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Conservation Priorities for Threatened Fish to Withstand Climate Crisis: Sustainable Capture and Protection of Inland Hydrographic Ecosystems

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Abstract: Globally, suitable freshwater habitats are undergoing alterations and fish population declines, primarily attributed to the swift changes in climate and land use. Developing an effective conservation policy for freshwater fish necessitates careful consideration of the impacts of climatic and spatial factors. This study focuses on the analysis of 64 threatened freshwater fish in Bangladesh to anticipate their current and future climatically suitable habitats, utilizing the *bioclim()* species distribution model. Additionally, this study examines existing inland hydrographic networks and their corresponding harvest rates. The findings indicate that approximately 75% of the area of occupancy for the studied species is currently climatically suitable, but this is expected to decrease to 13% under future climate scenarios. Notably, 27 threatened species are at risk of lacking climatically suitable habitats in the future within their current area of occupancy. The three components of hydrographic networks—floodplains, rivers, and natural lakes—play varying roles in providing a climatically suitable habitat for the studied species. For instance, only 34% of threatened fish species are projected to find a suitable habitat over flood areas, 23% over rivers, and 16% over lakes. Existing protected areas presently offer limited protection (21% suitable area), expected to decline to 6% in the future, with no dedicated protected areas for freshwater fish. Floodplains are highlighted for providing habitat connectivity and facilitating brood fish dispersal. However, the unregulated and unmonitored annual harvest of freshwater fish from floodwater and rivers poses a potential silent cause for rapid population decline. Prioritizing the management of hydrographic components to maintain habitat connectivity, legal protection for threatened fish species, and establishing permanent protected areas for fish are crucial aspects in developing a conservation policy to mitigate the impact of future climate scenarios on threatened freshwater species.

Keywords: climate change; conservation policy; floodplains; habitat suitability; IUCN threatened fish; SDM

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1. Introduction

Between the surface aquatic habitats, the total area of fresh waterbodies (0.77% of 1,386,000,000 km^3 water) is much smaller than the vast marine water [1,2]. Freshwater bodies consist of an ‘open or lotic water body’ like rivers and canals and a ‘close or lentic water body’ like lakes and ponds. Although these small habitats accommodate a great diversity of species ranging from Protozoan to Chordates [3], they are facing a dramatic decrease in suitability, alteration, and fragmentation due to the rapid changes in climate and anthropogenic land use [4,5]. While habitats are unsuitable and disconnected, particular natural selection pressures significantly contribute to the decline of freshwater fish communities. For instance, the limiting factors of the habitat [6,7], species’ tolerance and adaptation mechanisms weakening [8], limitations in resource allocation [9], unstable population structures [10], pollution, and susceptibility to disease [8,11–13] are highly contributory selection pressures in declining species. In comparison to other Chordates, the decline in freshwater fish species often goes unnoticed and this causes severe consequences on threatened species. A comprehensive analysis of the status and distribution of suitable and accessible existing habitats, coupled with an examination of the population dynamics of these threatened taxa across a broad spectrum of climate and habitat variables, can provide the essential information needed by conservation policymakers.

During the last Red List assessment, there were five parameters employed to determine the conservation status of species; those parameters are (A) population size reduction, (B) the geographic range in the form of either the extent of occurrence or area of occupancy, (C) a small population size and decline, (D) a very small and restricted population, and (E) quantitative analysis [14]. Due to the absence of corresponding information from many countries, the assessment ended up mostly using the area of occupancy (AOO) and extent of occurrence (EOO) in parameter B and in the sub-category of parameter A, while other parameters were noted as 'unknown' or 'not assessed'. Moreover, AOO and EOO referred to the aquatic areas where the species were recorded to occur, but did not indicate that the habitat is climatically and ecologically suitable for the species. It is noteworthy that the AOO and EOO of inland waterbodies, both lotic and lentic, are rapidly decreasing due to the anthropogenic land use activities in many developing countries [15]. Thus, the degree of changes in the existing area of occupancy should be analyzed thoroughly to understand the dynamics of the occupancy and distribution.

