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Fishery and population dynamics of Asian leaf fish *Nandus nandus* (Hamilton, 1822) for sustainable management implications: Insights from West Bengal, India

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Abstract

The Asian leaf fish *Nandus nandus* (Hamilton, 1822), a crucial small indigenous freshwater species of the Nandidae family, plays a pivotal role in supporting the livelihoods of fishers reliant on subsistence and marginal fisheries across India and neighbouring countries. There is only limited quantitative data on its exploitable status. Length frequency based growth and mortality dynamics of this species was studied from monthly samples collected from the wetlands of West Bengal during 2020-2021. Parameters of the length-weight relationship (a = 0.00892, b =3.244 and r^2 =0.9364) indicated positive allometric growth. The von Bertalanffy growth parameters were estimated as L_∞ = 18.38 cm TL and K = 1.2 y^{-1}. Mortality estimation indicated total mortality Z = 2.89 y^{-1}, with natural mortality M = 2.33 y^{-1} and fishing mortality F = 0.56 y^{-1}. The growth performance index (ϕ`) was 2.69. Length at capture (Lc_{50}) was determined to be 14.3 cm TL, with current exploitation rate (E_{cur}) of 0.19, underscoring an opportunity to enhance fishing efforts and reduce natural mortality. Beverton and Holt yield per recruitment analysis indicated maximum exploitation rate (E_{max}) of 0.41. With $E_{0.1}$ at 0.35 and E_{cur} at 0.19, it is evident that the species is underexploited and there is scope to increase the effort to achieve maximum economic yield.

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Introduction

The Asian leaf fish *Nandus nandus* (Hamilton, 1822), also known as the Gangetic leaf fish, or mud perch is a freshwater and brackishwater species belonging to the family Nandidae. It is widely distributed across the Indian subcontinent, including countries like Bangladesh, India, Malaysia, Myanmar, Pakistan, Thailand, and Vietnam. This benthopelagic and omnivorous species typically inhabits slow-moving or stagnant waters found in streams, rivers, pools, lakes, canals and reservoirs (Talwar and Jhingran, 1991; Rainboth, 1996; Froese and Pauly, 2000). It is valued both as a food fish and for the aquarium trade. At any given time, the market value of this fish is 20% higher than any of the Indian major carps due to its taste and nutritional value. According to the International Union for Conservation of Nature (IUCN, 2021), the Asian leaf fish is classified under the category of Lower Risk Least Concern. However, recent reports suggest that populations in rivers and wetlands are declining due to indiscriminate fishing, unplanned construction of bridge and flood protection embankments, use up of low land water for irrigation, residual effect of pesticides or insecticides, habitat degradation, siltation, and the effects of climate change driven by anthropogenic activities (Hossain, 2014; Hossain *et al*., 2015, 2017; Sharmin *et al*., 2016; Saikia *et al*., 2021). Mredul *et al*. (2021) noted the widespread distribution of *N. nandus* in the Indian subcontinent, particularly in wetlands and deep pools affected by inundation. As the omnivorous feeding habit of this species includes a wide variety of food (Debnath and Saikia, 2020), the fish has increased demand in the commercial culture system in West Bengal. Known as a significant source of dietary nutrition, *N. nandus* has been reported to contain 52.5% protein, 2% fat, 0.21% carbohydrates and 5.7% minerals (Ray and Dhar, 2012). The declining population of *N. nandus* in aquatic ecosystems (Chakraborty, 2021) highlights the urgent need for conservation efforts.

