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Indian Journal of Animal Sciences **96** (2): 156–163, February 2026/Article
https://doi.org/10.56093/ijans.v96i2.176420

Length-frequency based stock assessment of *Puntius sophore* (Hamilton, 1822) in Kasaraiya Dhar Wetland, Bihar, India

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Received: 24 February 2026; Accepted: 15 May 2026

ABSTRACT

The population dynamics of *Puntius sophore* was investigated in Kasaraiya Dhar Wetland, Bihar, India, using monthly sampling (n=149) over a period of one year. Length–frequency data of *P. sophore* were analyzed using the FAO-ICLARM Stock Assessment Tools II (FiSAT II). Growth parameters, including asymptotic length ($L\infty$) and growth coefficient (K) were estimated through ELEFAN on von Bertalanffy Growth Function. The estimated growth parameters were asymptotic length ($L\infty$) = 102.90 mm, growth coefficient (K) = 0.65 yr^{-1} and length at zero age (t_0) = –0.177 yr. The positive allometric growth length-weight relationship (W = 2E-06$L^{3.4158}$; R^2 = 0.9345) and Fulton's condition factors (1.0169 and 1.0446, respectively) indicated favourable habitat conditions for *P. sophore* in Kasaraiya Dhar. Natural mortality (M) was estimated at 0.93 yr^{-1}, total mortality (Z) at 1.75 yr^{-1} and fishing mortality (F) at 0.81 yr^{-1}. Exploitation ratio (E = 0.40) confirmed that *P. sophore* stocks were currently underexploited relative to the optimum of E= 0.5. The dominance of natural mortality over fishing mortality reflected limited fishing efficiency due to dense macrophyte cover, which provides refuge and breeding habitat. Overall, the study indicates that *P. sophore* populations in Kasaraiya Dhar are in good condition and were being moderately exploited under prevailing ecological conditions. Macrophyte management needs to be prioritized to support recruitment and achieve for maximum sustainable yield *P. sophore* from Kasaraiya Dhar. The findings provide essential baseline information for future stock assessments and for developing strategies aimed at the rational and sustainable exploitation of this species.

Keywords: Exploitation ratio, Growth parameters, Kasaraiya Dhar wetland, Mortality, *Puntius sophore*,

Wetlands are indispensable aquatic ecosystems providing critical services, including water purification, flood regulation and carbon sequestration (Lianthuamluaia *et al.* 2024; Mitsch *et al*. 2025). In rural regions, they are vital for food security, particularly through the harvest of small indigenous fishes (SIF) like *Puntius sophore* (Hamilton 1822) (Hossain *et al*. 2013, Choudhury *et al.* 2015, Singh *et al*. 2023). Despite its importance, *P. sophore* faces escalating threats from habitat degradation, climate change and unregulated fishing in inland aquatic ecosystem (Mitra *et al.* 2005, Sandilyan 2022). However, population structure, growth, reproduction and feeding habits, breeding and proximate composition of *P. sophore* have been documented by various researchers in India and Bangladesh (Supple Table 1), but stock-specific data for the Middle Gangetic region, particularly Bihar, remains critically lacking. In Bihar, the study by Ahirwal *et al.* (2022) provided biometric evaluation from the River Ganga, but no comprehensive stock assessment (including mortality, exploitation ratios and recruitment patterns) has been conducted for the ecologically distinct wetlands of Bihar. Such wetlands are highly vulnerable to hydrological alteration and macrophyte overgrowth, making stock assessment mandatory to establish baseline population parameters before potential declines occur. Stock assessment is a fundamental activity for sustainable fisheries management, and provids essential data on growth, recruitment and mortality (Sparre and Venema 1998, Shewit *et al.* 2021). Such parameters are vital for tracking population condition in ecological sensitive wetland like - Kasaraiya Dhar (Lianthuamluaia *et al*. 2024). The present study evaluated the population structure, growth dynamics and recruitment of *P. sophore* in Kasaraiya Dhar. It also estimated natural, fishing and total mortality rates alongside exploitation levels while analyzing length-weight relationships and condition factors to assess overall growth performance. The findings from this year-long investigation aimed to provide an evidence-based framework for the conservation and management of SIF species with ensuring the long-term sustainability of wetland fisheries.

