.45	3.30
Pampa	421.05	0.590	4.40	5.08
Achenkovil	394.80	0.600	4.37	5.00

Table 2. Mortality rates (year−1) and exploitation level of *Horabagrus brachysoma* from different rivers on the Western Ghats.

River	Total mortality rate (*Z*)	Natural mortality rate (*M*)	Fishing mortality rate (*F*)	Exploitation rate (*E*)
Chalakudy	2.08	0.63	1.45	0.70
Periyar	2.91	0.82	2.09	0.72
Muvatupuzha	2.07	0.99	1.08	0.52
Pampa	1.30	0.62	0.68	0.53
Achenkovil	1.25	0.63	0.62	0.49

Table 3. Length of first capture (Lc), E_{10}, E_{50} and E_{max} of *Horabagrus brachysoma* from different rivers on the Western Ghats.

River	Length at first capture (*Lc*) mm	E_{10}	E_{50}	E_{max}
Chalakudy	268.42	1.000	0.442	1.000
Periyar	288.22	0.753	0.406	0.834
Muvatupuzha	197.86	0.718	0.399	0.802
Pampa	267.63	0.707	0.403	0.821
Achenkovil	242.16	0.707	0.398	0.794

als suggests that specimens are being caught even before they reach sexual maturity, which contributes to future recruitments. Virtual population analysis (VPA) revealed that the species experienced considerable natural mortality in Achenkovil and Pampa Rivers at a young age, but the fishing mostly targeted comparatively larger sized individuals in Chalakudy, Periyar, and Muvatupuzha Rivers (Fig. 6). 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 range between 0.398- 0.442 (E_{50}) and 0.794-1.00 (E_{max}) respectively in various river system (Fig. 7). The current level of exploitation was found in between 62% and 87% of the maximum exploitation (E_{max}) from the five river systems.

Conservation management measures

The current study is likely the first study on community-based data monitoring systems in small-scale inland fisheries in Western Ghats of India and it shows that yellow catfish are under heavy exploitation pressure and native populations are vulnerable to collapse in the absence of immediate management interventions. Monitoring, Control, and Surveillance (MCS) systems in the Western Ghats play a crucial role in regulating fishing activities, ensuring compliance with conservation measures, and protecting aquatic ecosystems from overfishing and illegal practices. Controlling the overall harvest of yellow catfish could be the most significant management method for conserving the *H. brachysoma* population, however reducing fishing effort in an artisanal subsistence fishery like India is nearly difficult. As a result, management interventions for the protection of *H. brachysoma* in Western Ghats rivers should be based on a combination of technical measures such as restrictions on fishing gear and mesh size limits, closed seasons, non-fishing zones, and the introduction of catch quotas. There is currently no upper size limit for landing *H. brachysoma* in Western Ghats rivers. Implementing an upper size limit stimulate stock recovery and improve the sustainability of its fishery. The length at first maturity of *H. brachyso-*

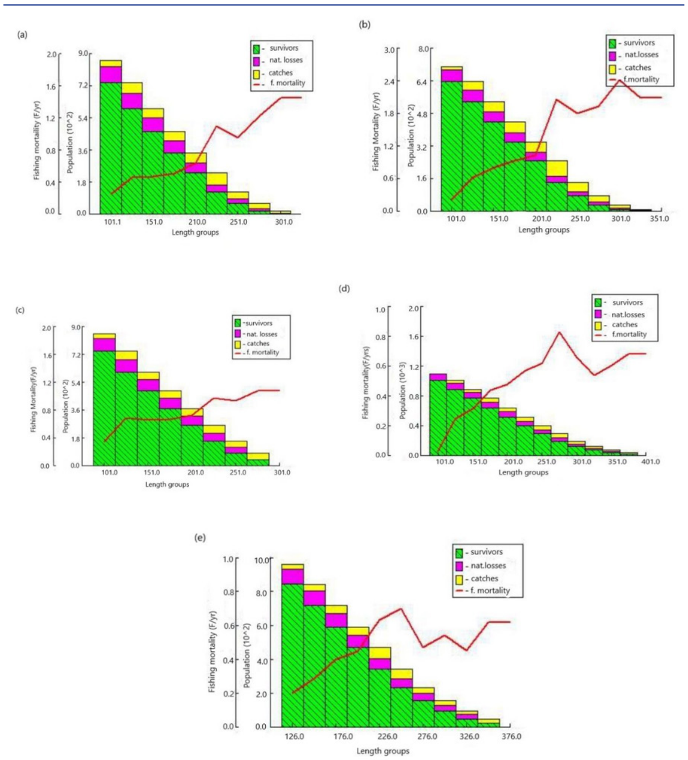

Figure 6. Length-structured virtual population analysis (VPA) of *H. brachysoma* from different rivers on the Western Ghats (a) Chalakudy (b) Periyar (c) Muvatupuzha (d) Pampa (e) Achenkovil.

