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RESEARCH

Fishery, growth, mortality, and stock assessment of endangered *Tor putitora* from Tehri dam reservoir, Uttarakhand, Himalayan foothills of India in relation to environmental variables

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Abstract The current study determined *Tor putitora* (Hamilton, 1822) fishery, growth, mortality, and population characteristics using length-frequency data assembled monthly from the Tehri dam reservoir in Uttarakhand from January to December 2022. The estimation data was separated into 40-mm class intervals, and population parameters were investigated and computed using the FiSAT-II software tool. $W = 0.0101\ L^{2.996}$, where $a = 0.0101$ and $b = 2.99$, were determined as the length-weight relationships, and the growth performance index (ϕ) was computed to be 5.40. *Tor putitora* commercial catches in the Tehri dam reservoir were dominated by length groups of 360–399 and 320–359 mm. Different growth parameters were estimated using length-frequency data as $L_\infty = 987.00$ mm, $K = 0.26$ yr^{-1}, and $t_0 = -0.0003$ years. *Z*, *M*, and *F* mortality coefficients were estimated to be 1.01, 0.27, and 0.73, respectively. At the end of the first, second, third, fourth, fifth, sixth, and seventh years, the fish measured 226, 400, 535, 638, 718, 780, and 827, respectively, respectively. The estimated value of the exploitation rate (*E*) was 0.73 using the length-converted catch curve approach, which was determined to be somewhat higher than the optimum value (0.50). *Tor putitora* recruitment patterns from the Tehri dam reservoir reveal that the species only has one recruitment pattern every year, and that solely occurs from June to September. The current exploitation level (0.73) has already exceeded the maximum

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fishing pressure (E_{max} = 0.508), indicating that there is a decline in the catch at the current fishing pressure, and a further increase in fishing efforts may lead to a decline in the stock, which may be detrimental to the sustainable fishery of *Tor putitora* in the Tehri dam reservoir, Uttarakhand, India.

Keywords *Tor putitora* · Tehri dam reservoir · Population dynamics · FiSAT-II · Growth parameters · Recruitment · Uttarakhand

Introduction

When compared to other Himalayan fishes, *Tor putitora* is one of the most attractive freshwater fish species, a favourably popular game fish, an "intangible and intelligent" fish species, a 'flagship' species, and an angler's delight (Everard & Kataria, 2011; Gupta, Sivakumar, et al., 2014b). Species of the genus *Tor*, as well as those of the genera *Naziritor* and *Neolissochilus,* are commonly referred to as mahseer. There are 46 mahseer species worldwide, with 23 belonging to the genus *Tor*, 22 to the genus *Neolissochilus*, and one to the genus *Naziritor* (Eschmeyer et al., 2004; Pinder et al., 2019). *T. putitora*, often known as the golden or Himalayan mahseer, is the largest mahseer species in India, growing to 275 cm in length and weighing 54 kg (Everard & Kataria, 2011; Nautiyal et al., 2008; Talwar & Jhingran, 1991). *Tor putitora* can be found in the South Himalayan drainage rivers (namely the Brahmaputra, Ganges, and Indus) from India to Pakistan, Bhutan, Myanmar, and Nepal, with its range also extending into the Eastern Brahmaputra catchments, which include the north-eastern states of India and Bangladesh (Rahman, 1989a, b).

The fish is exploited due to its size, golden colour, stunning look, and deliciousness, becoming a significant fishery around the Himalayan foothills. Anglers view the endangered *T. putitora* as one of the finest sport fishes, and it serves entertainment to sportsmen both in India and overseas. Golden Mahseer has been recognized as a valuable fish variety by fishermen because of its larger size, firm texture, high trade value, and extended shelf life. Mahseers have been declining in number and size in various parts of India in recent years (Joshi, 1988; Joshi & Raina, 1997; Pathani, 1994; Sehgal, 1971; Sehgal, 1991) due to undiscriminating fishing of brood stock and juveniles, rapid environmental deprivation of aquatic ecosystems, and dam, barrage, and weir construction as part of river valley projects (Nautiyal, 1990, 1994). As a result, the mahseer stock is threatened by several factors, including overfishing and the decreasing yield from various fish sources.

The mathematical relationship between fish length and weight is a useful measure to evaluate overall health, growth, maturity, and reproduction (LeCren, 1951), and length-weight relationships are additional tools that fishery biologists can use to assess population health (Cone, 1989). The asymptotic length, which is based on the length-weight connection, is an important component of Beverton and Holt's (1957) dynamic pool model. Estimating population factors aids in determining the most effective strategy to use and manage aquatic life resources such as fish and prawns (Sparre & Venema, 1998). It employs a variety of statistical and mathematical models to provide quantitative estimates of how different management approaches will affect fish populations (Sparre & Venema, 1998). It is required to examine how various environmental changes affect the biological and physical properties of a fish species, family, or group using various population parameter models (Beverton & Holt, 1957). Population dynamics in fin and shellfish are essential because they aid in understanding population production rates by estimating growth, mortality, and recruitment patterns (Bhakta et al., 2020; Chung & Woo, 1999). Because these characteristics influence population dynamics, they provide useful information on breeding regularity, individual and stock rejoinders to environmental changes, recruitment success, and stock structure, among other areas (Chirwatkar et al., 2021). Stock assessment demands providing objective scientific and quantitative studies for fisheries management (Hilborn & Walters, 1992). Due to the data requirements of classic or conventional stock assessment methodologies, only about half of the exploited fish species have been assessed globally (Ricard et al., 2012).

Dams were generally built to serve as water reservoirs, in addition to additional services such as flood control, irrigation, hydropower generation, water supply, fishery activities, and so on (Bid & Siddique, 2019b; Bid & Siddique, 2022). Every dam has an estimated volume of water holding capacity at the time of construction, but it gradually decreases due to siltation (Bid & Siddique, 2019a; Bid & Siddique, 2019b), which also applies to the Tehri dam reservoir. The construction of any dam offers various advantages as well as disadvantages for the local inhabitants (Bid & Siddique, 2019b). The Tehri Dam (261 m) on the Bhagirathi River near Tehri in Uttarakhand is India's most recent dam (Bid, 2016). Tehri Dam is a rock and earth-fill embankment dam that creates a 3.54 cubic kilometre reservoir with a surface area of 52 km^2. The massive multipurpose Tehri dam reservoir is located near the confluence of the Bhagirathi and Bhilangana rivers in old Tehri town, about 80 km upstream from Rishikesh in Uttarakhand's Garhwal region. Both rivers originate in the higher Himalayan glaciers and flow through deep gorges, lush forests, and human settlements. The Gaumukh river is the source of the Bhagirathi, whereas the Khatling glacier is the source of the Bhilangana (Khadse et al., 2019).