Climate change is considered a key process when determining the distribution of a suitable climate space for a species [16]. Since freshwater fishes are ectothermic, they are anticipated to be greatly affected by the lack of a climatically suitable habitat [17]. The lentic habitats, small lakes, and ponds in tropical countries are often perennial, and the drying out of those waterbodies is usually prolonged due to climate alteration [18]. In addition to the habitat connectivity, protected areas are often established to safeguard various Chordates from threats, but such conservation efforts for freshwater fishes are not extensive. Identifying climatically suitable areas for further establishing new protected areas and a 'coldspot' for those threatened fish species may increase the compatibility of conservation strategies [19]. Studying the shape, size, and geographical distribution of the suitable climate spaces over hydrographic networks (river, lakes, and floodplains) and protected areas may provide baseline information about the dynamics of the habitat suitability [20] and may help when designing conservation strategies.

In addition, non-sustainable fish harvesting practices from inland habitats have a great impact on rapid population decline in freshwater fish species [21]. In many countries like Bangladesh, freshwater fish is the main protein source for human consumers, though the capture of fishes from open waterbodies is poorly monitored [22]. Also, the rapid growth in fish culture industries is transforming the small-to-medium-sized inland freshwater bodies into controlled culture ponds for farming. This transformation is reducing the accessibility to those controlled habitats for native fish species [23]. Therefore, overharvesting, continuous reduction of the available habitat, and the impact of hybrid and exotic fish might have a harmful impact on the available habitat and stable population of the native threatened fish community. Analyzing the harvest from open and closed waterbodies may provide information about the population dynamics of freshwater fish for conservation ideas.

Bangladesh is a low-elevation country consisting of a massive network of more than 400 rivers accompanied by various lentic freshwater bodies like haors, baors, beels, and lakes [24]. Being situated in between Indo-Himalayan and Indo-Burmese hotspots, the country has diverse ecological structures with wide floodplains, 12 bio-ecological zones [25], and 7 climatic sub-regions [26]. This ecologically diversified country is home to about 253 freshwater fishes, of which more than 25% species were declared as threatened by IUCN Bangladesh [27] (Supplementary Table S1). This assessment has pointed out that habitat loss, overexploitation, and the culture of exotic fish are the key threats to the threatened fish species in Bangladesh [5,27]. In addition, this country is predicted to face a huge climate change impact in the future, where the existing AOO and EOO may lose their climate suitability [28]. While assessing the regional conservation status, the availability and climatically suitable habitat and population status of the threatened freshwater fish should be taken into consideration for the next assessment.

Considering this fact, this study aimed to determine the shape, size, and geographical distribution of current and future climatically suitable habitats of the threatened freshwater fishes of Bangladesh over the existing inland hydrographic network. We also analyzed the harvest, catchment area, and established protected areas to produce baseline information for potential conservation strategies.

2. Materials and Methods

2.1. Occurrence Data Collection

One-hundred occurrence points for each of the sixty-four threatened freshwater fish species were obtained from the area of occupancy (AOO) polygons of the latest Red List assessment in 2015 [27]. For each species, these occurrence coordinates were randomly collected from those polygons using a balanced acceptance sampling (BAS) algorithm to prevent the overlapping of random points from the same quadrate of 1×1 km^2 [29].