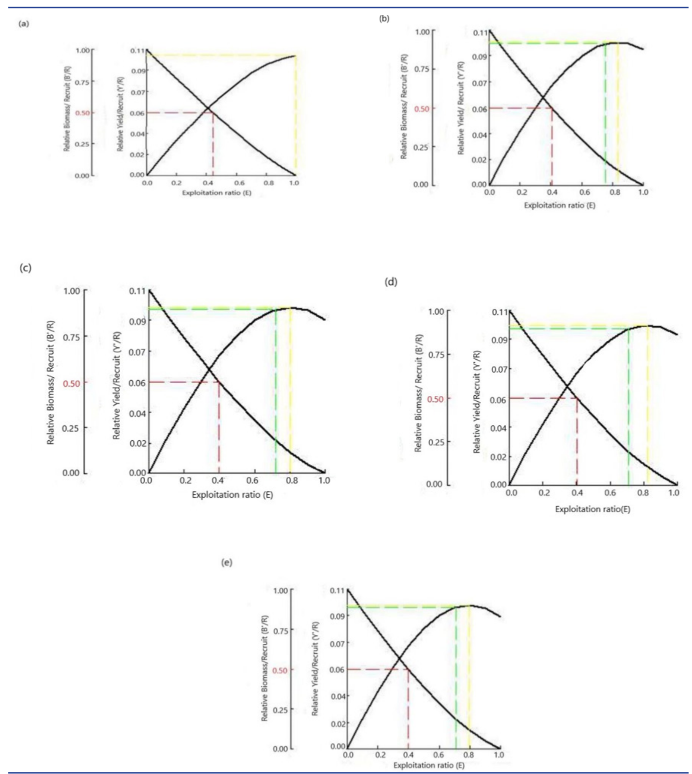

Figure 7. Relative yield per recruit (*Y′/R*) and relative biomass per recruit (*B′/R*) plots of *H. brachysoma* from different rivers on the Western Ghats (a) Chalakudy (b) Periyar (c) Muvatupuzha (d) Pampa (e) Achenkovil.

ma was estimated to be 175-188 mm in males, and 168 - 185 mm in females (Bindu et al., 2012; Chandran and Prasad, 2014). A minimum catch size limit of 200 mm can be enforced in the rivers to prevent recruitment overfishing. Allowing them to attain this size ensures they have the opportunity to spawn at least once, aiding in the conservation of the species. In addition to setting size limits, restrictions on net mesh size should be implemented.

Heavy exploitation of juveniles of *H. brachysoma* was occurred due to unethical fishing practices such as fishing traps and electrocution (Shaji and Laladhas 2013). Presently, there are no regulations in place to prohibit the use of electric fishing in the monsoon floodplain fishery in Kerala, which results in the unintended mortality of juvenile fish and could disrupt population dynamics and future stock recruitment. Currently, the fishers use gill nets with mesh sizes ranging from 20 and 60 mm, resulting in the capture of small-sized juvenile fishes before they reach maturity. Gill nets should have a minimum mesh size of 40-80 mm to prevent the capture of immature juveniles. Restriction on the limits on mesh size or size of the fish to enforce is challenge for developing management measures for small-scale subsistence fisheries in Western Ghats Rivers. To protect the yellow catfish population during its critical breeding period, a four-month closed season (June-September) should be implemented in Kerala state, coinciding with the Southwest monsoon months when they spawn. In cooperation with local fishermen, a temporary shutdown of the fishery during the spawning season (closed season) should be developed. This measure aims to safeguard the spawning stock and support the enhancement of recruitment levels. In the Western Ghats, establishing protective areas and no-fishing zones (NFZs) for *H. brachysoma* can be especially effective in regions with unique habitats, such as Thattekad and Pooyamkutty along the Periyar River, as well as Athirappilly and Vazhachal along the Chalakudy River. Catch quotas for each fishing fleet will be developed in consultation with local fishermen, scientists, and fisheries managers for each river. To prevent the indiscriminate exploitation of catfish in the rivers of central Kerala, the Department of Fisheries, Government of Kerala in collaboration with the Kerala State Biodiversity Board (KSBB) and Kerala Forest and Wildlife Department should establish a strict prohibition on fishing. To ensure compliance, a penalty of Rs. 50,000 and imprisonment for up to six months should be imposed on offenders. Effective enforcement and strict monitoring of existing legislation can significantly contribute to reducing the harvesting of mature catfish from natural waters. Ultimately, engaging local communities in conservation efforts is crucial for the long-term protection of catfish populations.

Statements & Declarations

Compliance with Ethical Standard: This is an observational study. The Cochin University of Science and Technology (CUSAT) Research Ethics Committee has confirmed that no ethical approval is required.

Conflicts of Interest: The authors declare that they have no conflict of interest.

Consent to Publish: The author's obtained consent from all individual participants for whom identifying information is included in this article.

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