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Assessing the sustainability of lepidophagous catfish, *Pachypterus khavalchor* (Kulkarni, 1952), from a tropical river Panchaganga, Maharashtra, India

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Abstract

Background: The Western Ghats of India, one of the global biodiversity hotspots and freshwater eco-regions, harbors several fish species which not just form the important part of the world's freshwater biodiversity yet in addition are the vital segment of livelihood of the neighborhood population. The rate of fish decline in the Western Ghats is alarming. The absence of organized study and data scarcity on basic biology and life history traits of several species could be one reason behind the decline, and thus it is difficult to execute conservation action/s. This is especially true, particularly for data-deficient species for which definite data related to distribution, population size, and trend is not available. The present study deals with the detailed investigation of population dynamics of catfish species, *Pachypterus khavalchor*, which is data-deficient species inhabiting the Western Ghats of India and forms an important component of freshwater inland fishery, providing nutritional and financial security to the local community.

Methods: Specimens for the present study were collected monthly for a period of 1 year from the River Panchaganga and length–frequency data were analyzed using FiSAT II software.

Results: Length–weight analysis of pooled (male + female) data suggested the fish exhibited higher exponent than expected under isometry, indicating the positive allometric growth of *P. khavalchor* in the Panchaganga River. The asymptotic length ($L\infty$) and the growth rate (K) were estimated as 149.63 mm and 0.71 year^{-1} respectively. Potential longevity (t_{max}) and length at first capture (Lc) were estimated as 4.22 years and 73 mm respectively. The total (Z), natural (M), and fishing mortality (F) were estimated as 2.23 year^{-1}, 0.88 year^{-1}, and 1.35 year^{-1} respectively. The current exploitation rate ($E_{cur} = 0.60$) was found to be almost 90% that gives the maximum relative yield per recruit ($E_{max} = 0.67$). Recruitment pattern revealed two peaks, suggesting the fish have two spawning bouts each year.

Conclusions: The stock of *P. khavalchor* in the Panchaganga River may be in near full exploitation under the current harvesting strategy, with a high chance of recruitment failure in the future. Additional studies on the reproductive biology of *P. khavalchor* would be particularly welcome for the imposition of the seasonal closure for effective conservation of stock.

Keywords: Lepidophagy, Fishery, Data scarcity, Freshwater ecosystem, Recruitment, Aquatic conservation, Mortality

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Background

The Western Ghats of India is well known for its exclusive biodiversity and also classified as a freshwater eco-region with more than 300 species of the freshwater fishes (Abell et al., 2008; Molur, Smith, Daniel, & Darwall, 2011; Myers, Mittermeier, Mittermeier, Da Fonseca, & Kent, 2000). Nearly 30% of the species inhabiting the Western Ghats have been categorized as threatened in the IUCN Red list (Dahanukar, 2011; Dahanukar, Raghavan, Ali, Abraham, & Shaji, 2011; , Ramprasanth, Ali, & Dahanukar, 2018a). However, several endemic and threatened species continue to be harvested at unsustainable levels through artisanal and open-access fisheries throughout the Western Ghats (Das et al., 2017; Keskar, Raghavan, Kumkar, Padhye, & Dahanukar, 2017; Kharat & Dahanukar, 2013; Prasad, Ali, Harikrishnan, & Raghavan, 2012; Raghavan, Ali, Dahanukar, & Rosser, 2011; Raghavan et al., 2018a). According to Darwall et al. (2018), another most important and fundamental cause for the freshwater biodiversity crisis is the insufficient consideration of impacts on freshwater ecosystems in decision-making and policy. However, decision-making and policy establishment require the reliable data on the population dynamics/trend, and thus the information inadequacy on population dynamics for majority of endemic species hindered the development of appropriate conservation action plans (Cooke, Paukert, & Hogan, 2012; Dahanukar et al., 2011; Luiz, Woods, Madin, & Madin, 2016; Morais et al., 2013). At present, the Western Ghats of India harbor 26 data-deficient species and majority of them are likely to be threatened with extinction (Dahanukar et al., 2011; Molur et al., 2011). Because of lack of substantial information on population dynamics, the data-deficient species are not at the forefront of the conservation agenda (Luiz et al., 2016; Morais et al., 2013; Possingham et al., 2002). As data deficiency not only means the absence of records, but it may indicate dangerously low abundance, Mace et al. (2008) clearly stated that "data-deficient species should be afforded the same degree of protection as a threatened species until more information is forthcoming." Keeping the above thought in view, it is fundamentally critical to have data on population biology parameters of known data-deficient species inhabiting the Western Ghats of India for their effective conservation and management.