2.2. Climatic and Spatial Factors

Nineteen bioclimatic variables were collected from the WorldClim2.0 database [30]. These Bioclim variables were centered and standardized to z-values (Z score $= \frac{x-\mu}{\delta}$; x is the original score, μ is the mean value, and δ is standard deviation) to avoid biases due to different magnitudes of variables. To minimize the multicollinearity, the highly correlated (Pearson's $r > 0.9$) variables were removed and 12 bioclimatic variables were selected primarily for further analysis, along with three biogeographical variables (floodplains, bioecological subzones, and climatic sub-regions) relevant to the occurrence area (Figure 1). The categorical biogeographic variables were transformed into continuous values by quantifying the proportional occupancy of the AOO (area of occupancy) across the categories of a raster. For instance, each pixel in the bio-ecological subzone raster was assigned values ranging from '1' to '12', corresponding to 12 distinct bioecological subzones in Bangladesh. Suppose a species occupies 70% of its AOO within category '1' of this raster and 30% within category '3'. In this case, every pixel within category '1' is designated as 0.7 and each pixel in category '3' is labeled as 0.3. Pixels outside these categories are designated as 0. This conversion of pixel values reflects the relative occupancy of a species across multiple categories. A similar transformation was applied on three biogeographical variables before using them to train the climate model. Twenty-three future climate projections of the shared socioeconomic pathway 370 (ssp370) were used to predict twenty-three future suitable climate maps for each species [31].