Information on population parameters such as the length-weight relationship, growth and mortality parameters of this species are limited. Available studies focus primarily on the length-weight relationship and condition factor (Table 1). As the temporal ecology of floodplain wetlands is diverse, their association with the fish assemblage is not stable (Kumari *et al*., 2023). The evaluation of length at maturity/asymptotic length (L_m/L_α ratio) using the von Bertalanffy growth model function can be utilised for wild fish resource management purposes (Kumari *et al*., 2018). Studies have assessed the likelihood of fish escapement based on body length and depth (Kumari *et al*., 2019). Historically, a few studies were done regarding the biology (Gupta, 2018; Goswami and Dasgupta, 2004; Sarkar *et al*., 2009) and the vulnerability of this species under the changing climate (Lianthuamluaia *et al*., 2023) in the West Bengal. Other studies on *Nandus* sp. conducted in India and Bangladesh at the same ecoregion *i.e.,* the lower Gangetic floodplain regions are summarised in Table 1. However, comprehensive data on growth and mortality parameters are scanty for systematic assessment and monitoring of its natural population and reproductive biology. Understanding these population dynamics; specifically growth, recruitment and mortality, is imperative for implementing sustainable management strategies and achieving effective conservation outcomes. Therefore, the objective of the present study was to investigate the population dynamics of *N. nandus* in the floodplain wetlands of West Bengal, India.

Materials and methods

Study site and sampling

Samples were collected from commercial catches in floodplain wetlands across three distinct regions: Murshidabad (Katiganga), Nadia (Bhomra) and Bardhman (Purbasthali) districts of West Bengal (Fig. 1). The wetlands selected for sampling, *viz.,* Katiganga (22 ha), Bhomra (46 ha) and Purbasthali (219 ha), served as the primary locations for monthly sample collection from August 2020 to July 2021. Fish specimens were collected using gillnets and drag nets, chosen randomly based on their size range from various landing sites. Each fish was identified using standard literature and its length was measured with a vernier caliper to an accuracy of 0.01 cm. The weight of each specimen was recorded to the nearest 0.1 g. The length-weight relationship for pooled data (comprising both male and female specimens) was assessed using the equation

Table 1. Review of previous studies on *N. nandus* in lower Gangetic floodplain regions

Authors	Description of study	Location	Habitat
Parameswaran *et al*. (1971)	Induced breeding	Assam, India	Fish farm
Das and Zamal (2000)	Developing a suitable rearing technique	Mymensingh, Bangladesh	Lab condition
Das *et al*. (2002)	Study of early developmental stages	Mymensingh, Bangladesh	Lab condition
Pal *et al*. (2003)	Induced breeding	Mymensingh, Bangladesh	Lab condition
Goswami and Dasgupta (2004)	Analysis of morphometric and meristic characteristics	West Bengal, India	Floodplain wetlands
Ng and Jaafar (2008)	Description of a new species	West Bengal, India	River
Sarkar *et al*. (2009)	Induced spawning	Malda, West Bengal, India	River
Zohora *et al*. (2010)	Morphological and allozyme variation in fish populations	Bangladesh	Floodplain wetlands and rivers
Sarder *et al*. (2012)	Development of cryopreservation protocol for fish sperm	Mymensingh, Bangladesh	Floodplain wetlands and river
Begum *et al*. (2017)	Developing a standard protocol for brood development, induced breeding and larval rearing	Gopalganj, Bangladesh	Floodplain wetlands
Islam *et al*. (2017)	Length-weight relationship and condition factor	Dinajpur, Bangladesh	River
Sharmin *et al*. (2017)	Effect of different food on the growth and survival	Bogra, Bangladesh	Floodplain wetlands
Gupta (2018)	Compilation of the overall biology of the fish from published sources	India	-
Kapuri *et al*. (2020)	Description of a new fish species	West Bengal, India	River
Mredul *et al*. (2021)	Reproductive and biometric features	Gopalganj, Bangladesh	Floodplain wetlands
Rahman *et al*. (2023)	Observations on reproductive biology and gonadal cycle	Gazipur, Bangladesh	Floodplain wetlands
Lianthuamluaia *et al*. (2023)	Reproductive vulnerability under changing climate	Assam and West Bengal, India	Floodplain wetlands
Tasnim *et al*. (2023)	Review of biological features, distribution and conservation	Bangladesh	-
Haque *et al*. (2023)	Effect of stocking densities on growth and production performance	Bogura, Bangladesh	Pond
Kawsar *et al*. (2023)	Estimation of well-being status of wild fish	Moulvibazar, Bangladesh	Floodplain wetlands