Tor putitora, an important cold-water sport fish, is reported to be diminishing owing to overfishing and habitat loss. Data from many ecosystems is required for restoration to determine the causative causes responsible for its decrease (Nautiyal & Lal, 1984a, b). Golden Mahseer numbers have dropped dramatically because of overexploitation, and the fish is now listed as an 'endangered' species on the IUCN Red List Status (IUCN, 2022). Many researchers have documented an alarming decline in mahseer population size and quantity, notably in subcontinental mountain rivers (Dinesh et al., 2010; Gupta et al. 2014b, b; Nautiyal, 2014; Nautiyal et al. 2008).

The relevant works on biology of *Tor putitora* have been carried out by Mirza (1976), Das and Pathani (1978), Pathani (1981, 1983), Pathani and Das (1979a, b), Johal and Tandon (1981), Nautiyal and Lal (1982, 1984a, b, 1985, 1988), Nautiyal (1984a, b, 1994), Dasgupta (1991a, b), Bhatt et al. (1998, 2000), Kishor et al. (1998), Nautiyal et al. (1997, 2008), Joshi et al. (2018). Most of these documents have concentrated on the biology and ecology of the fish but not as much on its growth, mortality, and population stocks.

Materials and methods

Sampling sites and collection of samples

Between January and December 2022, length frequency data was obtained from the Tehri reservoir's Dobra Chanti landing center (Fig. 1). The Tehri reservoir is India's tallest dam, built near the confluence of the rivers Bhagirathi and Bhilangana in Uttrakhand. Before the dam, the Bhagirathi River flowed freely to Devprayag. The Bhagirathi's 46-km route from Chinyalisaur to Koti Colony is currently being turned into a massive Tehri reservoir. The reservoir completely obstructed mahseer's upstream and downstream migrations. The sampling sites (Dobra Chanti) are located at 30° 26′ 49.6" N and 78° 25′ 59.5″ E. The samples were collected at monthly intervals using gill nets with mesh sizes ranging from 40 to 90 mm and cast nets with mesh sizes ranging from 15 to 20 mm.

Total fish and *T. putitora* catch data were collected monthly from the Dobra Chanti landing center of the Tehri dam reservoir. The total length (TL) and weight of the fish specimens were measured to the nearest 0.01 g using a measuring board and an electronic balance. The TL was calculated by measuring the distance between the tip of the snout and the tip of the longest caudal fin rays. On the day of sampling, the total catch of the species was observed and recorded. For the growth parameter and other population parameter assessments, length-frequency data was acquired and divided into 40 mm class intervals.

Population parameters

By entering the pooled sample at 40 mm class intervals at the ELEFAN I module of FiSAT-II software version 1.2.2 (Gayanilo Jr et al., 1996), the von Bertalanffy growth parameters L_∞ and K were determined. The age at zero length (t0) was calculated using Pauly's (1979) empirical equation.

$$\log_{10}\left(-t_0\right) = -0.3922 - 0.275\log_{10}L_\infty - 1.038\log_{10}K$$

Where L_α is the asymptotic length, and K is the growth coefficient.

Utilizing the von Bertalanffy growth function, it was possible to estimate the growth and age:

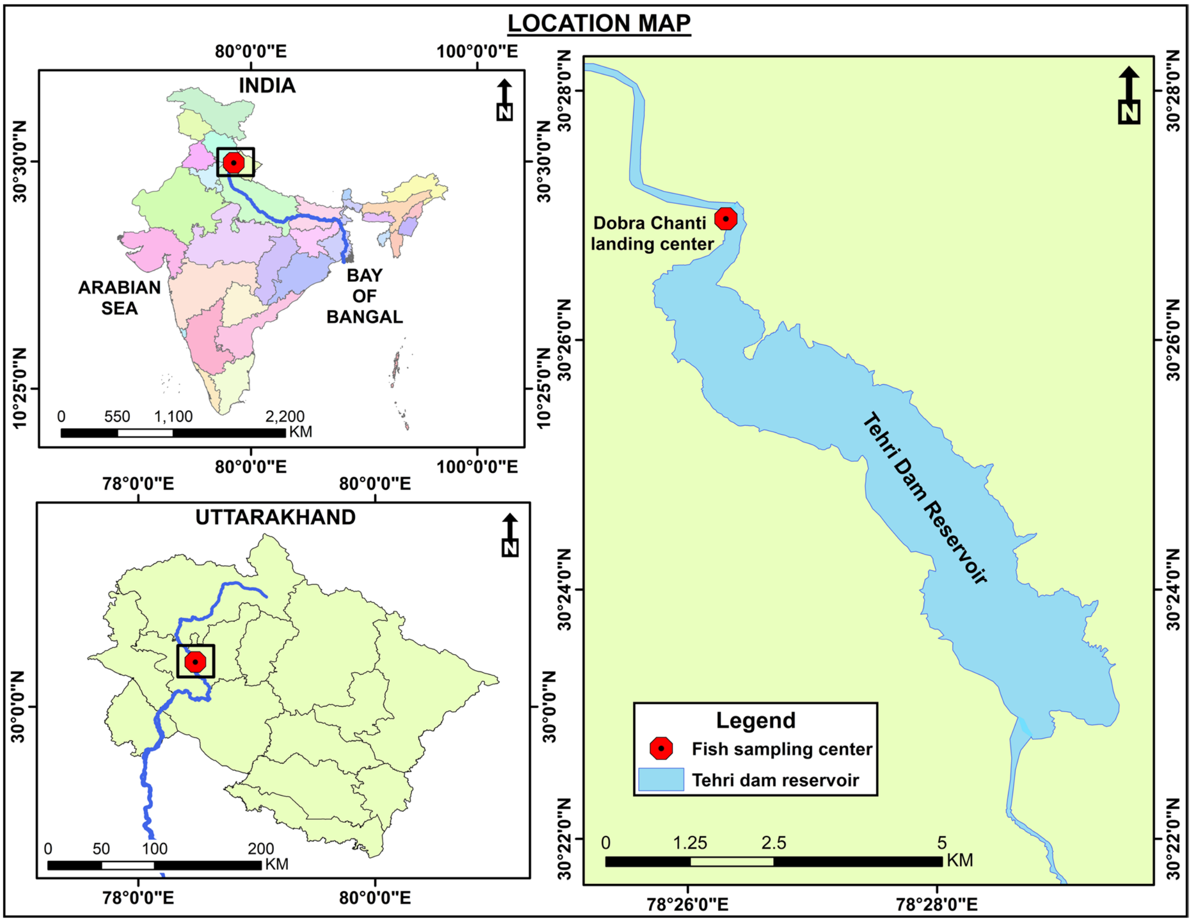

Fig. 1 Map showing the collection sites of *T. putitora* from the Tehri dam reservoir

$$L_t = L_\alpha\left(1 - e^{-K(t-t_0)}\right)$$

Where Lt is the fish's length at age t, e is the exponential growth coefficient, L_α is the asymptotic length, K is the growth coefficient, and t_0 is the age at zero length (initial condition parameter).