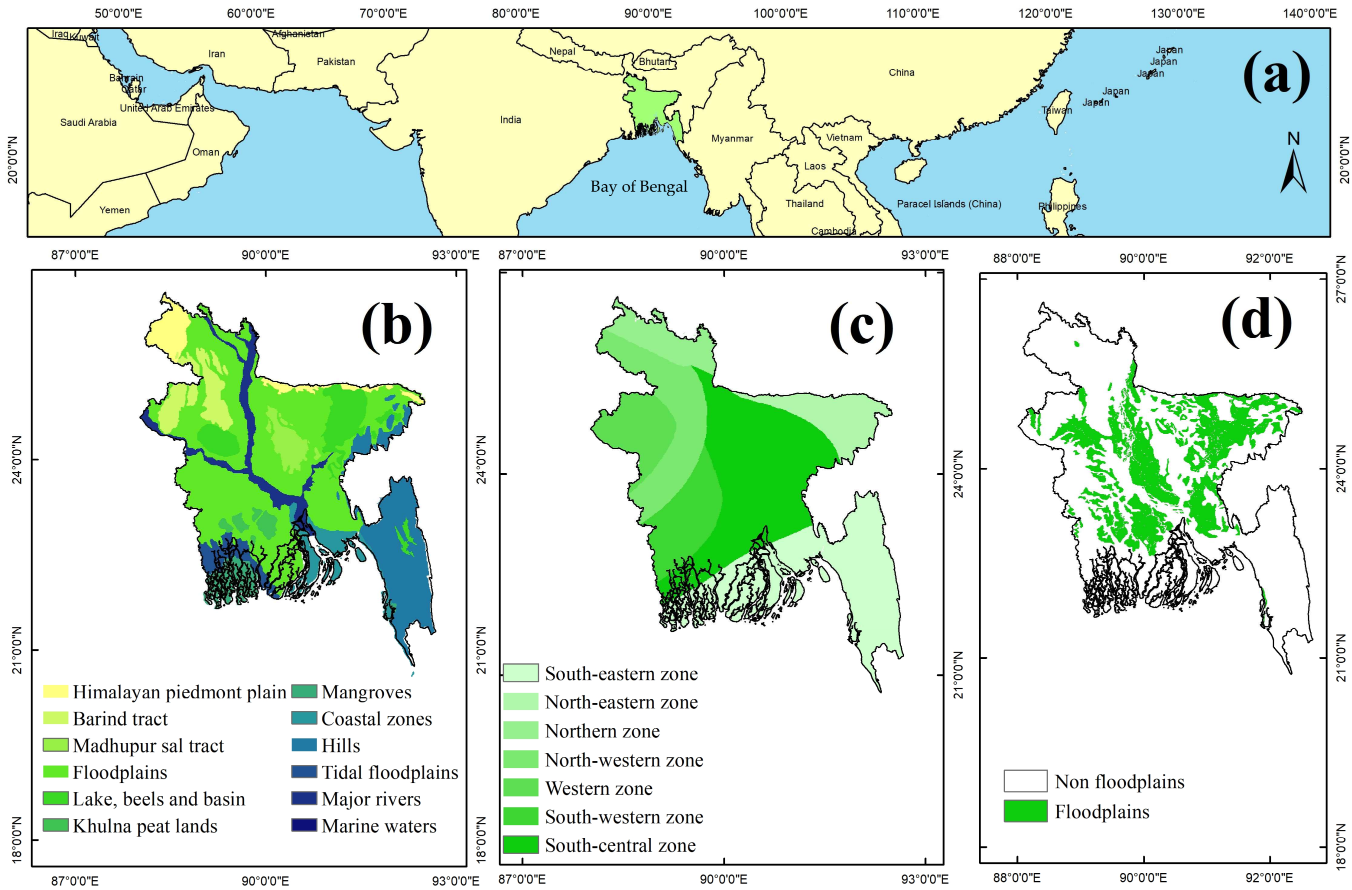

Figure 1. The study area, (**a**) Bangladesh, and the distribution of three spatial variables, (**b**) bio-ecological subzones (adopted from [25]), (**c**) climate sub-regions (adopted from [26]), and (**d**) regularly flooded areas (adopted from [32]).

2.3. Species Distribution Model

Suitable climate niches were projected by training the *bioclim()* algorithms of the dismo package [33] using the 12 climatic and 3 biogeographical variables derived from the occurrence points of each species. The algorithm calculated the probability value of occurrence of any species for each pixel (1×1 km^2) across the raster of Bangladesh. The occurrence probability values lower than 0.001 were reclassified to zero for standardization purposes, using the *reclassify()* function in R programming. Following this method, the suitable climate maps of 64 species were generated based on current and future climate prediction. For future predictions under 23 future climate scenarios, 23 probability maps were produced for each species. To consolidate these into a single map per species, a weighted average method was applied. Besides mapping, the suitable climate space over the terrestrial location was not considered in the analysis. The species richness map was generated by aggregating the area of occupancy polygons of 64 species into a single map. A similar aggregation method was used to generate two more SR maps (SR on current and future climate) by integrating the predicted map for the current and future climate for 64 species. These three SR maps will provide comparative information about the observed richness of species, richness under the current climate condition, and richness under the future projected climate scenario.

2.4. Inland Hydrographic Network

The spatial polygons used to denote the current rivers and lakes of Bangladesh were 6264 and 2001 km^2 in size, respectively. The polygons of inland rivers were collected from the Earthworks shapefile repository of the Stanford library [34]; inland lakes data were collected from the Office for the Coordination of Humanitarian Affairs (OCHA) services for the Humanitarian Data Exchange (HDX), of which the original source is the Local Government Engineering Department (LGED) of Bangladesh; and the dataset was updated by the World Food Programme (WFP), Map Action, and OCHA [35]. A total of 9699 km^2 of the 49 protected area polygons (excluding the marine PA) in Bangladesh was obtained from the free online repository of the World Database on Protected Areas [36] and 35,328 km^2 of the regularly flooded area polygon was collected from a source map of the Prime Minister's Official Library published in a paper [32]. These spatial polygon data of rivers, lakes, floodplains, and protected areas were used to crop and measure the climatically suitable aquatic habitat for the 64 threatened freshwater fish species. The cropped area presents the climatically suitable freshwater habitat over the hydrographic components and the protected areas. Twenty-years data (from 2003 to 2022) on the area of the lakes, rivers, and floodplains, along with the yearly harvest from these water bodies, were collected from the year book of Fisheries Statistics of Bangladesh [37]. Similarly, the area used and the harvest obtained from the fish farming water bodies were collected from the same source and were used to understand the rate of transformation of small waterbodies for fish culture in Bangladesh. Notably, tiny creeks and ponds were excluded from the suitable climate analysis because these water bodies cannot be used to crop or mask the raster pixel of the independent variable raster.