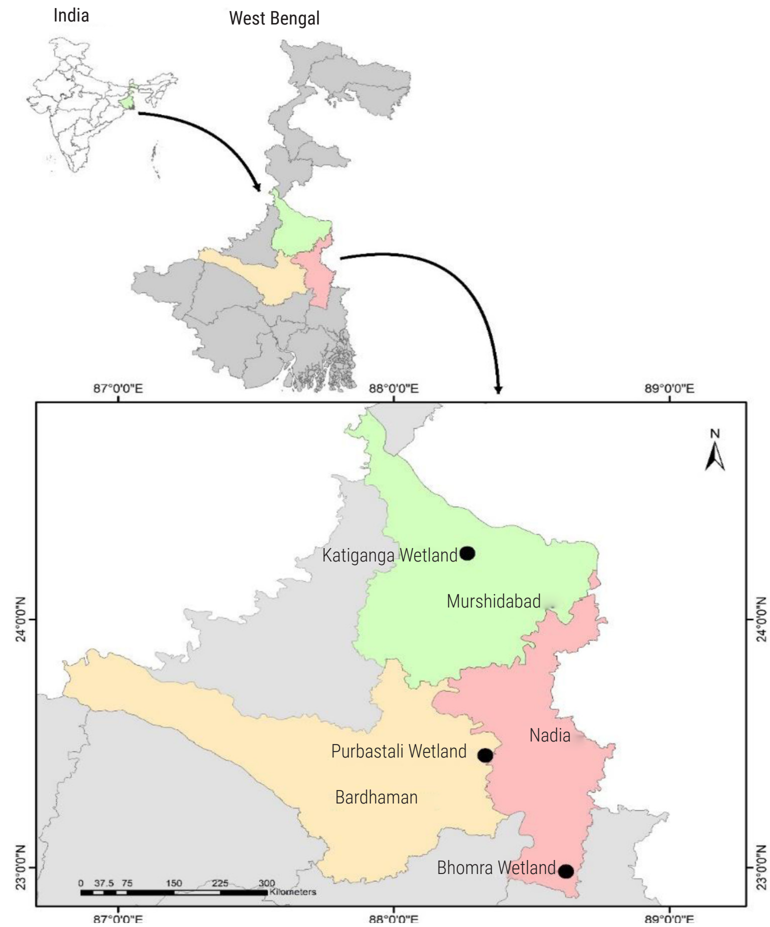

Fig. 1. Study area map showing three wetlands from where *N. nandus* were sampled

$W=aL^b$, where 'W' is the total weight of the fish, 'L' is the total length (measured from the tip of the snout to the tip of the caudal fin), '*a*' is the constant (intercept value) and '*b*' is the allometric coefficient (slope). Regression analysis of log-log plots for the length and weight of pooled data was conducted after excluding outliers, following recommendations by Froese (2006). Length-frequency data were collected for 585 specimens during the study and grouped into 10 mm class intervals for growth analysis.

Data analysis

The parameters of von Bertalanffy's growth model, specifically the asymptotic length (L_∞) and growth coefficient (K), were estimated using the ELEFAN-I (Electronic Length Frequency Analysis) module within the FiSAT-II software program. This software, developed by Gayanilo *et al*. (1995), is part of the FAO-ICLARM Stock Assessment Tools. The growth performance index (ϕ`) was estimated according to the method described by Munro and Pauly (1983), as detailed below:

ϕ` = Log_{10} (K)+ 2 X Log_{10} (L_∞)

The MPA (Model Progression Analysis) was conducted to further refine the growth parameters obtained from ELEFAN-I. The monthly composition of the length frequency distribution was segmented into different cohorts based on the method outlined by Bhattacharya (1967). The instantaneous total mortality coefficient (Z) was estimated using the length-converted catch curve method (Pauly 1983). The natural mortality rate (M) was estimated using Pauly's empirical formula (1980), as depicted below:

$\log(M) = -0.0066 - 0.279 \log(L\infty) + 0.6543 \log(K) + 0.4634 \log(T)$

where, L_∞ in cm, K in year^{-1} and T is the mean annual ambient temperature (°C).