MATERIALS AND METHODS

Monthly sampling was carried out at Kasaraiya Dhar wetland, which is located east of Khagaria town in Bihar,

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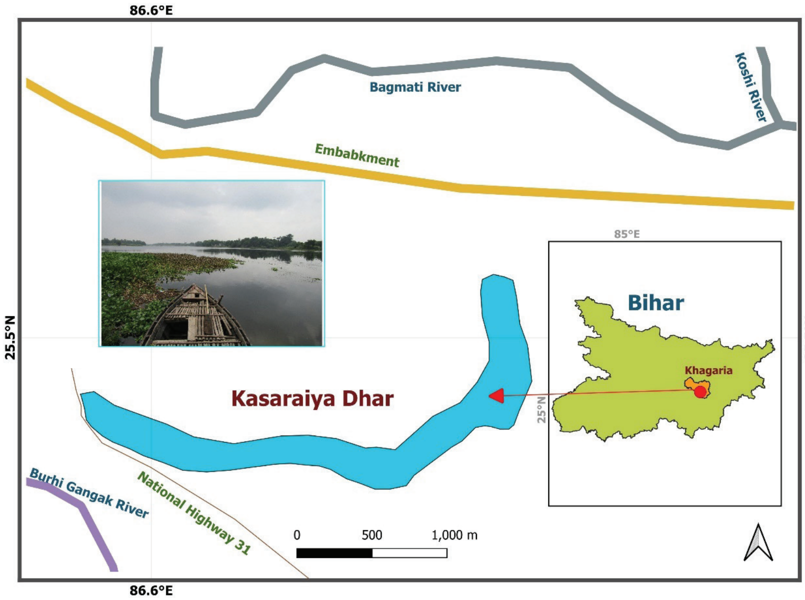

Fig. 1. Map of study area in Bihar

a perennial oxbow lake in Khagarai District. Kasaraiya Dhar extends approximately 6 km, from national highway (NH31) on the western side to Farreh on the north-eastern side covering an area of more than 100 ha with 20 feet depth. The catchment area of this wetland has lost its connectivity from mother river (Burhi Gandak) due to formation of railway line and NH31 in western side and erection of embankment on Bagamati river in north-eastern side (Fig. 1). About 80% area of the wetland was occupied by water hyacinths (*Eichhornia crassipe*), Azolla (*Azolla pinnata*), lemna (*lemna minor*), Cyprus sp., *Hydrilla* sp., *Ceratophyllum* sp., etc throughout the year, water hyacinth was the most predominant species covering the area of more than 85%.

In the current study, 149 specimens 18.3-102.2 mm in total length (TL), and 0.054 to 13.619 g total weight (W) were collected monthly by the gill net (20-40 m length and 1.2 -1.5 m width, 10-15 mm mesh size, operation time 8 h) and *Chatti Jal* (a type of seine net with small mesh size, operated for 4 h from the traditional wooden boat (dingy) from January 2023 to December 2023. To minimize bias and ensure a representative population snapshot, catch data from both selective (gillnets) and non-selective (seine nets) gears were pooled. Further, no seasonal stratification or effort standardization was applied in this study during the sampling. The specimens were immediately placed in ice, and were transferred to the laboratory on the same day, where they were identified on the basis of morpholmetric and meristic taxonomical characteristics (Jayaram 1991; Talwar and Jhingran 1991). Each individual's total length (TL) was measured between the tips of the snout and the end of caudal fin to the nearest 1 mm using a digital vernier caliper (size - 0/150 mm) and weight was recorded to the nearest 0.1 mg using a digital balance (WENSAR TM-MAB 220).