2.5. Determination of Species Status

The conservation status of every studied species was re-assessed by following the B2 criteria of the IUCN Red List assessment guideline version 15.1. This re-assessment was conducted using the area of observed AOO, current climatically suitable area over AOO, and future climatically suitable area over AOO [14]. Briefly, a species with <10 km^2 AOO was considered critically endangered (CR), <500 km^2 AOO was endangered (EN), and <2000 km^2 AOO was vulnerable (VU) based on current observation, current estimation of climatically suitable areas, and future estimation of climatically suitable areas. Moreover, species were categorized into different risk groups based on the percentage of climatically suitable spaces over the three different habitats of the hydrographic network (rivers, lakes, and floodplains) of Bangladesh. A species with >75% suitable climate space over any of those habitats was recognized as the least-risk group and, subsequently, the low-risk group, moderate-risk group, and high-risk group were classified by assessing >50 to <75% suitable area over those habitats, >25 to <50%, and <25%, respectively. Threatened fish species at maximum risk were determined based on future prediction of 0% climate space within their current AOO. The efficiency of protected areas (PA) to provide suitable climate habitats for a species in present and future prediction was categorized as highly protected, moderately protected, less protected, least protected, and not protected. Categories were defined based on >75%, >50 to <75%, >25 to <50%, 1 to <25%, and 0% suitable habitats inside the PA.

3. Results

The size of the current climatically suitable area (CCSA) of the 64 studied species in Bangladesh varied from 11 to 128,433 km^2 and those are 0.85–183.33 times larger than the observed area of occupancy (AOO) of those species. While the species richness (SR) map generated from those predicted CCSA resembled the SR map of the observed AOO (Figure 2a,b), analysis revealed that the CCSA of each species did not completely overlap with their respective AOO. For instance, an average of around 75% of the areas of the observed AOO of the studied species are located within their CCSA. This suggests that not only does some portion of the AOO extend beyond the CCSA, but also, some parts of CCSA lie outside the observed AOO. For future climate conditions, the Bioclim model found highly shrunken and severely fragmented suitable climate spaces for the studied species (Figure 2c). The sizes of the predicted future climatically suitable areas are not only smaller (by about three and half times) than that the current size of the AOO of those species, but also, an average of 80% of the area of the 64 AOOs will be situated outside the future climatically suitable areas.

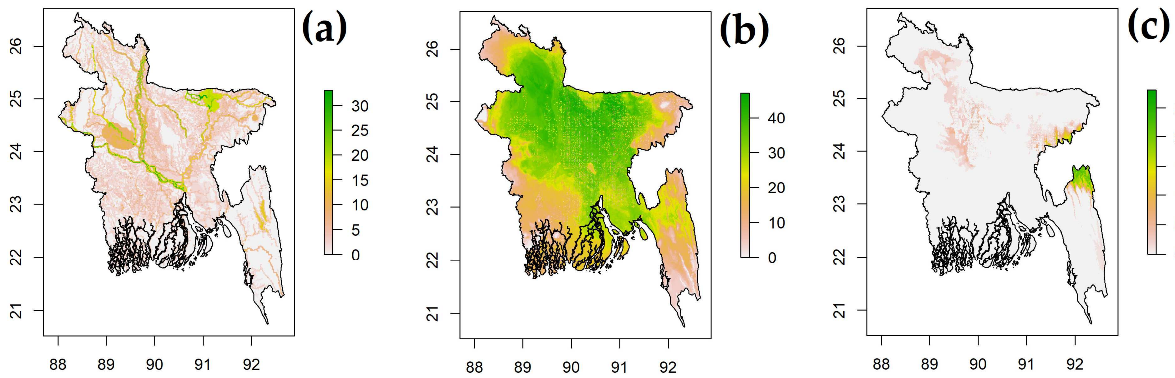

Figure 2. Species richness map of (**a**) observed occurrences, as well as (**b**) present and (**c**) future suitable climate space of threatened freshwater fishes in Bangladesh.