The growth performance index (ϕ) for the *T. putitora* population in terms of length growth was determined using the index of Pauly and Munro (1984).

$$\phi' = \mathrm{Log}K + 2\mathrm{Log}L_\infty.$$

Mortality parameters

The total mortality (Z) was calculated using the FiSAT application utilizing the length converted catch curve technique (Pauly 1983), and the natural mortality was estimated using Pauly's (1980) empirical formula:

$$\ln(M) = -0.0152 - 0.279\ln\left(L_\infty\right) + 0.6543\ln(K) + 0.463\ln(T)$$

Fishing mortality (F) was calculated as $F = Z - M$, where M is the instantaneous rate of natural mortality and Z is the instantaneous rate of total mortality. The F/Z equation was used to estimate the exploitation ratio (E).

Yield per recruit analysis

Through FiSAT II, the selection ogive approach was utilized to quantify relative yield per recruit (Y'/R) and biomass per recruit (B/R) as a function of exploitation level (E).

Virtual population analysis

Thompson and Bell's (1984) and Gulland's (1983) techniques (1969) were used to create relevant data for length-structured virtual population analysis (VPA). The species' inputs for the VPA (exponent value) were the estimated values of *L*, *K*, *M*, *F*, *a* (the length-weight relationship constant), and b (the length-weight relationship constant).

Water parameters

Water quality measurements were taken bimonthly at the chosen sample sites using the APHA-recommended techniques. To reduce the standard error, samples from each location were taken in triplicate (Apha et al., 2012). Deepness, water temperature (°C), transparency, dissolved oxygen, pH, specific conductivity, total alkalinity, and other factors were among the parameters. Throughout the sampling periods, a precisely defined sample hour (between 9.00 and 10.00 am) was maintained to allow for cross-temporal and cross-spatial comparison of the obtained parameters.

Results and discussion

Fishery, length-frequency distribution, and length-weight relationships

The total fish catch at the Dobra Chanti landing site was 2079.9 kg from January to December 2022, with *T. putitora* accounting for 94.13% of the catch composition (1969.5 kg) (Fig. 2). *T. putitora* was primarily caught using drift gillnets and cast nets, with the maximum production occurring in April and the lowest in September. During the spawning season of mahseer in the Tehri dam reservoir area, which runs from June to August, no or very limited fishing was recorded.

For the stock assessment study, length-frequency information for 476 *T. putitora* specimens was gathered and analysed from January to December 2022. The specimens measured 13.10 to 93.10 cm and weighed 23.90 to 8095.70 g. The specimens' average length was 37.52 ± 7.56 cm (mean ± SD), and the mean weight was calculated to be 617.41 ± 662.64 g. The length groups 360–399 and 320–359 mm dominated the commercial captures of *T. putitora* in the Tehri dam reservoir, according to length-frequency data analysis (Fig. 3). The length-weight relationships were determined to be $W = 0.0101\ L^{2.996}$, where $a = 0.0101$ and $b = 2.996$, with an adjusted r^2 value of 0.999, suggesting that the examined species grew isometrically. Figure 4 illustrates both the LWR curve and the regression equation.

Mahseer is one of the most threatened species in natural ecosystems (both rivers and reservoirs), and its abundance is rapidly plummeting. Gobind Sagar reservoir, formerly known as the Mahseer Storehouse, contributed as much as 9.0% of total capture in 1984–1995 but dropped to 1.0% in 1999–2000. During the 2016–17 season in the Pong reservoir, mahseer contributed 28.34 t, accounting for 7.42% of the total catch. According to IUCN (2015) and Sharma et al. (2015), *T. putitora* has decreased by more than 50% in the past and may decline by 80% in the future, owing to river management. *T. putitora* is threatened

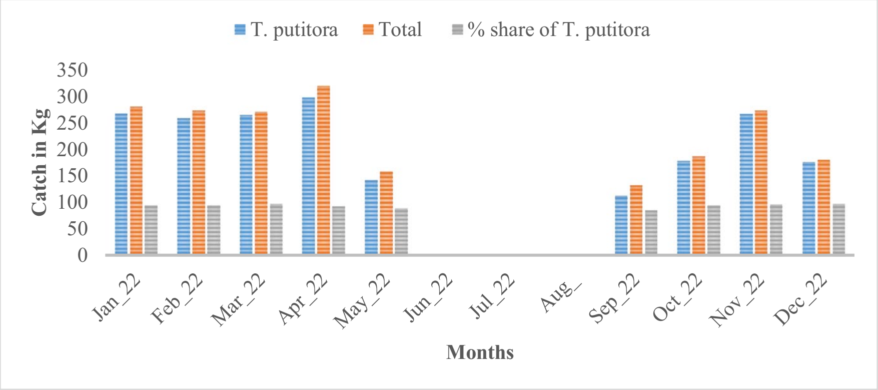

Fig. 2 *T. putitora* production data and percentage share against total production at the Dobra Chanti landing site of the Tehri dam reservoir

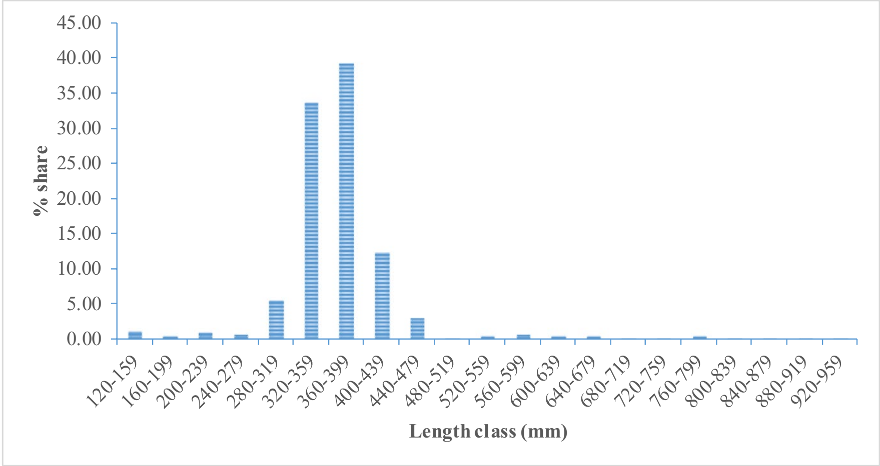

Fig. 3 *T. putitora* length-frequency distribution collected between January and December 2022 from the Tehri dam reservoir