A thorough audit of the raw data was conducted to avoid any inconsistencies in length-weight relationship calculation or outlier data points have been before estimation of length-weight relationship. The length-weight relationship (LWR) was estimated using the formula given by Le Cren (1951):

$$W = a\,L^{b}$$

The relationship was expressed in the logarithmic form as:

$$\text{Log } W = \text{Log } a + b \text{ Log } L$$

where, W = weight of fish in g, L = length of fish in mm, "a" and "b" are intercept and regression coefficient, respectively.

The FAO-ICLARM Stock Assessment Tools II (FiSAT II) is a standardized software package specifically designed for the analysis of length-frequency data, making it an indispensable tool for fish stock assessment for data-limited condition in tropical environments (Gayanillo *et al*. 2005). Electronic Length Frequency Analysis (ELEFAN) in (FiSAT II) was used for estimating fish growth parameters through von Bertalanffy growth function (VBGF) and mortality rates from length-frequency data. The ELEFAN relies on the assumptions that i) sample data is representative of the entire population's growth dynamics, ii) natural and fishing mortality are constant across the size classes iii) peaks (model) in a length-frequency histogram represent distinct age cohorts and iv) fishing gear used to collect the data does not significantly bias the size structure of the sample.

Length-frequency distributions for *P. sophore* were constructed using 10.0 mm class intervals of TL. A normal frequency distribution was established to fit the total length frequency distribution of *P. sophore*, employing the Microsoft excel. The asymptotic length ($L\infty$) and growth coefficient (K), were estimated using the ELEFAN module of FiSAT II (Gayanillo *et al*. 2005). Age at length zero (t_0) was calculated using the following equation Log10 ($-t_0$) = -0.3922 - 0.2752 log10 L∞ - 0.1038 log 10 K. Growth performance index (φ') was computed by the formula φ'=log K+ 2log L∞. Beverton and Holt's relative yield per-recruitment (Y/R) was estimated using the model of Beverton and Holt (1966). The instantaneous total mortality rate (Z) was estimated by using the length-converted catch curve. The natural mortality rate (M) was estimated by Pauly's empirical formula (Pauly 1980): ln (M) = -0.0152 - 0.279 ln (L∞) + 0.6543 ln (K) + 0.463 ln (T), where the mean water temperature was taken as 26.8° C (based on field survey data collection) and fishing mortality rate (F) was estimated as (Z - M). The current exploitation rate was calculated as E = F/Z (Ricker 1975). Fulton's condition factor (KF) was calculated using Fulton's equation (1904): KF = 100 × (BW/TL^3). Furthermore, the relative condition factor (KR) was calculated following Le Cren (1951): KR = BW/ (a × TL^b), where 'a' and 'b' are parameters of LWR. Both KF and KR are sensitive to short-term environmental fluctuations, reproductive cycles and sampling bias.

RESULTS AND DISCUSSION

The growth curves of *P. sophore* obtained through restructured length-frequency analysis revealed the presence of several distinct cohorts within the population in Kasaraiya Dhar wetland (Fig. 2). The result of present study indicated continuous recruitment and an extended breeding period throughout the year for this species. Such numerous cohort distribution suggested that the environmental conditions were favourable to support successive spawning events and sustained growth of *P. sophore* in this wetland ecosystem.