3.1. Present Prediction of Suitable Climate Spaces

Under current climate conditions, a significant portion of Bangladesh exhibits climatic suitability for the studied species. The majority of threatened freshwater fish species are anticipated to thrive within the river network (see major rivers in Figure 1b) and in waterbodies adjacent to the river network in the northern half of the country (Figure 2b). The waterbodies in the Chittagong Hill Tracts (CHT) in the southeast of the country are an interesting area and may provide suitable climatic niches for 20 studied species. Another promising region is the southwestern part of the country, encompassing the vast Ganges delta, providing a suitable climate for the threatened freshwater fish species. However, despite the large climatically suitable space, *Channa barca*, *Devario anomalus*, *Neolissochilus hexagonolepis*, and *Neoeucirrhichthys maydelli* face significant constraints, with almost no suitable climate space within the existing hydrographic network (<1% of the area in both open and closed water bodies) of the country. Including these 5 species, a total of 22 species have a <10% climatically suitable area in the available open water system of Bangladesh, whereas an average of only 41% of the available close lentic habitats are climatically suitable for all studied species. Interestingly, more than 90% of the flood area is climatically suitable for 55 studied species, but the other 9 species have less than 10% of the regularly flooded area that is climatically suitable.

3.2. Future Prediction of Suitable Climate Spaces

Our model projections indicate a significant, severe scarcity of suitable climate space over existing aquatic habitats by the year 2080 (Figure 2c). According to the model, an average of around 13% of the current AOO of the threatened species is predicted to be climatically suitable and 37 species may have no suitable climate spaces within the country in the year 2080. However, a portion of the hilly region in the southeast part of the country is identified as a future suitable area for 25 species. In the future, only a small percentage—18% over open water bodies, 17% over closed water bodies, and 6% over existing protected areas—will have suitable climatic niches for the studied species. Though the regularly flooded zone currently plays a significant role, it may face a decrease in suitability, with only an average of 37% remaining suitable for the 64 fish species in 2080. Surprisingly, 18 of these species may still find suitable spaces as extensive as the regularly flooded region of the country.

3.3. Recent Scenario of Fishing and Shape of the Hydrographic Network

The area of hydrographic components reveals noteworthy trends in recent times. The area of open inland waters, depicted by the shapes in Figure 3, has either decreased or remained stable, while the wild fish capture from these aquatic bodies has an upward trajectory (Figure 3a). Though the capture from rivers has doubled, increasing from 0.15 to 0.32 million metric tons in the last decade, the mass of harvested fish (0.8 Mmt) from floodwaters surpasses that from any lotic water body. Despite covering less than one million hectares in size, the 'beels' face the highest capture intensity (capture per areas ratio is ~1). In addition, the freshwater fish culture in close inland waters, including culture ponds, shrimp/prawn farms, and seasonal fish farming water bodies, has experienced a notable escalation over the years (Figure 3b). The fish production density per unit area from fish farming ponds and seasonal water bodies for aquaculture has doubled in the past 10 years. Meanwhile, although the size of the baors is decreasing, the capture remains consistent at around 0.1 million metric tons. Of the closed water bodies, the capture intensity was the highest in small-to-medium ponds.