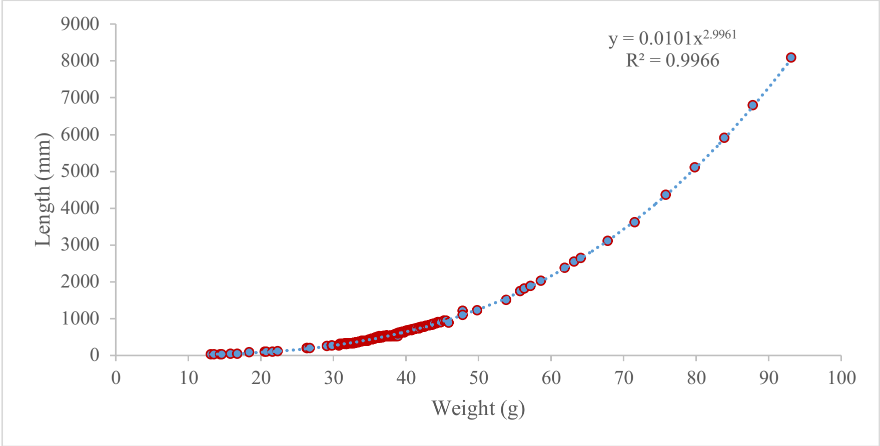

Fig. 4 *T. putitora* length-weight relationships acquired from Tehri dam reservoir between January and December 2022

by dams, barrages, and illicit sand/boulder mining, as well as poaching and indiscriminate brooder fishing (Gupta et al. 2014b, b, 2015; Lakra et al., 2010; Nautiyal, 2014; Pandit & Grumbine, 2012; Sharma et al., 2015).

The species' highest length was 931 mm, and length groups of 360–399 and 320–359 mm dominated commercial catches of *T. putitora* at the Tehri dam reservoir in Uttarakhand, India. While Banarescu and Coad (1991) recorded the species' largest length as 2750 mm and maximum published weight as 54.0 g (Rahman, 1989a, 1989b). While Singh et al. (2009) used non-linear statistical models to estimate the maximum size of *T. putitora* in different aquatic environments, they revealed that the species may attain a maximum length of approximately 3097 mm in Kumaun Lake and 2994 mm in Gobind Sagar, respectively. According to Nautiyal et al. (2008), the highest size of *T. putitora* from the Himalayan stretches of the Ganga River system was 137.7 and 135.9 cm in 1980–81 and 1994–95, respectively.

According to Bhatt et al. (2004), *T. putitora* from the mountain reaches to the Ganga dominated the catch composition of 250–320 mm length groups (27.9%), followed by the 340–370 mm length group with a 26.01% share. Singh and Nautiyal (2018) examined the length-frequency composition of the migratory population of putitora mahseer in the Alaknanda River near Srinagar, India, and determined that length groups of 300–400 mm dominated commercial catch compositions. While performing the study, we observed that the length groups of 360–399 mm dominated the length groups (39.08%), followed by 320–359 mm length groups (33.61%), which might be attributed to the adoption of higher mesh size nets.

We recognized an isometric growth pattern of *T. putitora* collected from the Tehri dam reservoir region of Uttarakhand in our study. Awas et al. (2020) reported a negative allometric growth pattern (b=2.982) of *T. putitora* from the River Poonch in the Pir Panjal Himalaya, India; Sharma et al. (2015) from the Poonch region of Jammu and Kashmir, India (b=2.940); Mir et al. (2015) from the Ganga River basin tributary in Uttarakhand, India (b=2.972), among others. Naeem et al. (2011) found that cultivated and wild *T. putitora* specimens from Pakistan's Attock District and River Korang had b values of 2.860 and 2.850, respectively, with no significant differences between farmed and wild stock. Pervaiz et al. (2012) observed an appealing allometric growth trend (b=3.210, and 3.140) of *T. putitora* from the Attock region of Pakistan. Table 1 summarizes the comparative length-weight relationship of *T. putitora* performed by other researchers in different bodies of water.

According to Ali et al. (2014), *T. putitora* grows in an isometric pattern and grows more slowly than other fish in its environment (Pathani & Das, 1980). Unprecedented river management and water withdrawals through a succession of dams are expected to endanger the expansion of the fish population in Himalayan rivers because lotic waters are regarded as more favourable to growth than lentic waters (Gupta, Nautiyal, et al., 2014a; Pandit & Grumbine, 2012).

Age and population parameters

The growth parameters L_∞ and K were estimated using the ELEFAN approach to be 987.00 mm and 0.26 yr^{-1}, respectively (Fig. 5), and the value for t_0 was calculated to be −0.0003 years. According to the asymptotic length value, *T. putitora* can grow to 987.00 mm in the Tehri Dam reservoir if not subjected to fishing activities. The estimated growth performance index φ' was calculated as 5.40. The presence of 15 growth curves, suggesting the presence of 15 cohorts or size groups of *T. putitora* in the Tehri dam reservoir, was discovered by superimposing length-frequency growth curves. As a result, *T. putitora* achieved lengths of 226, 400, 535, 638, 718, 780, and 827 mm after 1, 2, 3, 4, 5, 6, and 7 years, respectively (Fig. 6). The largest size measured in this study was 93.10 cm, with an estimated age of 11.25 years.

For the management and evaluation of fisheries, estimating a fish population's age and growth is essential. These projections, in general, aid in understanding the age distribution of the fluctuating catch, the maturity size at the time of capture, and the composition of the fish population. There have been few reports on the growth features of *T. putitora* from various water bodies in India and its bordering countries. Sparre and Venema (1998) determined that the growth coefficient k=1.0 yr^{-1} for fast-growing fish, 0.5 yr^{-1} for moderate-growth fish, and 0.2 yr^{-1} for slow-growing fish. The current value of k=0.26 shows that the species grows slowly. The current study also discovered a lower value of L_∞ than Nautiyal et al. (2008), who both analysed Ganga River dimensions in the Himalayas. Nautiyal et al. (2008) estimated k=0.035 yr^{-1} (1980–81) and 0.041 yr^{-1} (1994–95) of *T. putitora* from the Ganga River system in the Himalayas. Pathak (1991) found a low value of k=0.070 for *T. putitora* specimens taken

Table 1 *Tor Putitora* estimated length-weight relationship, investigated by several researchers from other water bodies

