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Multivariate ecological assessment of ten Indigenous IUCN threatened and near threatened freshwater fishes from South-West Regions of West Bengal, India

Deep Sankar Chini[1*], Niladri Mondal[2], Sourav Singh[3], Pratik Ghosh[1], Prasanta Patra[1], Biplab Mandal[1], Sudipta Kumar Ghorai[4], Dipak Bisai[3], Bidhan Chandra Patra[1]

[1]Department of Zoology, Vidyasagar University, Midnapore, India.
[2]Department of Biology, Katholic University of Leuven, Leuven, Belgium.
[3]Department of Geography, Egra S.S.B. College, Egra, India.
[4]Department of Zoology, Egra S.S.B. College, Egra, India.

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ABSTRACT

The freshwater fish diversity is significant in the food chain and is a nutrient source. Our study sites are home to diversified freshwater fishes due to their varied geography. For the first time, length–weight relationships of ten Indigenous International Union for Conservation of Nature-threatened fish species (were collected from the different sites from November 2019 to December 2022 in 3-month intervals. There were various types of nets with varying sizes of mesh, including gill net (0.5 to 4 cm), scoop net (0.3 × 0.3 to 0.5 × 0.5 cm), and cast net (up to 1 × 1 cm in a mesh up to 3.0 m^2 coverage). The "b" values range from 2.615 (*Wallago attu*) to 3.287 (*Channa orientalis*), and the correlation coefficient (r^2) is ≥0.90. In contrast, native fishes have negative allometric growth, and the condition factor (K_n) of these species' ranges (mean value ±SD) from 0.138 ± 0.04 (*Anguilla bengalensis*) to 0.793 ± 0.09 (*Clarius magur*). A new TL_{max} of *Parambassis lala* has been found (4.2 cm). Depending on the species available in this region, the species distribution modeling and non-metric dimensional scaling have been prepared, which will help build an area-specific conservation policy to restore the vulnerability. We also established a conservation strategy to develop sustainable fishery management guidelines based on the results.

1. INTRODUCTION

The different conservation practices and policy levels are influenced by biodiversity assessments globally. The International Union for Conservation of Nature (IUCN) Red List of Ecosystems was adopted by the IUCN as the global standard for ecosystem risk assessment in 2014, following a development period from 2007 to 2013 [1, 2]. The IUCN Red List of Threatened Species was established in the 1960s and revised occasionally [3]. Biodiversity assessment is expected to benefit conservation; however, this has yet to be proven. The inland water bodies are social and ecological systems that have supported humans and other animals in the past [4]. It is essential for different agricultural practices, economic support, drinking purposes, fishery, and other daily uses, and most importantly, it is the home for freshwater organisms [5]. About 10% of the world's discovered species, 30% of the vertebrate organisms, have been found in Earth's inland water bodies [6]. The diversity and population of freshwater fish are significant in stabilizing the local aquatic habitat in the food chain. For humans, it also acts as a protein-enriched food item. Besides, the inland fishery is crucial for the socio-economic upliftment of rural fisher folks [7]. Due to diverse habitats, climatic variations, and elevation variability, India has enormous biodiversity in every aspect of life [8]. However, this extensive diversity is now lost due to constant anthropogenic stressors brought on by urbanization, the rising demands for fish as food, global climate changes, pollution, and construction activity; the population of some freshwater fish species and their population trend has considerably decreased [9, 10].

According to IUCN version 2022-2 statistical data, out of 36,367 fishes, 25,351 are evaluated, where 3,551 species are under Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) status globally [11]. Even still, just 70% of all known fish have assessments in the IUCN Red List, and even fewer have assessments within the last 10 years or less. Approximately 30% of freshwater fish species for whom adequate data is available to assess their status are currently estimated to be threatened globally [12, 13]. Without special efforts, Moyle and Leidy [14] proved that by the end of the century, or possibly sooner, at least 40%–50% of

*Corresponding Author
Deep Sankar Chini, Department of Zoology, Vidyasagar University, Midnapore, India. E-mail: deepshankarchini @ gmail.com

all freshwater fish species will be extinct in the wild or very close to it. India possesses significant taxonomic, genetic, and ecological diversity, making it one of the world's most biodiverse nations. It has a variety of riverine systems (including cold-water rivers), a long sea shoreline, and a mangrove area, including fish-rich lakes, ponds, reservoirs, tributaries, streams, and canals [15]. India has the highest percentage of endemic freshwater fin fish species (27.8%) among Asian nations, next to China and Indonesia. According to IUCN (2008), India is home to 659 animal species (42 fish species) that are designated as globally threatened, making up around 3% of all fauna (16,928 species) [16]. However, per IUCN's latest report, India has 292 IUCN-threatened categorized fish species out of the evaluated ones. Unlike other states in India, West Bengal is diversified by 251 freshwater fishes (two CR, five EN, and nine VU) due to its unique geographical condition [17]. Besides, unregulated exploitation of inland fishery resources plays a crucial role in the conservation of threatened fishes. As per the FAO report, inland fisheries contributed approximately 12 million tons to the total global fish production, where aquaculture played a significant role in this sector in 2021 [18]. As per the Fishery Statistics data, in India (2022–2023), the inland fish production was 131.13 lakh tons, whereas West Bengal contributed 18.56 lakh tons [19]. If we look into the species of West Bengal's inland fish landing. The significant contributors are major carps (12.84 L ton), minor carps (0.20 L ton), exotic carps (1.90 L ton), murrels (0.11 L t), catfishes (0.37 L ton), and other freshwater fishes (0.56 L ton).