The catfish genus *Pachypterus* consists of three species viz. *Pachypterus acutirostris* (Day, 1870) distributed in Irrawaddy, Sittang, and Bago rivers, Myanmar (Eschmeyer, Fricke, & van der Laan, 2018; Kottelat, 2013); *Pachypterus atherinoides* (Bloch, 1794) distributed in river drainages of the Indian subcontinent north of the Cauvery, Bangladesh, Nepal, and Pakistan (Ahamed et al., 2018; Buragohain, 2018; Eschmeyer et al., 2018); and *Pachypterus khavalchor* (Kulkarni, 1952) which inhabits the Krishna River basin of Peninsular India (Dahanukar, Paingankar, Raut, & Kharat, 2012; Eschmeyer et al., 2018). Each of these species is extremely delicious and having good market demands in their distribution range and thus provides dietary and financial advantage to the local community (Buragohain, 2018; Gosavi, Kharat, Kumkar, & Navarange, 2018; Kumbar & Lad, 2014). Since *Pachypterus* species forms an important part of the open-access fisheries, they are getting exploited in their distribution range leading to a huge decline in population (Buragohain, 2018; Kumbar & Lad, 2014). In support to this, Dahanukar (2011) and Menon (1999) already pointed that several anthropogenic activities such as urbanization, industrial developments, and mining are contributing to dwindling population of *P. khavalchor*. Menon (2004) and Molur et al. (2011) further suggested that it could be a threatened species due to its fragmented population and non-availability of population data. As a result, presently, *P. khavalchor* is categorized as the "data deficient" species by IUCN (Dahanukar, 2011; Dahanukar et al., 2012; IUCN, 2018). However, despite of the variety of threats operating on the *P. khavalchor* presently, no conservation action plans are specifically directed towards conservation of this species. As a result of combined threats from different sources, data deficiency, and suggested possibility of the loss of this freshwater catfish species by (Menon, 1999), it is an immediate need to generate the data on the life history traits of *P. khavalchor* for instantaneous conservation action.

The persistence of any fish species in the given habitat is dependent on the life history traits of that species (Das et al., 2017, 2018; Kumar et al., 2014; Prasad et al., 2012; Raghavan et al., 2011, 2018a). Under the present environmental conditions, life history traits must generate sufficient recruitment for a given population to persist. In this context, considerable knowledge on length–weight relationships, growth, population structure, mortality (natural and fishing), exploitation level, and recruitment pattern of an exploited stock is essential for planning and management of fisheries resources, mainly when the species form the important component of the artisanal fisheries and lies at the base of the higher food web (Das et al., 2017, 2018; Kumar et al., 2014). Therefore, present investigation was carried out for the assessment and evaluation of various life history traits of *P. khavalchor* using length–frequency data collected for one year. This study generates first of its kind information on the life history traits and population dynamics of the genus *Pachypterus* in general and *P. khavalchor* in particular.

Methods

Study area, fish collection, and measurements

Monthly samples were collected during June 2015 to May 2016 with the help of a small-scale artisanal fishermen from the Panchaganaga River (17.28 °N; 74.18 °E), Maharashtra, India. The fishing method employed in this area by local fishermen mainly includes the use of gill net and cast net of variable mesh size. Specimens ($n = 427$) were collected and brought to the laboratory in ice-filled boxes. Standard length (SL; a fish's body length from the tip of its snout to end of its last vertebrae; it includes everything except the caudal fin) and total length (TL; it is the length of a fish from the tip of its snout to the end of the longer lobe of its caudal fin) were measured for each specimen to the nearest 0.01 mm using a digital vernier caliper (Mitutoyo, Japan). Weight (W) was determined to the closest 0.01 g using digital weighing balance (Contech, India). Specimens were fixed in 10% formalin after all measurements and are in the departmental collection of Modern College of Arts, Science and Commerce, Ganeshkhind, Pune, Maharashtra, India. Growth, potential longevity, mortality, recruitment pattern, probability of capture, length structured virtual population analysis (VPA), relative yield per recruit, and biomass per recruit were estimated using FAO–ICLARM Stock Assessment Tools II (FiSAT II, version 1.2.2) software (Gayanilo Jr., Sparre, & Pauly, 1998).

Length–weight relationships (LWRs)

LWR parameters were estimated according to the guidelines and equation given by Froese (2006):

$$W = {}_a\mathrm{SL}^b \tag{1}$$

where W is the body weight (g), SL is the standard length (cm), "a" is the intercept, and "b" is the slope of log-transformed linear regression. The coefficient of determination (r^2) was estimated as the goodness of fit. Student's t test was used to find out whether "b" value significantly deviated from the expected cube value of 3 (Sokal & Rohlf, 1987; Zar, 1984). The values of standard length and parameter b were compared with values in FishBase (Froese & Pauly, 2018). Analyses were performed using the program PAST version 3.13 (Hammer, Harper, & Ryan, 2001).