Author	Region	n	a	b	r^2	Growth pattern
Singh & Shafiq, 2022	Ranjit Sagar reservoir		1.909	2.932	0.991	Negative allometric
Naeem et al., 2011	Attock District, Pakistan (Farmed)	42	0.01660	2.860	0.997	Negative allometric
Naeem et al., 2011	River Korang, Pakistan (wild stock)	106	0.01710	2.850	0.991	Negative allometric
Pervaiz et al., 2012	Attock, Pakistan	27	0.00590	3.210	0.969	Positive allometric
Pervaiz et al., 2012	Attock, Pakistan	25	0.00440	3.140	0.987	Positive allometric
Bashir et al., 2015	Indus River Basin in Jammu and Kashmir, India	52	0.00870	2.960	0.993	Negative allometric
Mir et al., 2015	Ganga River basin tributary, Uttarakhand, India	29	0.01450	2.972	0.986	Negative allometric
Sharma et al., 2015	Poonch region of Jammu and Kashmir, India	36	0.00978	2.940	0.992	Negative allometric
Sharma et al., 2015	Indus basin tributary in the Poonch region of Jammu and Kashmir, India	36	0.00978	2.940	0.992	Negative allometric
Awas et al., 2020	River Poonch, Pir Panjal Himalaya, India	26	0.03280	2.982	0.978	Negative allometric
Present study	Tehri Dam Reservoir, Uttarakhand	476	0.0101	2.996	0.999	Isometric

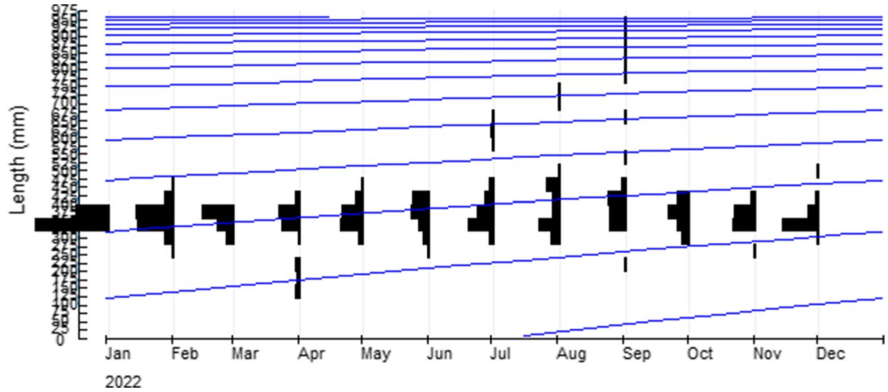

Fig. 5 Growth curve of *T. putitora* collected from the Tehri dam reservoir by employing ELEFAN I (L_∞ = 987.00, and K = 0.26 yr^{-1})

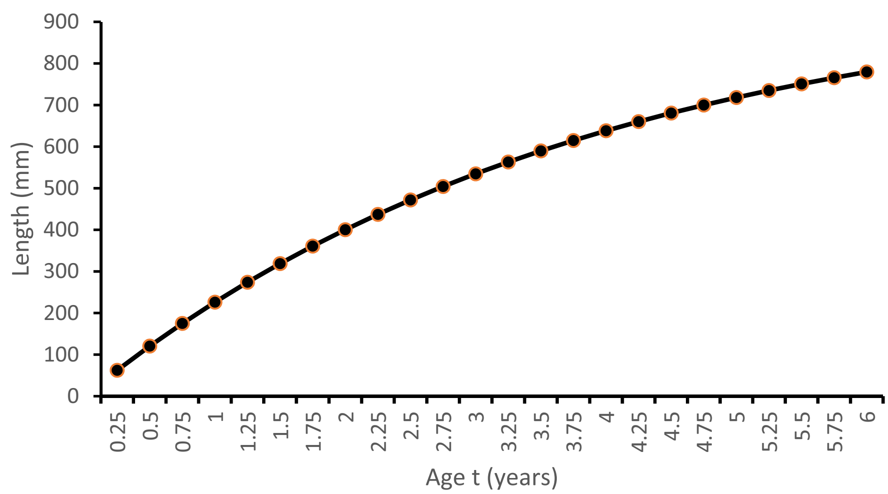

Fig. 6 Average length attained by *T. putitora* at different ages from Tehri dam reservoir

from the Sarju River in the Kamaun Himalaya. Changes in water parameters, food availability, metabolic activity, and pollution are just a few of the many factors that may trigger L_∞ and K changes within the same species (Sparre & Venema, 1998).

In the current study, the ϕ' value (5.40) was found to be slightly higher than that of Pathak's (1991). They discovered a value of 3.19 in specimens obtained from the Sarju River in the Kamaun Himalaya. In general, phi-prime values vary between 2 and 4 and are stable across species, families, and taxonomic groups (Mazumdar et al. 2012; Bhakta et al., 2020). The variation between species is mostly due to changes in K values, environmental variability, and various fishing intensities (Mazumdar et al. 2012). Abowei (2010) attributes a high-performance index to fish survival tactics' capacity to elude predators by growing swiftly and minimizing the risk of becoming prey.

Based on the scale ring count, *T. putitora* can grow to lengths of 190–220 mm, 250–231 mm, 340–370 mm, 430–460 mm, 520–550 mm, 580–610 mm, 580–670 mm, and 790–820 mm at the age groups of 1+, 2+, 3+, 4+, 5+, 6+, 7+, and 8+, according to Bhatt et al. (2004). They also saw a single specimen of 980 mm in length from the 9+ age group.

T. putitora were discovered by Johal et al. (1999) and Bhatt et al. (2004) in the Ganga River in Uttarakhand and the Gobind Sagar reservoir in Himachal Pradesh, respectively, at ages of 15+ and 17+. Bhatt et al. (2004) noted 5+ age classes in males and 9+ age classes in females in the Ganga foothills. We discovered that *T. putitora* can grow at 226, 400, 535, 638, 718, 780, and 827 mm at the end of 1, 2, 3, 4, 5, 6, and 7 years in our study, which is almost identical to earlier work. Table 2 summarizes other researchers' comparative population parameters (L_∞, K, and t_0) investigations of *T. putitora* from different water bodies.

Mortality and exploitation parameters

The total yearly mortality rate (Z) was determined using the length-converted catch curve approach by integrating the values of L_∞ and K. Total mortality (Z) was estimated to be 1.01 using the average yearly surface temperature of the Tehri dam reservoir throughout the study period of 16.2 °C; natural mortality (M) was 0.27, and fishing mortality (F) was 0.74. Fishing mortality was discovered to be somewhat higher than natural mortality. The calculated exploitation level (E) was 0.73 (Fig. 7), which was determined to be more than the optimum exploitation rate (0.5). Table 3 displays the various population parameters of *T. putitora* estimated from the Tehri dam reservoir.