Fishing mortality (F) was estimated using the formula:

F = Z-M

The current exploitation rate (E_{cur}) was estimated from the following formula (Ricker, 1975):

E_{cur} = F/Z

The Asian leaf fish is exploited using both selective and non-selective gears. To assess the relative Yield-per-Recruit (Y/R) and Biomass-per-Recruit (B/R) of *N. nandus*, the knife-edge selection procedure of FiSAT II was used. The input parameters for this analysis were the estimated L_{50}/L_∞ and M/K values.

Results

Length-weight relationship

Length-Frequency Distribution (LFD) analysis of *N. nandus* specimens collected from West Bengal revealed sizes ranging from 4.6-17.5 cm in total length (TL), with body weights (BW) ranging from 1.51-76.17 g. The parameters of the length-weight relationship were estimated as, a = 0.00892, b = 3.244 and r^2 = 0.9364 (Fig. 2). The exponent '*b*' (slope coefficient) in this equation indicated positive allometric growth, where weight increases faster than length. The length-weight relationship is crucial in fisheries and ecological studies as it provides insights into the growth and condition of fish populations, influencing management and conservation strategies.

Growth and mortality parameters

The growth parameters of *N. nandus* were crucially estimated to gain a comprehensive understanding of its life history and population dynamics. By determining parameters such as asymptotic length (L_∞) and growth coefficient (K), researchers aimed to evaluate the growth rates, maximum potential size and variability among individuals and populations of *N. nandus*. These insights are fundamental for effective fisheries management and conservation strategies. The growth parameters were assessed using Model Progression Analysis (MPA) through ELEFAN-1. The growth parameters, asymptotic length (L_∞) and growth coefficient (K) were estimated as 18.38 cm TL and 1.2 y^{-1} respectively (Fig. 3).

The growth performance index (ϕ`) was estimated as 2.69 (Fig. 4) indicating that *N. nandus* exhibits favourable growth relative to its potential under the prevailing conditions.

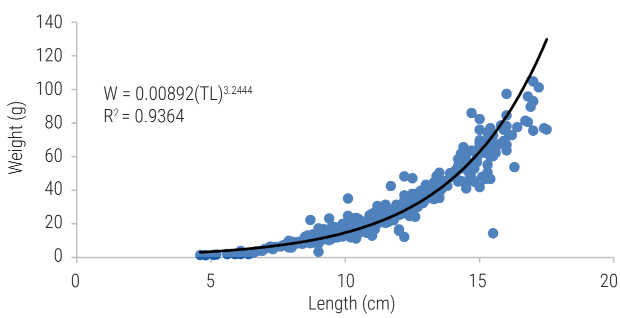

Fig. 2. Length-weight relationship of *N. nandus* (sexes pooled data) (*n* = 585)