Population structure

Frequency distribution forms the basis for the analysis, and thus standard length data were grouped in a length–frequency table with 2.5 mm as the smallest mid-length and 5 mm class intervals thereafter. To determine the population structure, contour plot was plotted using 10 mm length class of standard length (SL) in relation to different months.

Growth and potential longevity

Asymptotic length ($L\infty$) and the growth coefficient (K) were estimated using ELEFAN 1 method (Pauly, 1981, 1982; Pauly & David, 1981; Pauly & Morgan, 1987) by fitting the classical von Bertalanffy growth function (VBGF) as:

$$L_t = L\infty^* \left[(1 - \mathrm{Exp}\,(-K(t{-}t_o)\right] \tag{2}$$

In Eq. 2, $L\infty$ represents asymptotic length; K is the VBGF curvature parameter (growth constant), L_t is the length at time t, and t_0 is the hypothetical length at the age length zero. Using growth parameters ($L\infty$) and VBGF curvature parameter (K), the Growth performance index ($Ø'$) was calculated as (Pauly, 1979; Pauly & Munro, 1984):

$$\left(Ø'\right) = \mathrm{Log}K + 2\ \log L1 \tag{3}$$

The potential longevity ($t_{\max}$) was obtained using the equation $t_{\max} = 3/K$, given by Pauly (1983). Maximum possible extreme length for this species was calculated using the support function available in FiSAT II (Formacion, Rongo, & Sambilay, 1991). A selectivity curve was generated using linear regression fitted to the ascending data points from the plot of probability of capture against length, which was used to estimate the final value of length-at-first capture (Lc or L_{50}).

Mortality

The length-converted catch curve was applied for the calculation of the total mortality (Z) (Pauly, 1983). Natural mortality (M) was determined using the following Pauly's empirical equation (Pauly, 1980),

$$\ln\,(M) = -0.0152{-}0.279\ \ln\,(L\infty) + 0.6543\ \ln\,(K) + 0.463\ \ln\,(T) \tag{4}$$

where T is the average annual temperature, which is 26 °C.

Fishing mortality was (F) calculated by subtracting the M value from the Z value (Appeldoorn, 1984):

$$F = (Z - M) \tag{5}$$

Values of F and Z were used to calculate the current exploitation rate (E_{cur}) as per the formula given by Gulland (1985):

$$E_{\mathrm{cur}} = F/Z \tag{6}$$

Whether the present fishery resource status of study species is sustainable or not was assessed according to Etim, Lebo, and King (1999), where Z/K ratio ≈ 2 indicate over-exploitation.

Exploitation

The growth and mortality parameters were used as input for the length-structured virtual population analysis (VPA) analysis (Hilborn & Walters, 1992). Further, the current level of exploitation (E_{cur}) was estimated using relative yield per recruit (Y'/R) and biomass by recruit (B'/R) analysis with the Knife–Edge selection method (Beverton & Holt, 1966). Values of E_{50} (i.e., exploitation rate that resulted in a devalued of the unexploited biomass by 50%) and E_{max} (i.e. exploitation rate producing maximum yield) were calculated by plotting Y'/R vs. E_{cur} and of B'/R vs. E_{cur}.

Probability of capture and recruitment pattern

The probability of capture was estimated using the length-converted catch curve (Pauly, 1984). Recruitment pattern provides information related to the number of pulses per year and the relative strength of each pulse and therefore was calculated by reconstructing the recruitment pulses from a time series of length–frequency data (Moreau & Cuende, 1991).

Results

Descriptive statistics of the sample sizes (n), maximum and minimum values of SL, TL, and W for male, female, and pooled data, and estimates of the LWR parameters are presented in Table 1. New maximum total length was recorded for *P. khavalchor* (17.05 cm) as compared to previously reported in FishBase (15 cm; Talwar & Jhingran, 1991).

The frequency distribution of 427 individuals of different length class across months (Fig. 1) obtained during the present study indicated the occurrence of smallest individuals (55–60 mm) in August and largest individuals (140–145 mm) in January. The FiSAT II output of the restructured length frequency data of *P. khavalchor* population with the superimposed growth curve with the highest ideal fit index ($Rn = 0.339$) is given in Fig. 2. The asymptotic length ($L\infty$) was estimated as 149.63 mm and coefficient of growth (K) as 0.71 year^{-1}. The growth parameters estimated using the von Bertalanffy growth model for *P. khavalchor* and details of the mortality parameters calculated using the length converted catch curve (Fig. 3) are given in Table 2. Growth performance index ($Ø'$) was estimated as 4.201. Length at first capture (Lc) and the maximum possible predicted extreme length for *P. khavalchor* were found to be 73 mm and 143.51 mm respectively. Total mortality (Z) and natural mortality coefficient (M) were found to be 2.23 year^{-1} and 0.88 year^{-1} respectively. Fishing mortality coefficient (F) was found to be 1.35 year^{-1}.