The current study estimated overall mortality (Z), natural mortality (M), and fishing mortality (F) to be 1.01, 0.27, and 0.73, respectively, based on length-converted catch curve analysis. According to Nautiyal et al. (2008), *T. putitora* specimens collected from the Himalayan stretch of the Ganga River System had a M value of 0.054. The amount of fishing, disease, pollution, predation, old age, and other factors all have an impact on fishing mortality (Bhakta et al., 2020; Johnson et al., 2020).

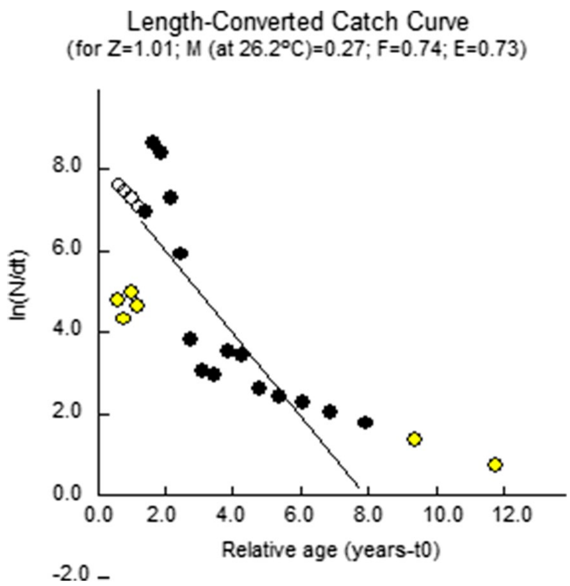

Fig. 7 A length converted catch curve was used to estimate the Z of *T. putitora* collected from the Tehri dam reservoir

Probability of capture, recruitment pattern, and yield per recruit

The estimated length values for *T. putitora* capture probabilities of 25% (L_{25}), 50% (L_{50}), and 75% (L_{75}) were 241.72 mm, 273.90 mm, and 307.12 mm, respectively (Fig. 8). *T. putitora* recruitment from the Tehri dam reservoir indicates that the species has a distinct recruitment period from June to September (Fig. 9). It is also possible that spawning of *T. putitora* from the Tehri dam reservoir begins in June and may continue until September.

Table 2 Estimation of L_∞, k, t_0 and ϕ of *some Tor* spp. studied by various researchers from other bodies of water

Species	Author	Region	L_∞ (mm)	k (yr^{-1})	t_o	(ϕ)
T. putitora	Johal & Kingra, 1989	Gobindsagar	135	–	–	–
T. putitora	Pathak, 1991	Sarju River, Kamaun Himalaya	1480	0.070	−0.25	3.19
T. putitora	Nautiyal et al., 2008 (1980–81)	Himalayan Stretch of the Ganga River System	272.2	0.055	−0.031	
			216	0.056	−0.015	
Tor tor	Desai, 2003	Paisuni,	787	0.61	–	–
		Ken	822	0.78	–	–
		Tons	946	0.50		
Tor tor	Desai, 2003	Narmada	875	0.136	–	3.02
T. putitora	Present study	Tehri Dam Reservoir, Uttarakhand	987.0	0.26	−0.0003	5.40

Table 3 Various population parameters of *T. putitora* collected from Tehri Dam Reservoir during January–December 2022 ($N=476$)

Parameter	Value
Asymptotic length (L_∞) in mm	987.00
Initial condition factor (t_0)	−0.0003
Growth coefficient (K) yr^{-1}	0.260
Growth performance index (ϕ')	5.40
Length at first capture (L_c) in mm	273.90
Total mortality coefficient (Z yr^{-1})	1.01
Natural mortality coefficient (M yr^{-1})	0.27
Fishing mortality coefficient (F yr^{-1})	0.73
M/K value	0.1.04
Exploitation ratio (E)	0.73

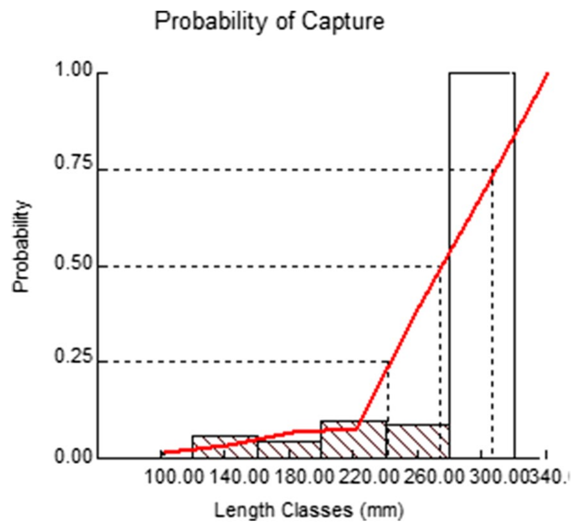

Fig. 8 Probability of capture of *T. putitora* collected from the Tehri Dam reservoir during January–December 2022

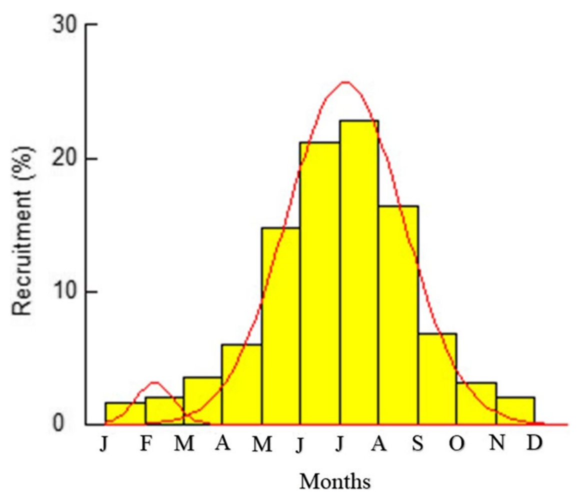

Fig. 9 Recruitment pattern of *T. putitora* collected from the Tehri Dam reservoir during January–December 2022