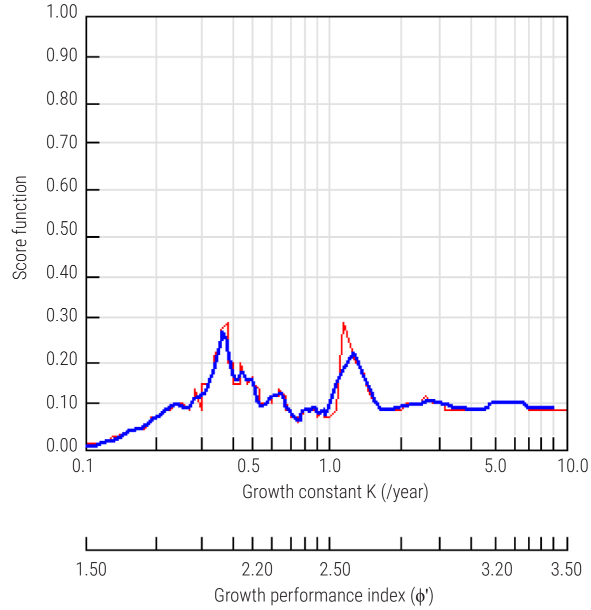

Fig. 4. Length frequency-based growth performance index (ϕ) of *N. nandus*

The instantaneous natural mortality rate (M) was estimated at 2.33 y^{-1} using Pauly's empirical formula. The instantaneous total mortality rate (Z) was estimated at 2.89 y^{-1} using the length-converted catch curve method. The instantaneous fishing mortality rate was computed as 0.56 y^{-1} (Fig. 5). These mortality rates indicate that 80% of the stock reduction is due to natural mortality, such as predation, diseases, or other survival factors, while the remaining 20% is due to fishing mortality. The M/K ratio was 1.94, indicating that the natural mortality rate is relatively high in relation to the growth rate. This ratio falls within the range of 1.0-2.5 suggested by Beverton and Holt (1956), which is considered typical for many fish species. A higher M/K ratio suggests that the species experiences significant natural mortality, likely due to factors such as predation, diseases and environmental conditions and that it grows quickly to offset these losses. The fishing mortality (F) in the present study is lower compared to natural mortality (M). The current exploitation rate (E_{cur} = 0.19) is less than the optimum exploitation rate (E_{opt}). The length-based cohort analysis shows that natural mortality (M) is higher in adults compared to juveniles and the maximum fishing mortality (F) was observed when the fish attained a length of 10.5 cm (Fig. 6).

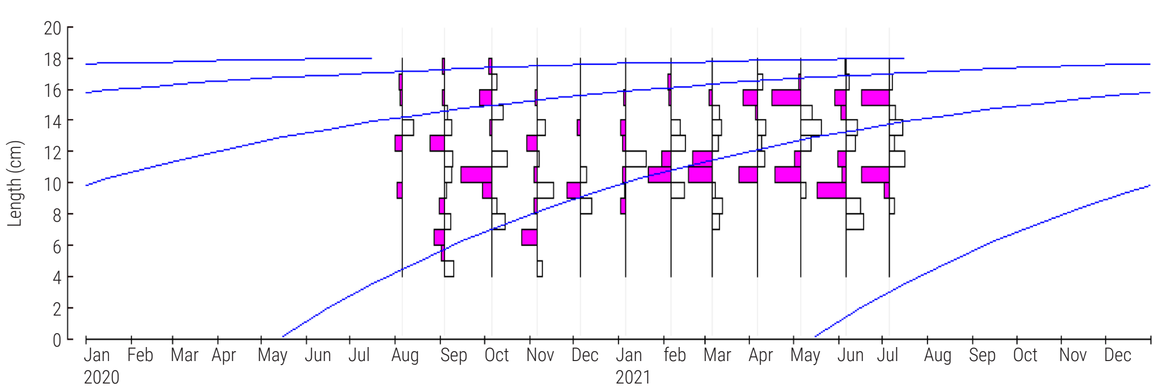

Fig. 3. The von Bertalanffy growth curve of *N. nandus* superimposed over the reconstructed length-frequency data (*n* = 585)

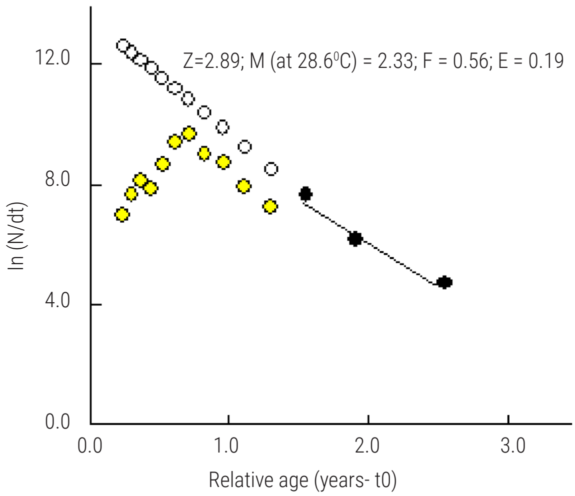

Fig. 5. Length-converted catch curve for estimation of mortality parameters of *N. nandus*

Gear selectivity and recruitment

The length at capture (Lc_{50}), or the length at which 50% of the fish in the stock become vulnerable to fishing gear, was estimated at 13.88 cm TL (Fig. 7). The L_{25} and L_{75} values for the species were estimated at 9.9 and 15.45 cm TL, respectively. The recruitment pattern revealed that the juveniles are recruited to the fishery year-round, with a peak during July, followed by May and August (Fig. 8). The estimated L_r/L_∞ was 0.37 and the length at recruitment (L_r) for the species was estimated at 6.8 cm TL. The estimated length at capture (Lc_{50}) of 13.88 cm TL was higher than the L_r.