The virtual population analysis (Fig. 4) revealed high natural mortality at a young age though the fishery principally targeted comparatively large sized individuals (from 52.5 mm onwards) as evident by the exponential decrease in survival rate. Exploitation levels estimated using relative yield-per-recruit (Y'/R) and relative biomass-per-recruit (B'/R) analysis based on knife edge selection were found to be 0.36 (E_{50}) and 0.67 (E_{max}) respectively (Fig. 5; Table 2). The current level of exploitation ($E_{cur} = 0.60$; Table 2) was found to be almost 90% that gives the maximum relative yield per recruit ($E_{max} = 0.67$) and almost twice than E_{50}, that maintained 50% of the spawning stock biomass (Fig. 5). Recruitment shows the bimodal pattern with the minor pulse in recruitment during the April–May and major pulse in September–October (Fig. 6). The minor pulse produced 28.13% and major pulse produced 29.62% recruitment.

Discussion

Uncontrolled exploitation of fishery resources by inland catch fisheries is considered as the second most noticeable threat to the freshwater fishes inhabiting the Western Ghats of India (Raghavan, Ali, Philip, & Dahanukar, 2018; Raghavan et al., 2018a; Smith et al., 2011). However, presently, the gap in the research examining the impact of biological resource use on freshwater biodiversity or livelihoods is surprising. Fishery management is a dependent field, and in order to implement management plans and conservation actions, concrete data on demography parameters (growth and mortality rates), status of populations (stock assessments), and number of fish harvested (exploitation levels and rates) is the primary requirement (Raghavan et al., 2011, 2013, 2018, 2018a). Nonetheless, such data are readily available and confined to a few of the large-growing tropical cyprinids such as the members of the genus *Tor* (Bhat, Nautiyal, & Singh, 2000; Raghavan et al., 2011, 2018a), with complete absence of information available on other

Table 1 Descriptive statistics, estimated parameters of LWRs ($W = a \times L^b$) for *Pachypterus khavalchor* from Panchaganga River (tributary of Krishna River System) of the northern Western Ghats of India sampled during June 2015 to May 2016

Sex	*n*	SL (cm)		TL (cm)		W (g)		LWRs regression parameters							
		Min	Max	Min	Max	Min	Max	*a*	CI of *a*	*b*	CI of *b*	Se(*b*)	r^2	*t*	*p*
Male	211	5.74	11.62	7.20	14.74	2.43	30.10	0.001	0.001–0.002	3.586	3.476–3.693	0.049	0.961	11.74	< *0.0001*
Female	216	6.56	14.22	7.94	17.05*	3.62	46.46	0.004	0.003–0.006	3.183	3.059–3.317	0.058	0.933	3.15	0.0018
Pooled	427	5.74	14.22	7.20	17.05	2.43	46.46	0.003	0.002–0.004	3.336	3.286–3.451	0.038	0.957	9.49	< *0.0001*

Italicized values represent significant difference

SL standard length, *TL* total length, *W* Weight, *n* number of samples, *Min* minimum, *Max* maximum, *a* intercept, *b* slope, *Se(b)* standard error of *b*, *CI* 95% confidence limits, r^2 coefficient of determination, *t* test for isometry, *p* level of significance