The asymptotic length (L∞), growth coefficient (K) and a theoretical age at obtained from ELEFAN analysis in FiSAT II showed the variation in goodness-of-fit across different growth coefficient (K) values. The peak score (0.309) K = 0.65 year^{-1} indicated optimal growth parameter, providing the best fit to the length-frequency data. The growth performance index (Φ′) corresponding to the optimal K value was estimated to be approximately 3.7–3.8 (Fig. 3), indicating moderate growth performance. This value falls within the expected range for small tropical cyprinids, including *P. sophore*, suggesting that the estimated growth parameters were biologically consistent. The estimated asymptotic length (L∞,102.90 mm) for habitat heterogeneity played a central role in regulating growth in Kasaraiya Dhar is comparable to values reported from similar wetland systems (Hossain *et al.* 2006), but lower than those observed in riverine environments (L∞ = 123.5 mm, K = 1.18 yr^{-1}, t_0 = –0.767 yr^{-1}, Φ′=4.241) such as the Sutlej (Kumar *et al*. 2021). Ahamed *et al*. (2012) observed comparatively lower growth rates in Bangladesh population (males: L∞ = 63.9 mm, K = 0.156 yr^{-1}; females: L∞ = 74.17 mm, K = 0.141 yr^{-1}). Such inter-regional variability in groth parameters is not merely descriptive but reflects the underlying ecological processes. According to Julius *et al.* (2025), fish growth patterns are also influenced by life-stage body morphology, reproductive cycles and fishing pressure. In the context of Kasaraiya Dhar, the moderate growth rate of *P. sophore* was likely to reflect the combined influence of relatively stable environmental conditions, moderate fishing pressure and habitat heterogeneity, which play a key role in regulating growth dynamics The moderate growth (K = 0.65 yr^{-1}; Φ′ = 3.7–3.8) observed in this study indicated a balance between resource availability and density-dependent constraints. In contrast, higher growth rates in riverine systems might be linked to greater water exchange, higher oxygenation and reduced habitat confinement. Habitat complexity in Kasaraiya Dhar, particularly dense macrophyte cover, appeared to be a key ecological driver shaping the population dynamics of *P. sophore* in this wetland. Macrophytes enhance structural complexity, providing refuge from predators and supporting diverse invertebrate prey communities, thereby influencing both survival and growth.

The total weight ranged from 0.054 to 13.619 g, while total length was varied from 18.4 to 102.2 mm. The LWR. weight of *P. sophore* showed correlation as R^2 = 0.9345 with 'a' = 2E-06 and 'b' (the regression coefficient) = 3.4158, which indicated a positive allometric growth (Fig. 4). The positive allometric growth in the length–weight relationship suggested that individuals gain weight at a faster rate than length. This is often interpreted as an indicator of good condition, such patterns can also arise from seasonal variability in feeding intensity, gonadal development and habitat-specific energy allocation. Similar to this study, the Pal *et al.* (2013) and Choudhury *et al. (*2015) observed the value of 'b' for *P. sophore* was as 3.24, indicating positive allometric growth. The observed variation in isometric growth reported in other regions (Hossain *et al.* 2006, Ahamed *et al.* 2012, Kumar *et al.* 2021), might therefore, be attributed to differences in hydrological regimes, trophic status and sampling periods rather than inherent population differences alone. However, values of 'b' in the present study was within the limits of 2.5-3.5 reported by Froese (2006) for finfish. It is also important to note that length–weight estimates can be influenced by sample size, size range and temporal pooling of data, which should also be considered during comparison.

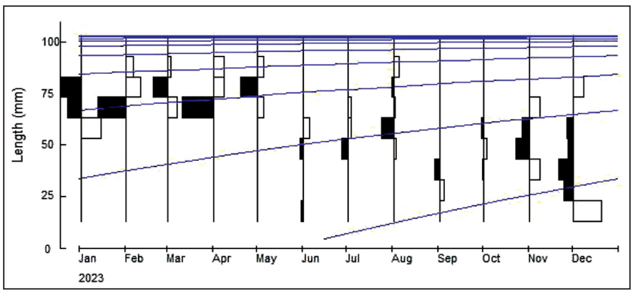

Fig. 2. The von Bertalanffy growth curve of *P. sophore* on length-frequency histogram