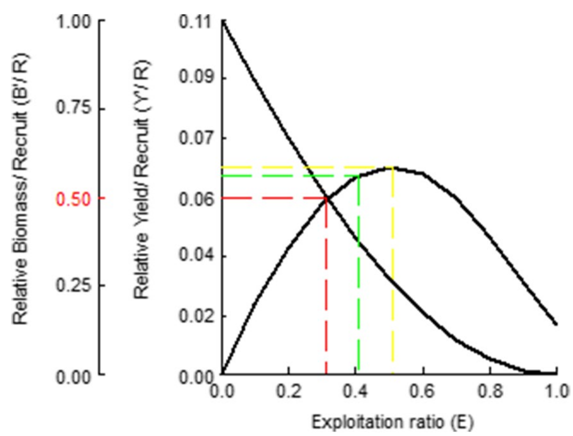

Fig. 10 Relative yield per recruit and relative biomass per recruit model using selection ogive curve for *T. putitora* collected from Tehri dam reservoir during January–December 2022

The relative yield per recruit (Y'/R) and biomass per recruit (B/R) of *T. putitora* were calculated using the FiSAT-II selection ogive procedure (Fig. 10). The input data to estimate those were L_c/L_∞ (0.278) and M/K value (1.04). The estimated E_{max}, $E_{0.1}$, and $E_{0.5}$ values from the relative yield per recruit (Y/R) analysis were 0.409, 0.314, and 0.508, respectively. The current estimation revealed that the maximum yield for *T. putitora* could be obtained at an E value of 0.508. Furthermore, when $E=0.314$, 50% of the biomass could be obtained as a yield, as shown in red in Fig. 10.

The probability of capturing any stock at different length groups is a crucial management consideration for fisheries (Bhakta et al., 2022; Mustafa et al., 2021). *T. putitora* length at first capture (*Lc*) was 273.90 mm, which is much smaller than the 770.5 mm length regarded as the size at first maturity as reported by Nautiyal (1994). There are few opinions on *T. putitora* reproductive capacity in various water bodies in India. *T. putitora* spawns twice a year, according to Johal and Tandon (1981), around April–May, and Malik (2011), between July and October. Initially, Khan (1939) discovered that *T. putitora* had three spawning seasons, which is contradicted by Hora (1940). According to Nautiyal (1994), the spawning season of *T. putitora* from the Alaknanda and Nayar, two key tributaries of the river Ganga and regarded as an annual breeder in the Garhwal Himalayas, occurs between July and September. *T. putitora*, on the other hand, spawns all year in India's Bhakra reservoir, according to Bhatnagar (1964). Snow trout, *Schizothorax richardsonii* spawn twice a year (July–October and January–February) in the river Gaula (Kumaon, Himalaya), according to Mohan (2011). Joshi et al. (2018) observed that *T. putitora* collected from the Kosi River in Ramnagar District of Uttarakhand spawns from July to September. The most accepted spawning seasons for *T. putitora* were during the monsoon season (Nautiyal, 1984a, b; Thomas, 1897), which agrees with the current findings. The comparative spawning season of *T. putitora* studied by other researchers is provided in Table 4. The knife-edge selection process yielded per-recruit values of 0.409, 0.314, and 0.508 at E_{10}, E_{50}, and E_{max}.

Virtual population analysis

The length at first capture ($Lc = L_{50}$) of *T. putitora* was estimated to be 273.90 mm using the probability of capture analysis and the selection curves (Fig. 11). The results obtained from length-structured VPA are depicted in Fig. 11. The input parameters used for VPA were $L_{\alpha} = 987$ mm, $K = 0.26$ yr^{-1}, $M = 0.27$ yr^{-1}, $a = 0.0101$, and $b = 2.996$ from the length-weight studies in gram and millimetre.

Fishing mortality for *Tor putitora* in the Tehri dam reservoir was considerably greater between length groups of 360–399 and 320–359 mm, according to the virtual population analysis. According to Bhatt et al. (2000), the age classes of *T. putitora* in the river Ganga that are most prevalent are those that are 2–4+ years old, and they made up about 73.0% of the species' overall catch. According to Bhatt et al. (2004), golden mahseer was the dominant species in the Ganga River's foothill section during 1993–1994, accounting for around 19% of the total annual catch. In addition, *Tor putitora* made a significant contribution to the commercial fishery in some lacustrine water bodies, including Gobindsagar reservoir, Pond reservoir, and Bhimtal (Johal et al., 1994; WWF, 2013).

Water parameters

Standard techniques were used to analyse the water quality attributes of the Tehri dam reservoir bimonthly, and the range and average data of selected

Table 4 Spawning season of *T. putitora* reported by other researchers in different water bodies

Author	Location	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Dunsford, 1911	Kumaun Lake			■	■	■	■						
Khan, 1939	Ganga River		■	■		■	■	■					
Pathani and Das, 1979	Lumaun Lakes				■	■	■	■					
Pathani, 1983	Kumaun River				■	■	■	■					
Nautiyal, 1984	Garhwal Himalayas				■	■	■	■					
Mohan, 2000	Gaula River					■	■						
Dobriyal et al., 2000	Garhwal Hills					■	■	■					
Nautiyal et al., 2007	Ganga River					■	■	■					
Malik, 2011	Garhwal region		■	■		■	■	■					
Joshi et al., 2019	Kosi River					■	■	■					
Present study	Tehri Dam Reservoir				■	■	■	■					

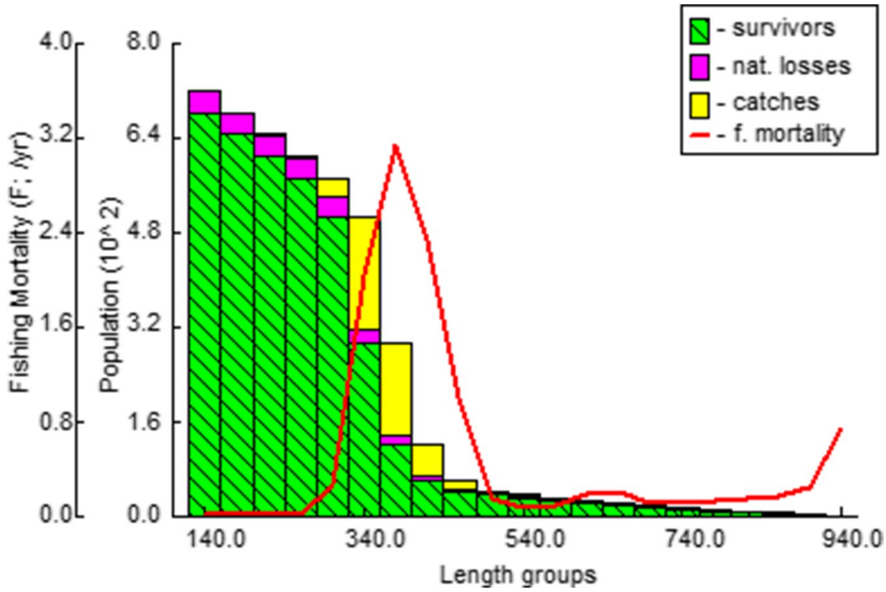

Fig. 11 Length-structured virtual population analysis of *T. putitora* collected from Tehri dam reservoir during January–December 2022