*New length record

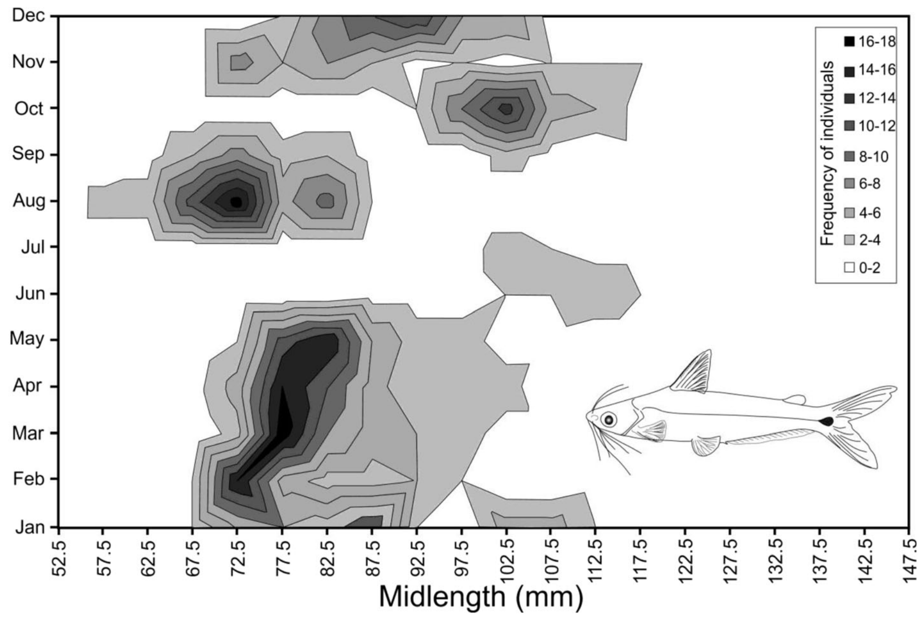

Fig. 1 Contour plot based on length–frequency analysis of *Pachypterus khavalchor* from the Panchaganga River collected during June 2015 to May 2016, Maharashtra, India

groups, including *P. khavalchor* which is presently categorized as the data-deficient species with possible speculation of its loss in the near future (Dahanukar, 2011; Dahanukar et al., 2012; IUCN, 2018; Menon, 1999). In this regard, the detailed investigation of the population dynamics of the data-deficient species inhabiting the Western Ghats of India is the key solution for imposing the conservation action plans. The present study provides the first of its kind information on the population dynamics and exploitation levels of the *P. khavalchor* and emphasized the instant conservation action for this species.

Fish growth can be measured as either isometric or allometric form (Gayanilo & Pauly, 1997; Sarkar et al., 2013). In isometric growth pattern, both the length and weight of the fish increase at the same rate. On the contrary, allometric growth can be either positive or negative. Positive allometric growth represents that higher increment in weight as compared to length (fish becomes stouter or heavier or deeper-bodied). Negative allometric growth represents a higher increment in length as compared to weight (fish becomes slender or lighter) (Ogunola, Onada, & Falaye, 2018; Wootton, 1998). Length–weight analysis of pooled (male + female) data suggested the fish exhibited significantly higher exponents (b = 3.336) than expected under isometry (b = 3), indicating the growth of *P. khavalchor* in the Panchaganga River was positive allometric. According to Beverton and Holt (1957), the departure of the 'b' value from three is rare in adult fishes. In our case, observed variation in the 'b' value could be attributed to several factors such as length range

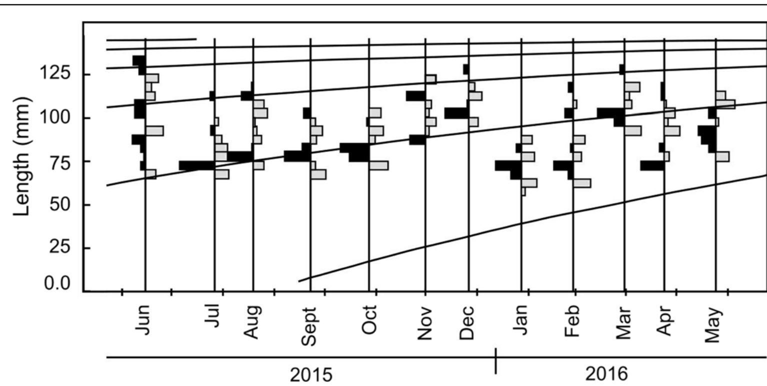

Fig. 2 The von Bertalanffy growth curve superimposed over length–frequency data of *Pachypterus khavalchor* from the Panchaganga River, Maharashtra, India

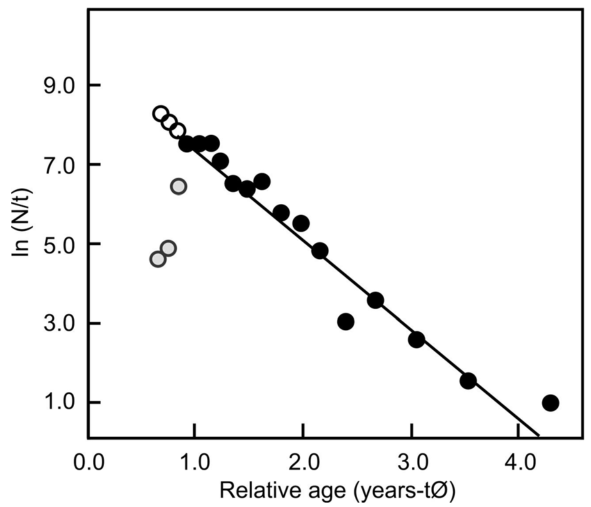

Fig. 3 Length-converted catch curve for *Pachypterus khavalchor* from the Panchaganga River, Maharshtra, India