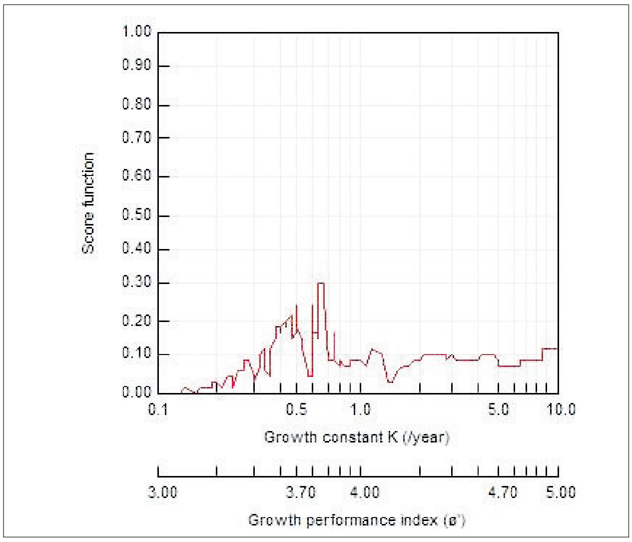

Fig. 3. K-scan plot obtained from ELEFAN analysis in FiSAT II

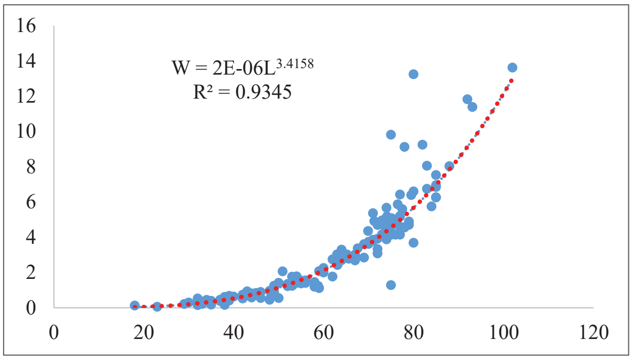

Fig. 4. Length-weight relationship of *P. sophore*

Condition factor is an important metric used to assess the health well-being, and fitness of fish in relation to their habitat. Condition factors indicated that the population is generally in good physiological condition; however, these indices should be interpreted cautiously. In the present study, the relative condition factor (KR) and Fulton's condition factor (KF) for P. sophore in Kasaraiya Dhar wetland were estimated at 1.0169 and 1.0446, respectively. Fulton's condition factor values close to or slightly above 1 are generally indicative of good fish populations with balanced somatic growth (Le Cren 1951). The observed KF value (1.0446) in this study aligned with the previous findings on P. sophore and related small indigenous fishes in similar freshwater environments (Pal *et al.* 2013; Choudhury *et al.* 2015), where healthy populations often exhibit K values ranging from 0.9 to 1.2 depending on season, age and habitat quality. The relative condition factor (KR), which compared the observed weight of a fish to its expected weight based on length, also exceeded 1, further reinforcing the conclusion that P. sophore in Kasaraiya Dhar was not under significant physiological stress. Comparable studies have reported similar or slightly higher condition factor values for P. sophore populations in undisturbed habitats, while populations exposed to higher pollution levels or overexploitation tend to show reduced condition factor values (Hossain *et al.* 2006, Ahamed *et al.* 2012). Thus, the current results did not only highlight the suitability of Kasaraiya Dhar as a viable habitat for this species but also reflected the relatively undisturbed status of this wetland system, in terms of fishery.