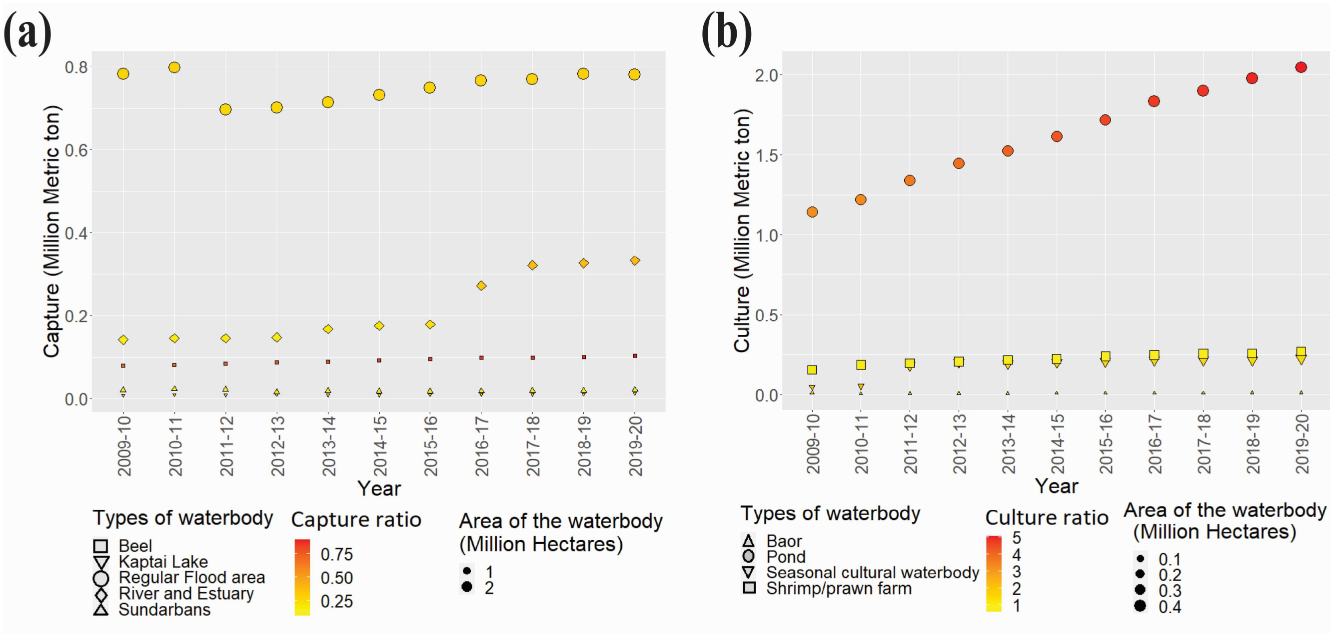

Figure 3. Size (in millions of hectares) of and harvest (in millions of metric tons) from (**a**) lotic and (**b**) lentic aquatic habitats in the recent past (2002–2022); the shapes indicate types of habitat categories, the sizes of those shapes denote the change in habitat area, and the color intensity means the proportional ratio of harvest in unit area.

3.4. Re-Assessing the Species Status

Based on the current distribution of species, more than 50% of the area of occupancy (AOO) is considered climatically suitable for 58 studied species. Concerning the future climate, the same portion of the AOO is projected to become unsuitable for 59 fish species. An analysis of the current AOO, considering only B2 criteria of the IUCN Red List assessment guideline, reveals that 27 species are under threatened categories (CR-01, EN-11, and VU-15). A similar assessment, performed using the climatically suitable AOO, shows that 32 species fall under threatened categories (CR-01, EN-11, and VU-20) (Figure 4). In a further prediction on future climate conditions, the suitable AOO indicates that 49 species will likely fall under threatened categories (CR-31, EN-14, and VU-04).