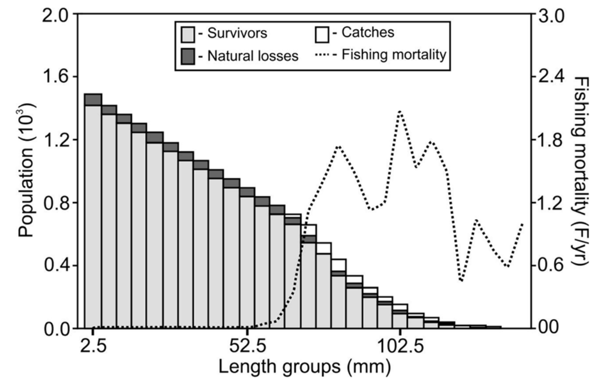

Fig. 4 Length-based virtual population dynamics for *Pachypterus khavalchor* from the Panchaganga River, Maharashtra, India

used, season, stomach fullness, gonadal maturity, diet, sampling gear, mesh size, fishing pressure, and presence or absence of disease and parasite (Froese, 2006; Ogunola et al., 2018). However, these factors were not considered in the present study, and thus the observed variations in LWRs parameters could be due to the effect of a single factor or synergistic effect of multiple factors. Fish with ideal growth shows the coefficient of determination (r^2) between 0.90 and < 1 (Hanif, Siddik, Chaklader, Pham, & Kleindienst, 2017). The r^2 value in the present study was found to be within expected range (> 0.93) indicates the proper fitness of the model for growth and good health status of the study species. Length–weight relationships (LWRs) data of the fishes have several applications such as indirect estimation of body weight based on the body length, calculation of condition indexes, and also for comparisons of species' growth trajectories (Chen et al., 2018; Froese, 2006; Ogunola et al., 2018). Additionally, LWRs are essential tools for the monitoring and conservation of fish populations, because they allow us to increase the effectiveness of management strategies, whether for control (e.g., introduced species), exploitation (e.g., inland fisheries), or conservation of species at risk (Rodríguez-Olarte, Taphorn, & Agudelo-Zamora, 2018). Presently, no information is available from other known localities on the LWRs parameters of *P. khavalchor* thus comparative analysis cannot be performed.

The earlier study by Prasad et al. (2012) on Yellow Catfish *Horabagrus brachysoma* (Günther, 1864), which is another member from family Horabagridae showed asymptotic length ($L\infty$) and VBGF K value as 422 mm and 0.55 year^{-1} respectively. In comparison with the results of Prasad et al. (2012), the *P. khavalchor* exhibit lower asymptotic length (149.63 mm) and high growth rate (0.71 year^{-1}). The growth performance index value ($ø'$) of 4.201 observed in the present study was found to be comparatively higher than that obtained for other tropical freshwater catfish species including those belonging to the families Schilbeidae (initially *P. khavalchor* was classified under the family Schilbeidae and is recently classified into family Horabagridae; $ø'$ between 2.18 and 2.78) (Etim et al., 1999), Claroteidae ($ø' = 2.32$) (Abowei & Davies, 2009) and Synodontidae ($ø' = 3.09$) (Ofori-danson, Vanderpuye, & De Graaf, 2001). High growth rates and growth performance index could be considered as the positive point in

Table 2 Growth, mortality, and exploitation parameters of *Pachypterus khavalchor* from the Panchaganga River, Maharshtra, India

Growth and longevity parameters		Mortality and exploitation parameters	
Asymptotic length ($L\infty$)	149.63 mm	Total mortality (Z)	2.23 year^{-1}
VBGF growth constant (K)	0.71 year^{-1}	Natural mortality (M)	0.88 year^{-1}
Minimum length in sample (L_{min})	57.50 mm	Fishing mortality (F)	1.35 year^{-1}
Maximum length in sample (L_{max})	142.5 mm	Length at first capture (Lc)	73 mm
Growth performance index ($Ø'$)	4.201	Exploitation ratio (E_{cur})	0.60
Potential longevity (t_{max})	4.22 years	Exploitation ratio (E_{max})	0.67
Normalization constant (a) of LWR	0.0032	Exploitation ratio (E_{50})	0.36
Scaling power (b) of LWR	3.33	Z/K ratio	3.14