Mortality of fish highlights the habitat structure and ecological processes of the wetland. The present study estimated the natural mortality (M) of *P. sophore* at 0.93 yr^{-1} using Pauly's empirical formula under an average water temperature of 26.8°C. The total instantaneous mortality (Z) was computed as 1.75 yr^{-1} from the length-converted catch curve, while fishing mortality (F) was estimated at 0.81 yr^{-1} (Fig. 5). These results indicated that the natural mortality slightly exceeded fishing mortality, suggesting that non-fishing factors such as predation, disease and environmental stressors contributed more significantly to total mortality than the fishing pressure in the wetland. The relatively lower fishing mortality can be attributed to the dense cover of submerged and floating macrophytes prevalent in the wetland ecosystem (Bharti *et al.* 2025). Such vegetation forms a thick canopy that restricted the effective operation of conventional fishing gears like gill nets and seine nets, thereby reducing fishing efficiency and overall capture rates (Manna *et al.* 2024). Simultaneously, the dense macrophyte cover might also increase predator–prey interactions within confined spaces. However, it is important to acknowledge that mortality estimates derived from length-converted catch curves assume steady-state conditions and constant recruitment, which may hold true in Kasaraiya Dhar. The balance between the natural and fishing mortality observed in the study implied that *P. sophore* stocks in Kasaraiya Dhar were currently under moderate fishing pressure and are not being overexploited.

The present study also revealed that *P. sophore*

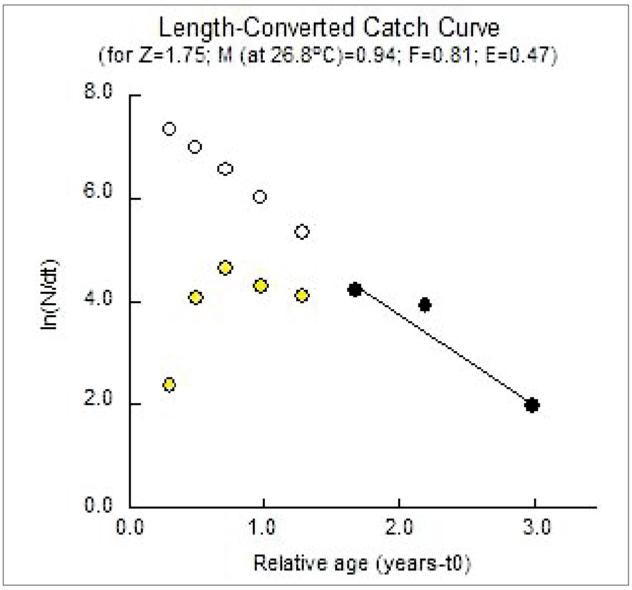

Fig. 5. Mortality estimation by length-converted catch curve method

exhibited a prolonged spawning period in Kasaraiya Dhar, with a distinct peak during February to March (Fig. 6). The observed spawning pattern in this study aligned closely with the findings of Choudhury *et al*. (2015), who reported highest GSI values for *P. sophore* in March in Tripura, suggesting similar reproductive timing under comparable climatic conditions. Hasan *et al.* (2018) observed the maximum GSI in April for *P. sophore* populations in Gazipur, Bangladesh, while Awal *et al*. (2023) reported an extended spawning season from May to July, with peak activity in June for *Pethia sophore* populations in Bangladesh. The earlier spawning peak recorded in the present study compared to Awal *et al.* (2023) may be attributed to local environmental factors such as water temperature, photoperiod, food availability and habitat characteristics. Variations in hydrological regimes, nutrient availability and population density may also modulate the timing and duration of spawning. Our finding on breeding of *P. sophore* in Kasaraiya Dhar is consistent with the previous study by Hasan *et al.* (2018), who noted that species of the genus *Puntius* typically exhibit a prolonged breeding period from April to August with a peak during monsoon. The prolonged recruitment pattern and extended spawning season observed in the present study are characteristic of small tropical fishes inhabiting wetland ecosystem. Rather than being solely an indicator of favourable conditions, continuous recruitment may represent an adaptive strategy to cope with hydrological uncertainty, ensuring population persistence of *P. sophore* in Kasaraiya Dhar. The earlier spawning peak (February–March) compared to other regions suggested that local temperature regimes, photoperiod and water level dynamics play a decisive role in reproductive timing. In wetlands, even slight shifts in hydrology can alter spawning pattern, larval survival and recruitment success.