The southwest regions of West Bengal encompass a vast diversity of indigenous freshwater fishes [20]. Fishes were reported independently in different patches from these areas. The IUCN Red List of Threatened Fishes (IUCN-RLTF) has also been reported from this region previously [21–23]. Nevertheless, regarding the conservation aspect, assessing those fishes has yet to be accomplished in different areas. A species distribution model (SDM) can help in various factors, including conservation planning, assessment of resources available on the given site, and ecosystem restoration service [24]. Also, these fish are already facing a severe declination of their population [25]. The introduction of *Ompok bimaculatus* in the fish culture also has been successful in some parts of North East India, which proves knowing their habitat structure and their status in West Bengal will also be fruitful for the fisheries industries [26].

SDM and aims to estimate the similarity of the conditions of the study site to the location of the known occurrence for the individual high-risk fishes. The climate data is also used as a predictor for the modeling [27]. Researchers use SDM to assess invasive species and their management. It is also a valuable technique for predicting the environmental impact on the threatened fish around the study site [28]. To understand fish physiology, the length–weight relationships (LWRs) are frequently used to convert total length (TL) into body mass (W) [29]. LWRs and growth pattern analysis can provide succinct scientific data about the changes in health, stock assessment, and other biological data [30]. Additionally, the condition factor (K_n) by Fulton can be used to compare the physiological robustness of these fish on a quantitative approach and offers information on the health status of the species in relation to the environmental variables [31]. Besides, the growth pattern analysis of these fishes will provide vital information about their current trends based on their local habitats. Considering consciousness about environmental change and its ecological impact, SDM, occurrence, and richness data to map and analyze the IUCN-RLTF has become extremely valuable.

So, for the first time, the SDM, occurrence, non-metric dimensional scaling (NMDS), availability on matrix plot, growth pattern, LWRs, and conditioning factor of IUCN-threatened freshwater fishes from southwest regions of West Bengal have been assessed with real-time data to understand their present scenario. Studying biological parameters and their distribution pattern provides valuable insight for future aspects.

2. MATERIALS AND METHODOLOGY

2.1. About the Study Area

South-west regions of West Bengal comprise four districts - Paschim Medinipur (9,295 Km^2), Jhargram (3,037 Km^2), Bankura (6,788 Km^2), and Purulia (6,259 Km^2). The Global Positioning System locations are from West 85°49′10.8″ (E) to East 87°53′36.7″ (E) and from South 23°41′56.8″ (N) to North 21°45′51.2″ (N). The study area is confined by Bardhaman, Hooghly, Purba Medinipur, and Howrah districts in the north to east of the West Bengal state. From the West to south, the boundary of these districts is limited by Odisha and Jharkhand states. An exceptional macroclimatic condition prevails in this area. The region combines scenery (from hilly regions to flat landscapes). Geographically, the lowest portion of India's "Chhota Nagpur Plateau" is located in the Purulia and Bankura district, which is also West Bengal's most western district [32]. The major flowing rivers are Darakeshwar, Subarnarekha, Silabati, Kangsabati, and Kelehgai. Other small river channels are also in this area, indirectly connected to the Ganga River (except Subarnarekha). Besides, many dams, reservoirs, bundhs, and lakes are also available, indicating the vast potential of freshwater habitat. A geographic information system (GIS) based map of the study area, location points, the central riverine system, and reservoirs has been prepared by ArcGIS software (Version 10.4) for a better understanding of the survey-based data (Fig. 1).

2.2 Fish Sample Identification, Catchment, and Environmental Parameters

The survey-based data were collected from 43 sampling stations covering the central riverine system, tributaries, reservoirs, dams, and lakes. The assessment was conducted from November 2019 to October 2022, and 3-month interval data was collected from the mentioned study sites. The IUCN-RLTF samples are collected from local fishermen and the fish markets at the nearby study sites. We always go to all the fish vendors and the fisher folks to see what they catch. To minimize the bias, we took fish specimens from each vendor and fisherfolk (10 fish for each species if they all have

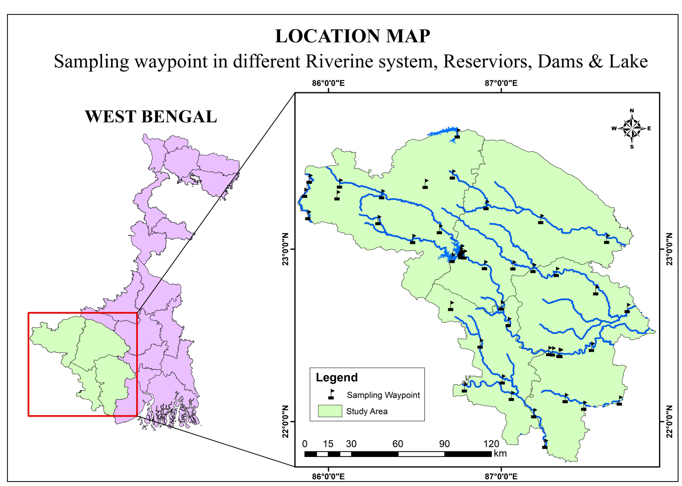

Figure 1. GIS-based mapping of the study area and different sampling points.