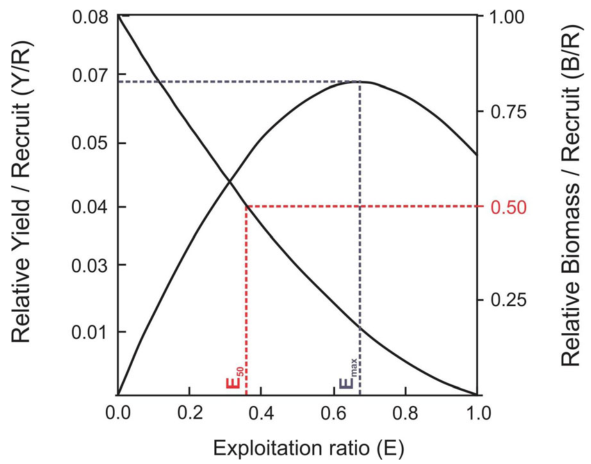

Fig. 5 Relative yield-per-recruit (*Y′/R*) and relative biomass-per-recruit (*B′/R*) analysis for *Pachypterus khavalchor* from the Panchaganga River, Maharashtra, India

terms of the aquaculture practice for this species (Raghavan et al., 2018a; Williams, Vijayalekshmi, Benziger, Karim, & Nair, 2016). Additionally, high growth performance index value in *P. khavalchor* is an interesting observation because as phi prime (ø′) is known to be highly species-specific parameter with their values being similar within related groups or taxa (Prasad et al., 2012). Interestingly, it has been shown that the ø′ value remains constant between populations of the same species (Pauly, 1979, 1981; Pauly & Munro, 1984). Lack of data on ø′ across the distribution range of *P. khavalchor* restricts between population comparisons.

The length at first capture (*Lc*) and maximum possible predicted extreme length for *P. khavalchor* for the population was estimated to be 73 mm and 143.51 mm, respectively, indicating that more than 50% of the population is being caught before they grow half of their maximum size. The *Lc* not only provides important information regarding the estimated real size of fish in the fishing area that are being caught by specific gear, but also enables the fishery managers to determine what should be the minimum size of the target species of a fishery (Kolding, Tirasin, & Karenge, 1992; Prasad et al., 2012). Due to the complete absence of the published data on reproductive biology parameters of this species, it is hard to interpret whether the immature individuals are exploited. However, several times extremely small-sized *P. khavalchor* population was observed (57.50 mm; minimum size in the study population) in the market for selling indicating that *P. khavalchor* is likely to be fished out before they mature and breed, subsequently contributing to reproductive damage and thus could be reducing the spawning stock of the species. Information on the size at maturity would be useful in re-appraised of mesh-size in this area to prevent cropping of small individuals. Clearly, investigations designed to understand various reproductive biology parameters of this species with special attention on the size at maturity would be particularly welcome.

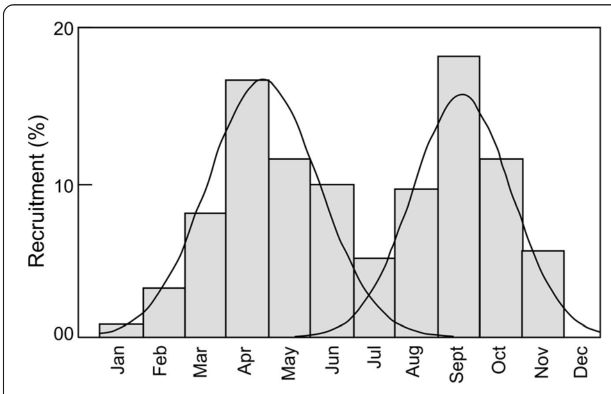

Fig. 6 Recruitment pattern for *Pachypterus khavalchor* from the Panchaganga River, Maharashtra, India

Based on the virtual population analysis, it is clear that juvenile (< 52.5 mm in size) of the *P. khavalchor* facing high natural mortality in the study area. Absence of data on the natural mortality from other localities restricts our intraspecific as well congeneric comparison. However, the observed natural mortality (0.88 year^{-1}) in *P. khavalchor* was found to be higher as compared to the other catfish species such as *Clarotes laticeps* (0.87) (Abowei & Davies, 2009), *Schilbe intermedius* (0.81) (Etim et al., 1999) and *Schilbe mystus* (0.28) (Kolding et al., 1992). Such high natural mortality could be attributed to various factors such as predation, diseases, or different environmental stressors acting independently or synergistically (Caveriviere & Toure, 1996; Raghavan et al., 2018a; Richu, Dahanukar, Ali, Ranjeet, & Raghavan, 2018). However, the exact information on the factor/s causing higher natural mortality at the small size of *P. khavalchor* is not known and thus need further investigation. On the contrary, mortality of larger size individuals (> 67.5 mm) indicating the greater fishing pressure. According to the Kumbar and Lad (2014) various catfish species inhabiting the Krishna River basin including *P. khavalchor* is subjected to various threats such as habitat modifications caused by dams, habitat loss due to sand mining, rapid development in urbanization, increasing pollution, overexploitation, destructive fishing methods (dynamite fishing). Higher fishing mortality in *P. khavalchor* could be attributed to the any of the above mentioned factor/s.