Table 5 Water quality parameters of the Tehri Dam reservoir for 2022

Parameters	Range	Mean ± SD
Depth (m)	8.20–52.20	23.98 ± 15.73
Water temp. (°C)	17.70–31.30	23.63 ± 4.77
Transparency (cm)	55.00–355.00	199.67 ± 87.86
Specific conductivity (μS/cm)	79.60–150.00	114.61 ± 23.73
pH	7.40–9.76	8.44 ± 0.77
DO (mg/l)	7.00–8.20	7.76 ± 0.37
TDS (mg/l)	56.30–96.00	77.03 ± 13.12
Turbidity (NTU)	2.47–22.90	9.82 ± 6.73
Total alkalinity (mg/l)	30.00–46.00	36.00 ± 5.31

parameters are shown in Table 5. During the monsoon season, there is a prevalent high-water capacity with a depth of 8.20–52.0 m. The water exhibited very high transparency and was somewhat less turbid (199.67 ± 87.86 cm). Low TDS (77.03 ± 13.12 mg/l) and conductivity (114.61 ± 23.73 S/cm) were induced by monsoon rain and dilution. The pH of the water was alkaline (8.44 ± 0.77), making it a good habitat for fish. The reservoir water's dissolved oxygen concentration was found to be adequate (7.76 ± 0.37 mg/l). The fact that the total alkalinity was low (36.00 ± 5.31 mg/l) could be attributable to rainfall dilution.

The parameters of the Tehri dam reservoir's water quality have been found to be suitable for fish growth, particularly for the endangered *T. putitora*, and it was further found that anthropogenic activities such as domestic, industrial, or agricultural discharge have no discernible impact on the reservoir's water quality (Khadse et al., 2019). According to Khadse et al. (2019), the following water parameters were found in the Tehri dam reservoir: pH 7.3–7.7, specific conductivity 102–130 μS/cm, turbidity 3.0–6.0 NTU, TDS 61–78 mg/l, total alkalinity 38–54 mg/l, etc. While Ayoade and Agarwal (2012) studied the physical and chemical parameters of water in the Tehri dam reservoir during the post-impoundment period and certain parameters were obtained: water temperature 16.5–29.3 °C, transparency 55–158 cm, turbidity 1–12 NTU, pH 4–9.8, DO 6.9–11.75 mg/l, conductivity 59.6–93.5 mg/l, TDS 31.04–46.8 mg/l, alkalinity 40–78.2 mg/l, etc. The physicochemical parameters of the Tehri dam reservoir were reported by Agarwal and Rajwar (2010) as follows: water temperature 7.03–27.03 °C, pH 6.79–7.98, DO 6.56–8.96 mg/l, alkalinity 37.2–70.8, and so on. The current record of water parameters is within the range of previous studies in the same environment.

Conclusions

Tor putitora is a game and food fish that lives in mountainous rivers. It grows slowly and has a long-life span. *Tor putitora* is a widespread species that can flourish in both lentic and lotic waters. The current study evaluated the fisheries, growth, mortality, and population information of *Tor putitora* collected from the Tehri dam reservoir in Uttarakhand between January and December 2022. The exponent *b* value was reported to be 2.996 based on the length-weight relationships, indicating an isometric growth pattern of the species in the studied environment with a high r^2 value of 0.999. According to the length-frequency distribution, length groups of 360–399 and 320–359 mm dominated commercial catches of *T. putitora* in the Tehri dam reservoir. This species' estimated fishing mortality (0.73) is higher than its natural mortality (0.27), indicating that it is already excessively exploited, which means fishing pressure should be lowered immediately. *Tor putitora* can grow to 226 mm, 400 mm, 535 mm, 638 mm, 718 mm, 780, and 827 mm at the end of the first, second, third, fourth, fifth, sixth, and seventh years, showing a moderate growth rate with a *K* value of 0.26 yr^{-1}. The current study shows that *T. putitora* is over-exploited in the studied water bodies, with an exploitation rate of 0.73, which is substantially higher than the optimum value (0.50) for sustainable yield.

The results indicate that the growth and mortality parameters of *T. putitora* are nearly identical to those of other *Tor* species found in Indian waters. The findings of this study will be useful in determining the population parameters of an extremely commercially significant species in the Tehri dam reservoir. The information acquired from this study will be useful in assessing population dynamics as well as fishing gear selectivity. Furthermore, current research revealed that *T. putitora* is subjected to heavy fishing pressure, which must be reduced immediately in order to ensure a sustainable yield in the Tehri dam reservoir in the future.

Thus, protecting the imperilled and highly valuable golden mahseer in the rivers of the Himalayas is of utmost importance. It is crucial to make considerable efforts for the protection of this exquisite fish species, even though the majority of Mahseer's important riverine habitats have been subjected to or are currently being regulated for irrigation and hydropower. Due to its ecological importance, the species has earned the nicknames "tiger of water" or "tiger of rivers," and it has been suggested that it serve as a "flagship" species to increase awareness among the public, conservationists, and fishermen. Priority should be given to ecosystem-based conservation management for *T. putitora*, which involves locating and safeguarding appropriate breeding habitats as well as banning fishing during the monsoon season. Sustainable fishing may be allowed during non-monsoon months with restrictions on gear size and a fine for catching fingerlings and juvenile fish. A long-term conservation plan would be to conserve mahseer ex situ by building hatcheries.

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Code availability "Not applicable" for that section.

Authors' contribution Dibakar Bhakta (DB)- Data entry, analysis, and manuscript writing.

Basanta Kumar Das (BKD)- Conceptualization, and editing.

Upendra Singh (US)- Field data collection, data entry and analysis.

Archisman Ray (AR)- Data entry and analysis.

Canciyal Johnson (CJ)- Data entry and analysis.

Venkatesh Ramrao Thakur (VRT)- Manuscript editing.

Sandeep Kumar Mishra (SKM)- Field data collection.

Sushil Kumar Verma (SKV)- Field data collection.

Absar Alam (AA)- Manuscript editing.

Dharam Nath Jha (DNJ)- Manuscript editing.

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Data availability This article contains all the study's data, which are also included in this article and are accessible upon proper request.

Declarations

Conflict of interest It is stated by the authors that they have no competing interests.

Ethical approval The study was carried out in accordance with the ethical committee of the institute's rules.

Consent to participate The study's authors received permission from them to take part.

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