more than 10 fish for each species). We also gathered information regarding the types of nets and baits they used for the catchment process. During fishing, mesh size of gill nets (0.5 to 4 cm), scoop nets (0.3 × 0.3 cm to 0.5 × 0.5 cm mesh size), and cast nets (up to 1 × 1 cm in a mesh up to 3.0 m^2 coverage area) are used by fisher folks. Sometimes, local fisher folks use mosquito nets (high-intensity polyethylene nets) and homemade fishing equipment (made from cotton or polyester) for fishing. After the catchment, fish are identified, followed by taxonomic classification [33–35]. The collected fish species were again validated from the IUCN server [11]. During this study period, we have also examined the environmental parameters such as pH, temperature, salinity, dissolved oxygen (DO), turbidity, and conductivity from the 43 sampling sites (3-month interval data), which was determined by the Systronic 371 water analyzer kit.

2.3. LWRs, Growth Pattern, and Condition Factor (K_n)

The LWRs were determined by the linear regression analyses where log W = log a + b log L (W = weight of the specimen, L = TL of the specimen, a = intercept and b = regression slope or coefficient, assessment of *a* and *b* were done at 95% confidence. In log-altered data, the outliers in this equation were removed during the calculation [36]. The TL and W are recorded at the precision of 0.1 cm and 0.01 g using standard measurement tools. In growth pattern analysis, if the regression coefficient values ($p < 0.05$) are b = 3.00, b > 3.00, or b < 3.00, then the data indicates isometric, positive allometric, or negative allometric growth for the fish species, respectively [37]. The relative condition factor (K_n) of the fish species was as per [38], K_n = w/W, where w = weight (g) of specimen and W = weight from the LWRs calculation.

2.4. Species Distribution Modeling

We used the occurrence data from the survey for the species distribution. The modeling for species distribution will only work efficiently when there is less sample bias and adequate sample records from the study site [39, 40]. To gather the bioclimatic variables, we used the dismo package in R (gathered from the World Climate database of "Bioclimatic variables") [41]. We created a RastarStack (layer of raster files) for the analysis. After accumulating the species occurrence data and environmental covariates, we fit it into the presence-only SDM. After that, we used the bioclim function on R to perform a distribution model based on the climatic data that predicted the value ranging from 0.1 to 1.0. The value is measured so that 1.0 will denote the locations where all the environmental variables have a median value, and 0.00 will denote the locations where at least one ecological variable is outside the range parameter of environmental covariates of the study site.

2.5. Non-Metric Multidimensional Scaling

We used NMDS to measure the abundance of species at each study site. NMDS is a distance matrix-based technique that uses the differences between each pair of units regarding any number of response variables. To see how the study sites differ or are similar, we used NMDS, as it takes the distance among the units, which will occur in the same rank order [42]. For our study sites, we used the NMDS to see how they look similar or dissimilar in species abundance in PAST software ver. 4.1 (Fig. 2).

3. RESULTS AND DISCUSSIONS

The previous reports showed six, fourteen, and twelve IUCN-threatened categorized fishes from Purulia, Bankura, and undivided Paschim Medinipur (now divided into Paschim Medinipur and Jhardgram), respectively [21–23, 43]. However, according to our data collection, 10 indigenous IUCN-RLF (Ver. 2022-2) have been found. These fish were already reviewed for the river Ganga and for their present status, distribution, and abundance [44], though, they have not been studied, and their distribution in the southern parts of West Bengal. The reported freshwater fishes are majorly from Order Siluriformes (*Ailia coila, Clarius magur, Ompok pabda, O. bimaculatus, Wallago attu,* and *Bagarius bagarius*), and others are under Anguilliformes (*Anguilla bengalensis*), Osteoglossiformes (*Chitala chitala*), Anabantiformes (*Channa orientalis*), and Perciformes (*Parambassis lala*). The IUCN red-list confirmed that most of these species are under near threatened and VU, and one species is under EN status. According to the population trend, the data shows eight species have a decreasing trend, while two species are unknown. The feeding habits of these fishes are either carnivorous or omnivorous (Table 1).

The maximum and minimum (TL in Centimeter) and weight (W in Gram), the slope (b), intercept (a), the confidence limit at 95% along with r^2 (level of significance) value (by regression analysis; $p < 0.05$), growth pattern and K_n value with standard deviation (±SD) has been determined for these ten indigenous IUCN Threatened categorized freshwater fishes which are documented from the study sites. A new TL_{max} of *P. lala* has been recognized (4.2cm) from the Purulia District.