The exploitation ratio (E = 0.40) of *P. sophore* in Kasaraiya Dhar (Fig. 7) indicated that the stock is currently

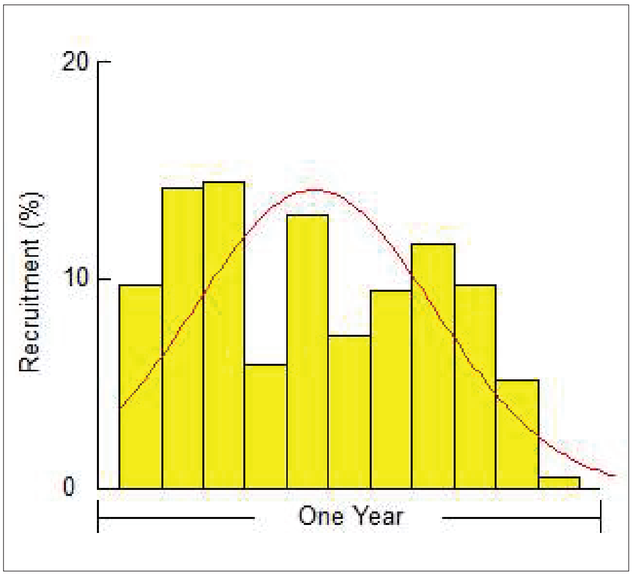

Fig. 6. Recruitment pattern of *P. sophore*

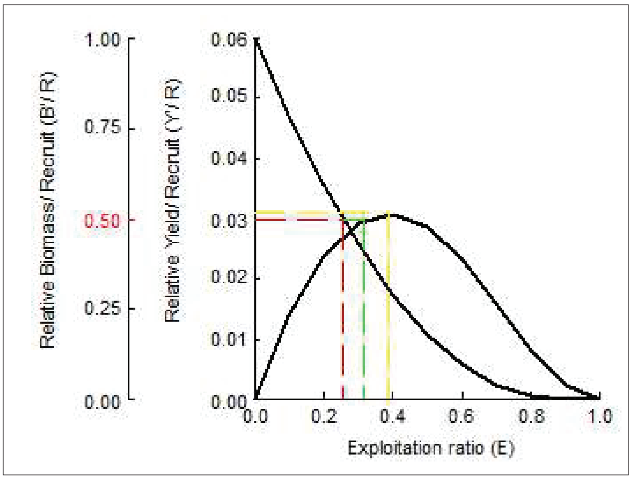

Fig. 7. Relative biomass per recruitment of *P. sophore*

underexploited; however, this should not be interpreted as a scope for unregulated increase in fishing pressure. According to Gulland (1971), an exploitation ratio of 0.50 (E = 0.5) indicates optimal exploitation, where fishing mortality equals natural mortality. When E exceeds 0.50, the stock is considered overexploited, while values below this threshold indicate under-exploitation. Therefore, the present result clearly signified that *P. sophore* in Kasaraiya Dhar was currently being harvested below its sustainable potential.

The results of the virtual population analysis (VPA) indicated that fishing pressure on *P. sophore* in Kasaraiya Dhar began at a mid-length of 58 mm, while the fishing mortality (F) was 0.20 yr^{-1}. The fishing mortality increased gradually with fish size and reached its maximum value of 0.80 yr^{-1} at a mid-length of 78 mm. Beyond this size, the fishing mortality remained constant, suggesting that larger individuals were not subjected to proportionally higher fishing pressure (Fig. 8). This pattern indicated that fishing activities primarily targeted medium-sized individuals, while both smaller and larger size classes experienced relatively lower fishing intensity. The maximum mortality beyond 78 mm may be attributed to the behavioural traits of larger fish that allowed them to escape the capture. This could be influenced by environmental factors such as dense macrophyte cover or restricted fishing operations. The results aligned well with the findings of Nissar *et al*. (2024), who reported a sharp increase in fishing mortality for *Pethia conchonius* beyond a length of 56 mm in Dal Lake, Kashmir Himalayas. Kumar *et al.* (2021) observed highest fishing mortality (1.03 yr^{-1}) at a mid-length of 117.5 mm for *P. sophore* in the Satluj *River*, Punjab. The comparatively a lower fishing mortality in Kasaraiya Dhar suggested a moderate fishing intensity, and possibly, lower fishing effort. In structurally complex habitats, low apparent exploitation may partly reflect reduced catchability rather than low fishing effort. Similarly, virtual population analysis (VPA) results indicating size-selective fishing pressure may be influenced by habitat-induced sampling