According to Gulland (1985), in an optimally exploited stock, fishing mortality should be equal to natural mortality ($F = M$), resulting in an exploitation rate (E) of 0.50. However, according to Patterson (1992) the fishing rate satisfying the optimal exploitation level of 0.5 tended to reduce the fish stock abundance and, hence, the former author suggested that 'E_{cur}' should be maintained at 0.40

for optimal exploitation of those stocks. In the present study the estimates of the fishing mortality (1.35 year^{1}) for *P. khavalchor* is close to twice as compared to natural mortality (0.88 year^{-1}) and exploitation (E) is 0.60 indicating that the study species is being heavily exploited and overfished in the study area. The results are further supported by the Z/K ratio (3.14), since according to Etim et al. (1999), Z/K ratio ≈ 2 indicate over-exploitation. The current exploitation level (E_{cur}) was estimated at 0.60 for *P. khavalchor* with predicted E_{50} and $E_{\max}$ of 0.36 and 0.67 respectively. This indicates that the present level of exploitation ($E_{\text{cur}} = 0.60$) is almost 90% that gives the maximum level of exploitation ($E_{\max} = 0.67$) and almost twice than E_{50} that maintained 50% of the spawning stock biomass. For continuity of the species in the study area, it is necessary to maintain at least 50% of the spawning stock and therefore the current level of exploitation need to decrease from 0.60 (E_{cur}) to 0.36 (E_{50}) which is approximately by 44%. Presence of the two bouts based on recruitment patterns indicating that *P. khavalchor* may exhibit two or extended spawning periods per year. However, a detailed investigation of various reproductive biology parameters such as gonado-somatic index, size at maturity, sexual dimorphism, spawning season, fecundity and spawning frequency is suggested.

Conclusions and implications for conservation

It is clear from the present investigation that *P. khavalchor* population facing the high rate of the exploitation and high fishing pressure in the study area of the Krishna River system hence appears to be unsustainable. Since currently there are no management plans for *P. khavalchor*, a chance of loss of this species is more in the near future. The rational exploitation of this species can be achieved by the implementation of conservation and management plans such as (a) decreasing the present fishing pressure by 44% of its current level, (b) size-limit regulation by gradually increasing the fishing gears mesh size, (c) reconsidering the design of the fishing methods adopted in the Krishna River to prevent capture of smaller individuals, (d) strict implementation of rules and regulations in order to minimize destructive fishing methods such as dynamite fishing, (e) time-limit regulation by restricting the fishing during spawning period, and (f) declaring a portion of the rivers inhabited by *P. khavalchor* as a natural history reserve (in support to Menon, 1999) to ensure persistence of this fish. Furthermore, due to lack of information across the distribution range, extensive and uncontrolled exploitation, and possibility of being threatened species, it is recommended to use the flag of potentially threatened (PT) species along with data-deficient status by IUCN as per suggestion by Jarić, Courchamp, Gessner, and Roberts (2016), so as to increase the focus of the scientific community and conservation decision-makers on *P. khavalchor* in order to avoid the risk that necessary conservation measures are implemented too late.

Abbreviations

B′/R: Relative Biomass per recruit; *E*: Exploitation; E_{cur}: Current exploitation rate; *F*: Fishing mortality; FiSAT II: FAO–ICLARM Stock Assessment Tools II; *K*: Growth coefficient; $L\infty$: Asymptotic length; LWRs: Length–weight relationships; *M*: Natural mortality; SL: Standard length; *T*: Average annual temperature; TL: Total length; $t_{\max}$: Potential longevity; VBGF: Von Bertalanffy growth function; VPA: Virtual population analysis; *W*: Weight; *Y′/R*: Relative yield per recruit; *Z*: Total mortality

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Availability of data and materials

Data is available with corresponding author and will be made available on request.

Authors' contributions

SMG and SSK designed the experiment, performed practical work, carried out the data analysis, and wrote the manuscript. PK and SDT contributed to the animal collection and practical work. All authors read and approved the final manuscript.

Ethics approval

In India, Indian researchers do not require permission to collect animals unless the locality of collection is in wildlife protected area (The Gazette of India, REGD. NO. D.L.–33004/99, section 17). Moreover, the present study was carried out in accordance with institutional and national guidelines for handling the experimental animals.

Consent for publication

No human subjects are included. No individual person's data are included.

Competing interests

The authors declare that they have no competing interests.

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