Relative yield per recruit

The analysis using the estimated L_{50}/L_∞ (0.75) and M/K (1.94) values as input parameters revealed that the exploitation rate that maximises yield per recruit (E_{max}) is 0.42, indicating the potential for increasing the current exploitation rate (Fig. 9). The $E_{0.5}$ value, which represents the exploitation rate at which B/R is reduced by 50% compared to the virgin stock, was estimated at 0.27. The study suggests that maintaining the optimum biomass of Asian leaf fish can be achieved at the $E_{0.5}$ level. However, the current exploitation rate (E_{cur}) was estimated at 0.19, which is lower than $E_{0.5}$. This indicates that there is room to increase fishing effort to maximise surplus production while still maintaining sustainable stock levels.

Discussion

The Asian leaf fish faces equal demand as both a food fish and an ornamental fish. However, it contributes minimally to the overall fish catch in wetlands, likely because it is not specifically targeted for food. Understanding the life history parameters of *N. nandus* is crucial for the effective conservation and sustainable utilisation of this species. In this study, the smallest fish observed measured 4.6 cm TL, which may be attributed to gear selectivity, highlighting potential biases in sampling methods. The maximum size (17.5 cm TL) observed exceeds that reported from Bangladesh (Hossain *et al*., 2017) but falls short of the maximum reported length (20 cm TL) by Talwar and Jhingran (1991). The length-weight relationship is pivotal