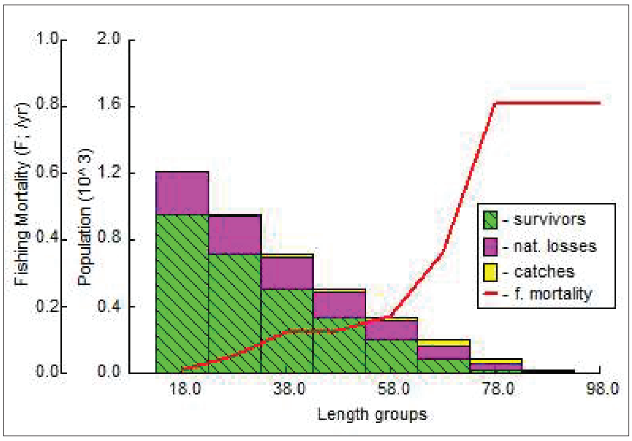

Fig. 8. Virtual population analysis of *P. sophore*

bias. Smaller individuals may be underrepresented due to mesh size limitations, while larger individuals may evade capture within dense vegetation. These methodological constraints might have been considered in cautious way during interpretation of fish stock in macrophyte covered wetland of Bihar like Kasaraiya Dhar.

The present study provided the first comprehensive assessment of the growth dynamics, condition factors, mortality, exploitation level and reproductive characteristics of *P. sophore* in the Kasariya Dhar wetland. The growth parameters ($L\infty$ = 102.9 mm; K = 0.65 yr^{-1}) and positive allometric growth (b = 3.4158) reflect a moderately growing, the stock of *P. sophore* which was well adapted to the local environment. The estimated condition factors (KR = 1.0169; KF = 1.0446) further confirmed good physiological status of the wetland. The mortality estimates (Z = 1.75 yr^{-1}; M = 0.93 yr^{-1}; F = 0.81 yr^{-1}) and exploitation ratio (E = 0.40) suggested that the population was under moderate fishing pressure and remained within sustainable harvest limits. Overall, while the population of *P. sophore* in Kasaraiya Dhar appeared to be stable and resilient, the observed patterns are shaped by a combination of hydrological dynamics, habitat complexity and life-history strategies. Continuous recruitment and a prolonged breeding season with peak spawning in February-March highlighted reproductive resilience and favourable ecological conditions. The presence of multiple cohorts and consistent recruitment indicate that *P. sophore* maintained a stable population structure in this wetland. At the same time, the reliance on length–frequency-based methods (ELEFAN) introduced inherent uncertainties, particularly in cohort identification. Incorporating complementary approaches, such as age validation, seasonal sampling, gear selectivity, gear standardization, habitat-specific and analyses statistical validation by bootstrapping and sensitivity analysis would further strengthen the future stock assessment of *P. sophore*.

ACKNOWLEDGEMENTS

Research was supported by the Indian Council of Agricultural Research, Department of Agricultural Research and Education, Government of India. The authors gratefully acknowledge the Director, ICAR-RCER, Patna, for providing facilities and valuable guidance during the course of this study and in the preparation of this manuscript.

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