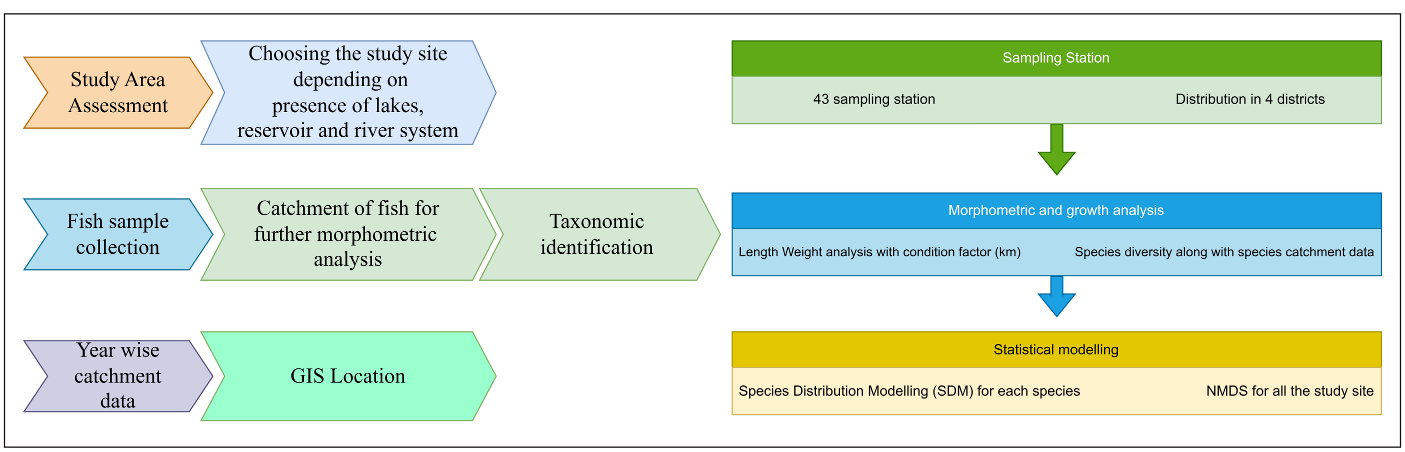

Figure 2. Flow diagram of the methodology used during this study.

Table 1. Taxonomic position, scientific name, origin, feeding habit, IUCN status (Vers. 2022-2), and population trend of the thirteen freshwater fishes from south-west regions of West Bengal.

Sl. No.	Order	Family	Scientific name	Feeding Habit	IUCN status	Population trend
1.	Anguilliformes	Anguillidae	*Anguilla bengalensis* (Gray, 1831)	Carnivores	NT	Unknown
2.	Osteoglossiformes	Notopteridae	*Chitala chitala* (Hamilton, 1822)	Carnivores	NT	Decreasing
3.	Anabantiformes	Channidae	*Channa orientalis* (Bloch & Schneider, 1801)	Carnivores	VU	Decreasing
4.	Perciformes	Ambassidae	*Parambassis lala* (Hamilton, 1822)	Carnivores	NT	Decreasing
5.	Siluriformes	Ailiidae	*Ailia coila* (Hamilton, 1822)	Omnivores	NT	Decreasing
6.		Clariidae	*Clarius magur* (Linnaeus, 1758)	Carnivores	EN	Decreasing
7.		Siluridae	*Ompok pabda* (Hamilton, 1822)	Omnivores	NT	Decreasing
8.			*Ompok bimaculatus* (Bloch, 1794)	Omnivores	NT	Unknown
9.			*Wallago attu* (Bloch & Schneider, 1801)	Omnivores	VU	Decreasing
10.		Sisoridae	*Bagarius bagarius* (Hamilton, 1822)	Omnivores	VU	Decreasing

NT = Near Threatened, VU = Vulnerable, EN =Endangered.

The district-wise number of each fish species was also recorded, with many fish samples found in Paschim Medinipur and fewer in Purulia district. During the sample collection, we could not find *C. orientalis* and *A. coila* in Purulia, *A. coila,* and *B. bagarius* in Paschim Medinipur. However, in the Bankura and Jhargram districts, we found all fish species except *O. bimaculatus* and *B. bagarius*, respectively (Fig. 3). Due to the significantly lower availability of these species, the total number of the documented sample (n) is also deficient. However, all the LWRs are statistically significant ($p < 0.001$) along with the high coefficient (r^2) value which ranges from 0.903 to 0.981. *Ailia coila*, *B. bagarius*, and *A. bengalensis* are rarely found with other fishes. The *b* value in the LWRs analysis of these species is in the permissible range of 2.5–3.5 [45]. The data has confirmed that *W. attu* possesses the lowest b (b = 2.615) while *C. orientalis* has the highest value (b = 3.287), which reflects these species' growth patterns and body shape (Table 2).