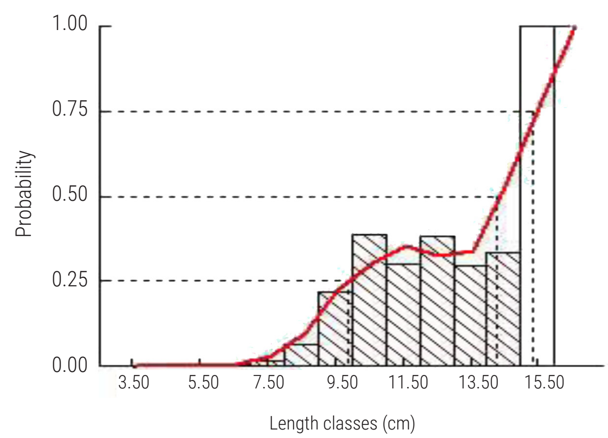

Fig. 7. Length at capture (Lc_{50}) of *N. nandus*

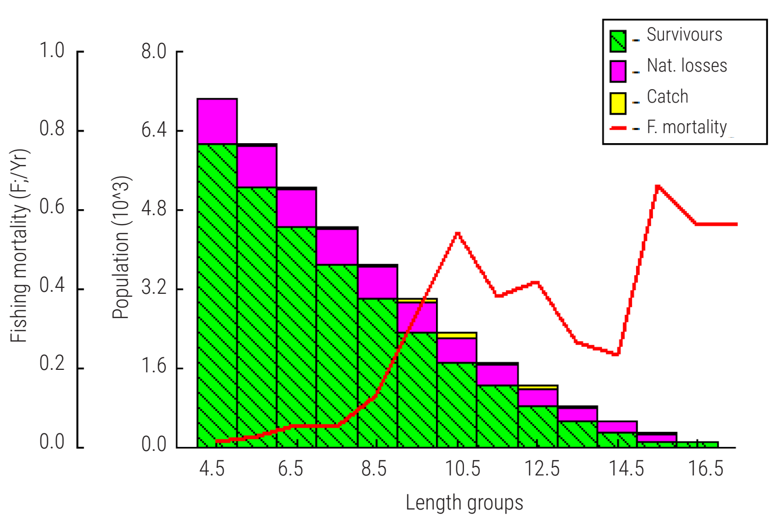

Fig. 6. Length-frequency based Virtual Population Analysis of *N. nandus*

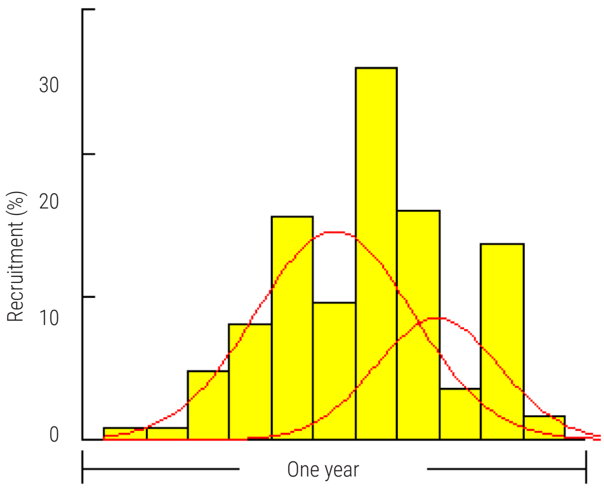

Fig. 8. Recruitment pattern of *N. nandus*

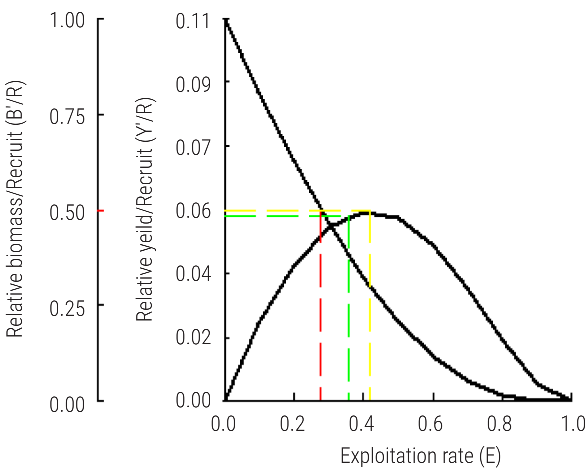

Fig. 9. Stock status of *N. nandus* using Beverton and Holt's Y/R model

in fisheries and ecological studies as it offers valuable insights into the growth patterns and overall condition of fish populations. For tropical fish species like *N. nandus*, the 'b' value in LWR is typically expected to fall within the range of 2.5-3.5 (Froese, 2006). However, detailed size-specific growth parameter data, particularly the 'b' value, for Asian leaf fish from India are scant in the literature, which complicates direct comparisons across studies based on length-specific analyses. The present study revealed 'b' values exceeding 3 across various size categories and habitats, consistent with the general trend observed in tropical fish species. These growth parameters provide critical insights into the ecological niche of *N. nandus*, including its interactions with prey and predators, and its overall contribution to ecosystem dynamics. The pooled sample analysis yielded a '*b*' value of 3.244, which aligns closely with findings from previous research conducted from Bangladesh waters. ranging from 3.04 to 3.22 (Hossain *et al*., 2017). This consistency across different geographical locations underscores the robustness of the observed growth patterns and suggests that environmental factors and habitat characteristics play significant roles in shaping these parameters. Comparative analysis of growth parameters across populations or regions helps identify factors influencing growth variability, such as environmental conditions, habitat quality and fishing pressure. Such insights are crucial for developing informed management and conservation strategies that aim to sustainably exploit and protect *N. nandus* populations in their natural habitats.

The Asian leaf fish, integral to several wetland ecosystems, is currently experiencing population decline across its range. Recent studies suggest that factors such as predation, diseases, and other natural causes significantly contribute to this decline (Kawsar *et al*., 2023). It is imperative to generate information on the estimated value of asymptotic length (L_∞) and growth coefficient (K) for effective fisheries management and conservation (Lianthuamluaia *et al*., 2023). Ahamed *et al*. (2024) reported that *N. nandus* exhibits an isometric growth pattern, with an asymptotic length estimated at approximately 17.95 cm TL and a growth coefficient K of 1.3 y^{-1}. The present study indicates a slightly higher 'L_∞' and a lower 'K' value compared to the observations of Ahamed *et al*. (2024). The 'K' value influences the age and size distribution within the population. A higher 'K' typically means individuals grow faster and reach maturity sooner, affecting population structure and recruitment patterns. The growth performance index (GPI) for the species observed by Ahamed *et al*. (2024) is comparable with our findings, indicating good growth potential. A higher GPI (ϕ) often correlates with good nutritional status and health in fish, suggesting that *N. nandus* is likely to obtain sufficient food and nutrients to support growth and maintain overall fitness. Despite its wide geographical distribution in South-east Asian countries, the stock of *N. nandus* is declining due to several anthropogenic interferences. Fisheries of this species are solely capture-based, with landings reflecting natural population levels.

Natural mortality influences life histories and characteristics through natural selection, reflecting the outcomes of organisms' behavioural and life history strategies (Jørgensen and Holt, 2013). This underscores the need for comprehensive studies and conservation efforts with a focus on mitigating the factors contributing to natural mortality. Understanding natural mortality is crucial for assessing the resilience of *N. nandus* populations to natural mortality pressures and for predicting population sustainability. In the present study, natural mortality was higher than fishing mortality, and the optimum exploitation rate (E_{opt}) was lower than the current exploitation rate (E_{cur}). The decline in the stock of Asian leaf fish is predominantly attributed to elevated natural mortality rates rather than fishing mortality. The gear used for fishing *N. nandus* might not be very efficient at targeting this species, resulting in lower fishing mortality. Gear selectivity can influence the amount and size of fish captured, affecting the overall fishing mortality. Tasnim *et al*. (2023) concluded that environmental degradation is the most significant cause of declining stock and rising natural mortality. The species has been reported to be declining in stock due to natural mortality in several wetlands in different regions (Jørgensen and Holt, 2013; Tasnim *et al*., 2023; Hossain *et al*., 2017). According to local fishers, the main reason for increased natural mortality is the drying of wetland channels, leading to habitat alteration. Other significant factors include the introduction of invasive species (Kamal *et al*., 2022). Reproductive and population vulnerability assessment of this species by Patt *et al*. (2008) and Lianthuamluaia *et al*. (2023) emphasise the need for developing guidelines and policy changes for conservation and management. Several studies found that *N. nandus*, although widespread, is less resilient due to low fecundity and life history threats from ecological alterations caused by climate change (Wood *et al*., 2014). This benthopelagic species faces significant vulnerability due to the high exposure and susceptibility of wetland habitats (Lianthuamluaia *et al*., 2023). Long-standing destructive fishing practices combined with habitat alterations have posed serious threats to its population (Denechaud *et al*., 2020). While numerous studies have explored the impacts of climate change scenarios, few have specifically assessed the vulnerability of fisheries, including *N. nandus* (Cochrane *et al*., 2009; Olusanya and van Zyll de Jong, 2018). This gap underscores the need for targeted research to inform effective conservation strategies for this sensitive species. The Y/R and B/R analysis in the present study highlights the potential for increasing the exploitation rate of *N. nandus* to achieve higher yields. However, it is essential to monitor and manage this increase carefully to avoid overfishing and ensure the long-term sustainability of the species. Further studies and continuous monitoring are recommended to adjust management strategies as needed, ensuring that fishing practices remain sustainable and effective in maintaining healthy fish populations.

Understanding the growth, mortality, and recruitment dynamics of *N. nandus* is essential for sustainable fisheries management, given its dual significance as both a food source and an ornamental fish. Balancing exploitation rates is critical to maintaining stock resilience and ensuring long-term viability. The present study underscores the importance of periodic assessments of population parameters and the implementation of adaptive management strategies to optimise yields while preserving biodiversity and ecosystem integrity. An $E_{0.1}$ value of 0.35 indicates that the particular fishery has not yet reached maximum economic yield, and there is scope to enhance fishing efforts and reduce natural mortality. This approach can increase economic returns and support the livelihoods of local fishers through responsible management practices. A recommended adaptation strategy involves restoring connectivity in wetland habitats and linking them to the main river channels, which would facilitate migration and dispersal of the species. Integrating habitat restoration with fisheries management offers a balanced approach that promotes both conservation goals and economic benefits, ensuring the sustainable use of *N. nandus* resources for future generations.

Acknowledgments

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