The native IUCN-RLTFs are also under this stress by these non-native fishes [46]. During this survey, non-native fishes such as *Gambusia affinis, Ctenopharyngodon idella, Pterygoplichthys pardalis, Hypophthalmichthys molitrix, Oreochromis mossambicus,* and *Piaractus brachypomus* have been found in wild habitats. The study established that the regression slope *b* varies from species to species, and each fish species has its specific growth rate. The condition factor (K_n) with a standard mean (mean value ±SD) of these species ranges from 0.138 ± 0.04 (*A. bengalensis*) to 0.793 ± 0.09 (*C. magur*). However, the high deviation of K_n is found in *W. attu.* The higher K_n value represents fish health based on food preferences and availability of the food items in the aquatic habitats (Fig. 4). Besides, this factor is also influenced by the physical form, different life stages, sampling in various time periods, nutrients, water quality, limitation in number, sexual well-being, age, competition with others, predation, and sex of the species [47, 48]. In inland water bodies, the feeding capacity of the native fish population is likely negatively affected, specifically when water quality has deteriorated. Building dams, reservoirs, and bandh on river streams can be a nutrient trap for aquatic organisms [49, 50]. So, in our study sites, a potential number of riverine constructions were established, which negatively impacted the growth of these populations. According to the water sampling, the range, mean with SD (standard deviation) of the environmental parameters such as pH (6.1–8.6; 7.36 ± 0.44), water temperature (15.6°C–38.8°C; 27.4 ± 5.71), DO (3.50–7.75 ppm; 5.60 ± 1.19), salinity (0.01–0.38 ppt; 0.13 ± 0.06), turbidity (28.7NTU-510.2NTU; 162.4 ± 74.24) and conductivity (0.01–0.45 mS/cm; 0.18 ± 0.01) opted from the define study area. As per the Central Pollution Control Board, Government of India, for the propagation of wildlife and fisheries, the mean DO and pH are within the permissible range (>4 mg/l and 6.5–8.5, respectively) which defines the water quality of the inland water bodies from the study areas. If we look into the minimum and maximum range, we can see that the value is below the permissible range in some areas due to anthropogenic activity, point and non-point sources of pollutants, surface runoff water, and soil texture from the specified sampling sites.

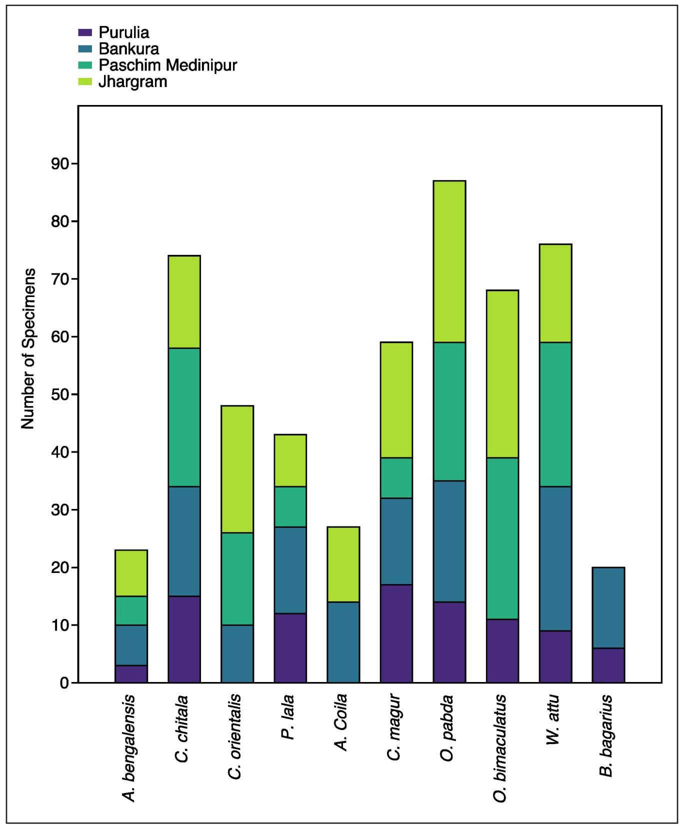

Figure 3. Individual species distribution patterns in Purulia, Bankura, Paschim Medinipur, and Jhargram districts based on data collection.

As these fish species are EN and need immediate attention, we used SDM analysis to estimate their current habitat. This model

Table 2. LWRs parameters, all statistical data, growth pattern, and condition factor (K_n) analysis for 10 indigenous threatened fish species from Southwest regions of West Bengal from November 2019 to December 2022.

Name	TL (cm)	Weight (g)	Parameters of the LWRs							
	Min-Max	Min-Max	n	α	b	CL 95% a	CL 95% b	r^2	Growth pattern	K_n±SD
1. *A. bengalensis*	17.0–40.7	15.1–956.0	23	0.003	2.909	0.001–0.009	2.61–3.21	0.951	-ve allometric	0.138 ± 0.04
2. *C. chitala*	20.1–40.7	65.4–670.4	74	0.001	2.904	0.006–0.016	2.75–3.05	0.954	-ve allometric	0.392 ± 0.05
3. *C. orientalis*	10.8–19.5	10.1–106.5	48	0.004	3.287	0.001–0.008	2.97–3.50	0.903	+ve allometric	0.414 ± 0.09
4. *P. lala*	2.2–4.2*	0.14–0.95	43	0.016	2.837	0.012–0.020	2.63–3.04	0.95	-ve allometric	0.607 ± 0.07
5. *A. coila*	7.0–13.6	5.92–40.2	27	0.021	2.863	0.013–0.035	2.64–3.08	0.967	-ve allometric	0.744 ± 0.09
6. *C. magur*	18.3–29.4	68.8–370.5	59	0.012	2.964	0.006–0.023	2.77–3.16	0.941	-ve allometric	0.793 ± 0.09
7. *O. pabda*	16.5–28.8	36.5–160.8	77	0.004	2.764	0.009–0.019	2.64–2.89	0.963	-ve allometric	0.334 ± 0.03
8. *O. bimaculatus*	20.0–31.0	52.5–251.7	66	0.011	2.825	0.006–0.020	2.65–2.99	0.945	-ve allometric	0.350 ± 0.03
9. *W. attu*	20.2–84.9	177.3–7105	76	0.052	2.615	0.032–0.827	2.50–2.74	0.956	-ve allometric	0.760 ± 0.21
10. *B. bagarius*	15.2–43.8	40.6–875.6	20	0.021	2.818	0.011–0.039	2.64–3.01	0.981	-ve allometric	0.621 ± 0.08

*New maximum total length (TL_{max}).
N = sample numbers; Min = Minimum; Max = Maximum; a = Intercept; b = slope; CL = confidence interval; r^2 = Correlation coefficient; K_n = Condition factor; SD = Standard deviation.

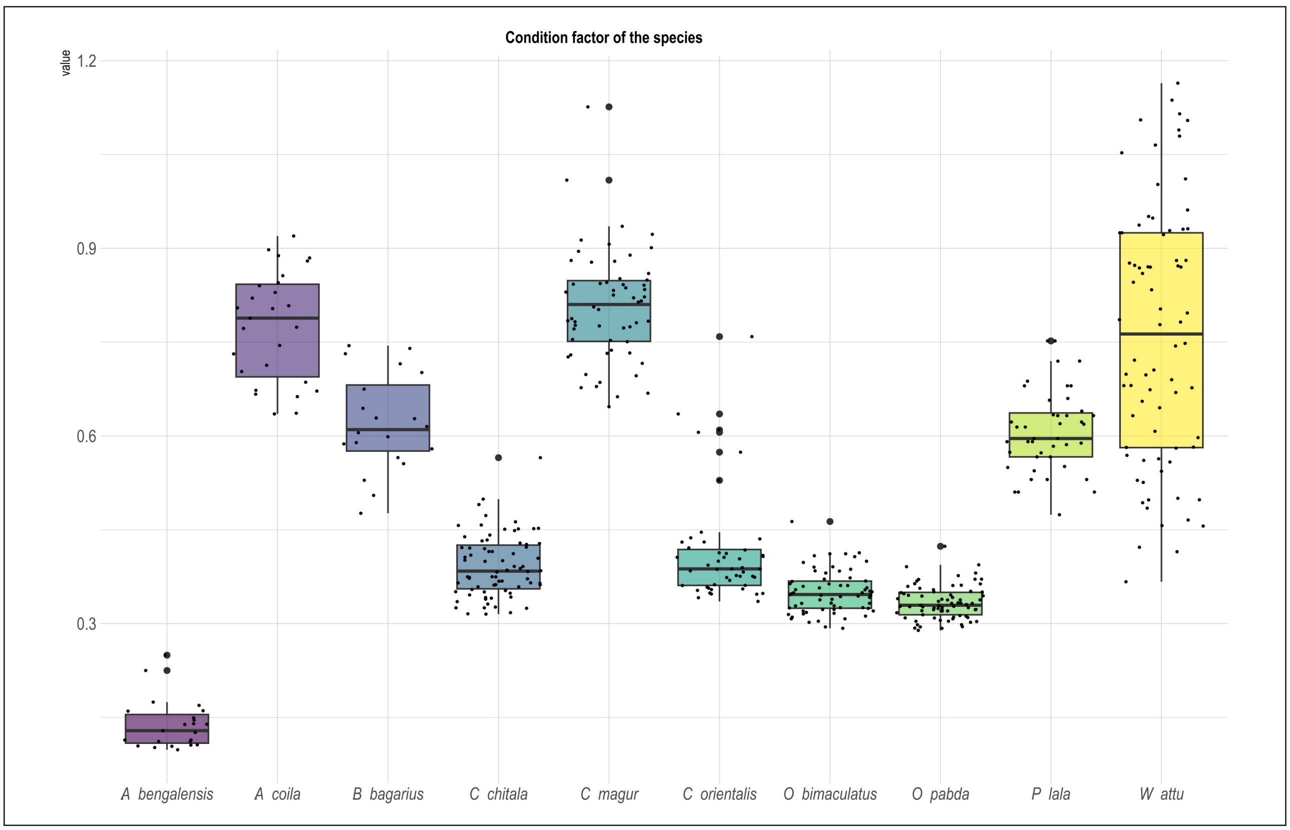

Figure 4. Box-plot (with standard deviation) of condition factors (K_n) in thirteen threatened fishes.

can also predict those species' future habitat, benefitting them in conservation practice [51]. Our analysis shows that *B. bagarius, C. orientalis, and P. lala* need to be well-distributed species around the study site. They also have less distributed zones on the map. We found a good distribution model for the abundant species *O. pabda, C. chitala, A. coila, C. magur, and O. bimaculatus.* This correlates with the sampling diversity on the study sites. We got many samples from the study sites with those species. SDM analysis was not adequate for the *W. attu and C. magur.* In analysis, we found less area on the map that suits the habitat for those species. This habitat suitability map can be essential for restoration management practice (Fig. 5a–j).

Our dataset and NMDS plot show no transparent distinct region or separation for our species abundance on the study sites. This suggests that all our study sites are closely related to each other in terms of species abundance. However, we can see a slight difference for the study sites, which can be clustered into two different types of habitats. As per the figure, we can see that the study sites of Paschim Medinipur and Purulia have a more comprehensive range of species

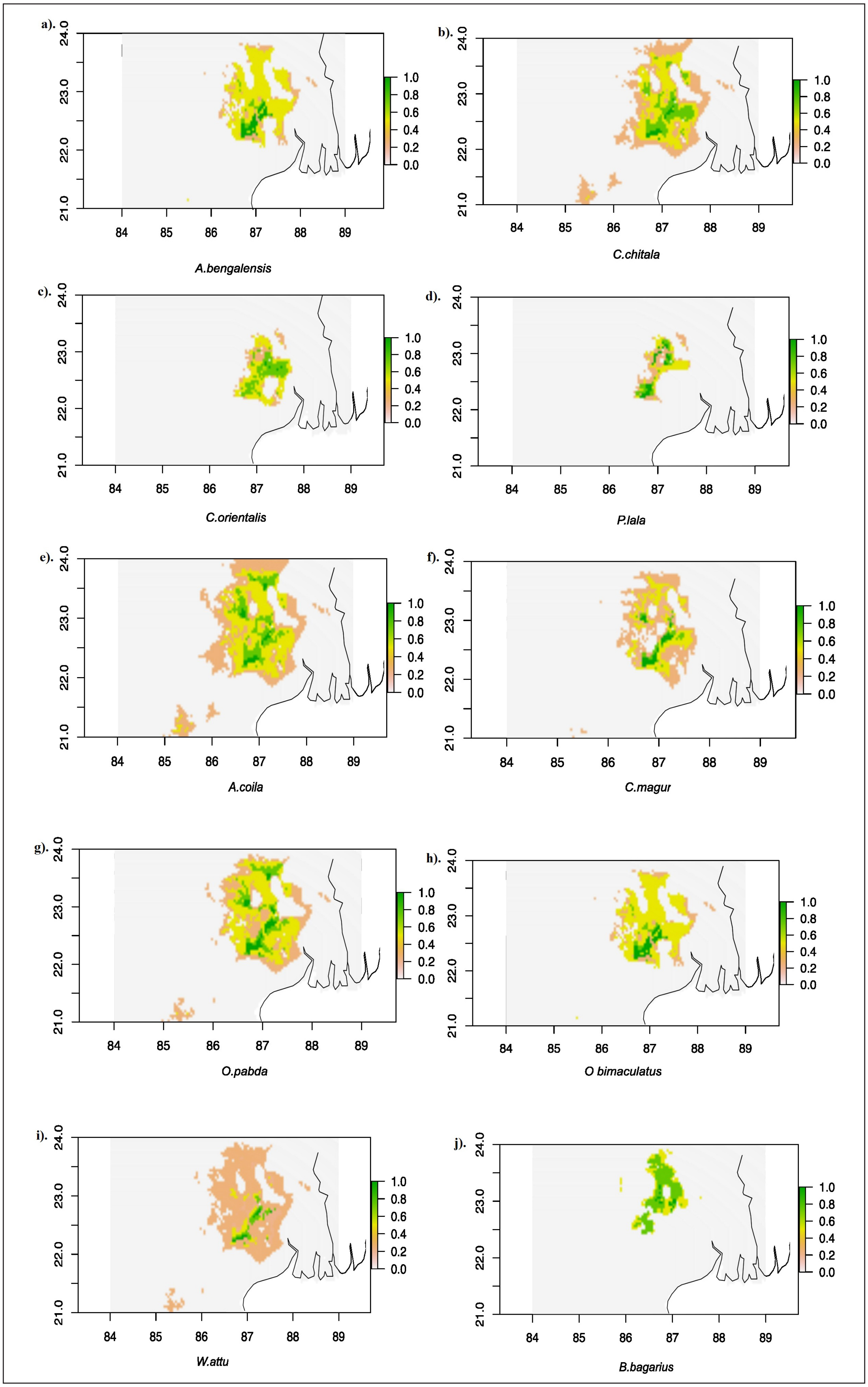

Figure 5. a–j: SDM based on occurrence data of the individual threatened fishes from the study area from November 2019 to December 2022.

abundance distribution, while the rest of the study sites do not have a broader range. This can be due to the large number of water bodies, dams, and reservoirs in both regions compared to the rest of the study sites (Fig. 6).

4. CONSERVATION STRATEGY

The resources of freshwater ecosystems are facing severe crises in the twenty-first century, affecting the ecosystem itself [52, 53]. The multivariate stressors are responsible for destroying the freshwater ecosystem and its resources. The freshwater habitats and species inhabiting them show a wide range of variations in their characteristics worldwide [6]. Numerous freshwater bodies have distinct climates and natural ecosystems; sometimes, they are geographically isolated, which calls for special attention [54]. Likewise, many freshwater species have different needs for conservation because of their valuation or threatened status. With the current or upcoming climatic changes and natural or artificial stressors, freshwater fishes will be forced to adapt rapidly to environmental conditions [55]. Otherwise, they must migrate to different locations or gradually face extinction [56]. However, the construction of dams, bridges, diversions, culverts in roads, and other concrete structures can modify or block the movement of native fish.

On the other hand, it also helps prevent the intrusion of non-native fish and fish diseases [57, 58]. For the conservation of the riverine ecosystem, geopolitical relations emerge as significant challenges and seem hard to crack. During the data collection and interaction with fisher folks, we found that people needed to be made aware of the biodiversity, loss of diversity, and its impact on their livelihood. According to local fishermen, the availability of these species is gradually decreasing (not found regularly other than 5–10 years back in the catchment). Studies related to the stock assessment and length distribution of the threatened fish show that they are indeed decreasing in population size. Fish size distribution in the protected areas, including their germplasm conservation management plans, has already been discussed by previous researchers [59]. However, these studies have yet to be done for the nonprotected areas with abundant threatened fish species.

Our urgent focus is conserving freshwater fish, especially IUCN-threatened ones. Therefore, we should take significant initiatives to make ordinary people aware of fish diversity loss, its evil effects, and their role in protecting native fish diversity and securing sustainable development. If we can successfully apply these strategies, the typical trajectory of population decline can shift upward, leading to a sharp recovery of the threatened fish population (Fig. 7).

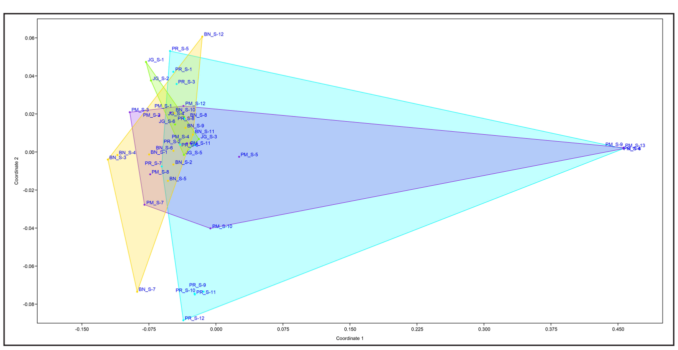

Figure 6. NMDS analysis from the collected data on ten Indigenous threatened freshwater fishes at 43 sampling sites from November 2019 to December 2022.

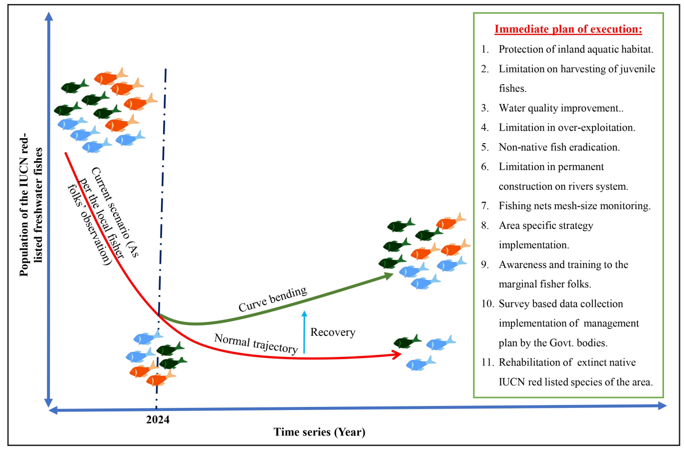

Figure 7. Conservation strategy model for indigenous threatened freshwater fishes.

5. CONCLUSION

The destruction of indigenous threatened freshwater fishes has an immense and prolonged impact on local aquatic habitats. According to the data analysis, they have shown a declining population trend. We also found that they do not uniformly distribute throughout the area, even though some are extinct from different southwest districts (*Cirrhinus cirrhosus* was previously reported but was not found during the study). Their morphology and growth pattern indicate their negative allometric growth pattern due to environmental stress. The abundance of non-native fishes can easily compete with indigenous fishes for food and habitat utilization. Their invasive nature or presence in wild habitats can be an alarming concern to the native threatened fishes. Besides, the primary concern is ecological factors like climate change, eutrophication, water quality change, surface runoff water, and gully erosion. Several non-ecological factors, such as pollution, sand mining, coal and mineral mining, juvenile fish harvesting, construction activity, and small mesh-sized nets, have become significant problems for their survivability in these regions. There is a huge gap between research outcomes, government policy, and ground-level implementation. So, there is an urgent need to conserve those IUCN-threatened fishes through the collaboration of researchers, government policymakers, management practitioners, and most importantly, local people to mitigate the mentioned factors. Our SDM and NMDS analysis ensures which areas require special attention and further inspection for these species to get conservation efforts. Our work will be the road map to establish a proper management and conservation policy for those species. An area-specific strategy implementation would be more fruitful than a broader aspect. The eco-restoration strategy can stabilize the riverine system, which will help to develop sustainable fishery management.

6. AUTHOR CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the International Committee of Medical Journal Editors (ICMJE) requirements/guidelines.

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8. CONFLICTS OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

9. ETHICAL APPROVALS

The fish samples were collected from local fishermen and the fish markets at the nearby study sites. Thus, ethical approval is not applicable.

10. DATA AVAILABILITY

All the data is available with the authors and shall be provided upon request.

11. PUBLISHER'S NOTE

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12. USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declares that they have not used artificial intelligence (AI)-tools for writing and editing of the manuscript, and no images were manipulated using AI.

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