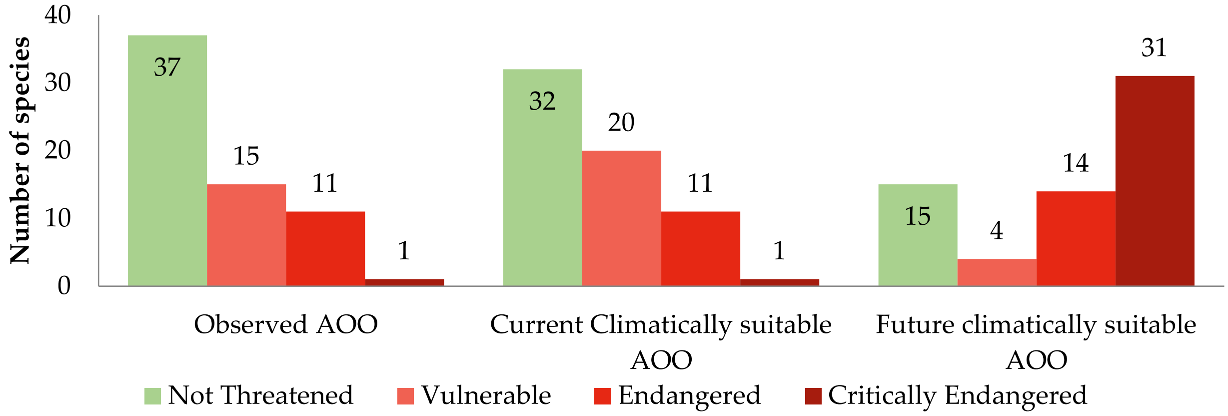

Figure 4. Analysis of status based on the area of occupancy (AOO) considering B2 criteria of IUCN Red List assessment guideline for observed AOO, current climatically suitable AOO, and future climatically suitable AOO.

3.5. Efficiency of Protected Areas to Provide Suitable Climate Space

However, the existing permanent protected areas (PAs) are not fully equipped to ensure maximum protection by assuring suitable habitats for any threatened fish species. Only an average of 20.56% of the protected areas were found to be climatically suitable for the studied species and the existing protected areas provide moderate protection for 16% of the species, low protection for 13% of the species, the least protection for 65% of the species, and there is no suitable habitat inside the PA for 6% of the species (Figure 5a). For the majority of the species (70%), PAs may provide the least protection (<25% climate habitat), and there will not be any suitable climate habitat for 30% of threatened species (Figure 5b). Examining the three components of the hydrographic network, floodplains emerge as the most crucial, providing climatically suitable and accessible habitats for the highest proportion of threatened fish species (69%) in the future, followed by rivers (50%) and lakes (40%) (Figure 6). Similarly, floodplains are also predicted to support the maximum number of species (34%), followed by rivers (23%) and lakes (16%) providing suitable climate space.

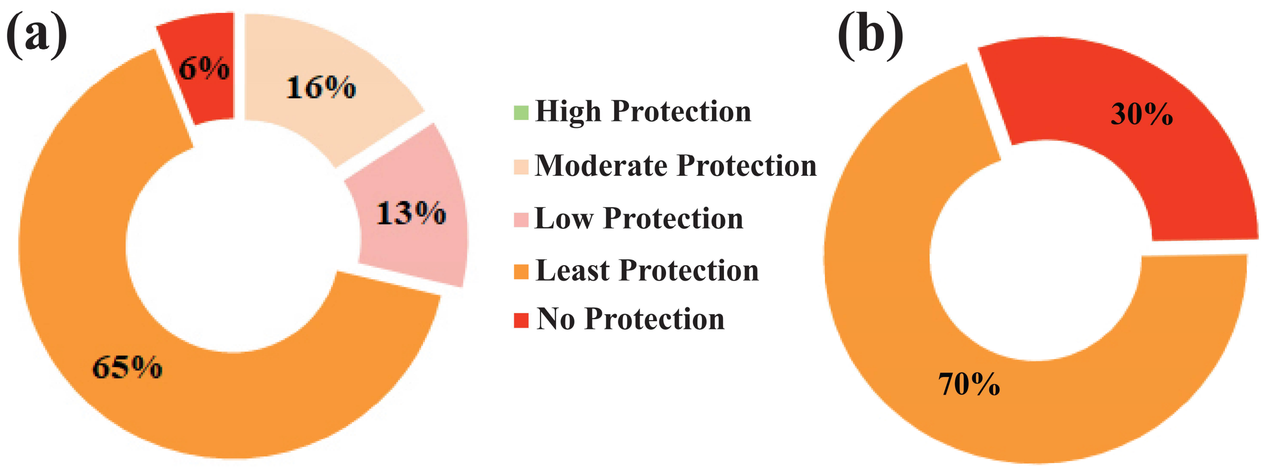

Figure 5. Efficiency of protected areas (PA) to provide suitable climate habitats for threatened fish in (**a**) present and (**b**) future predictions; high protection, moderate protection, low protection, least protection, and no protection categories are defined based on >75%, >50 to <75%, >25 to <50%, 1 to <25%, and 0% suitable habitat inside the PA.

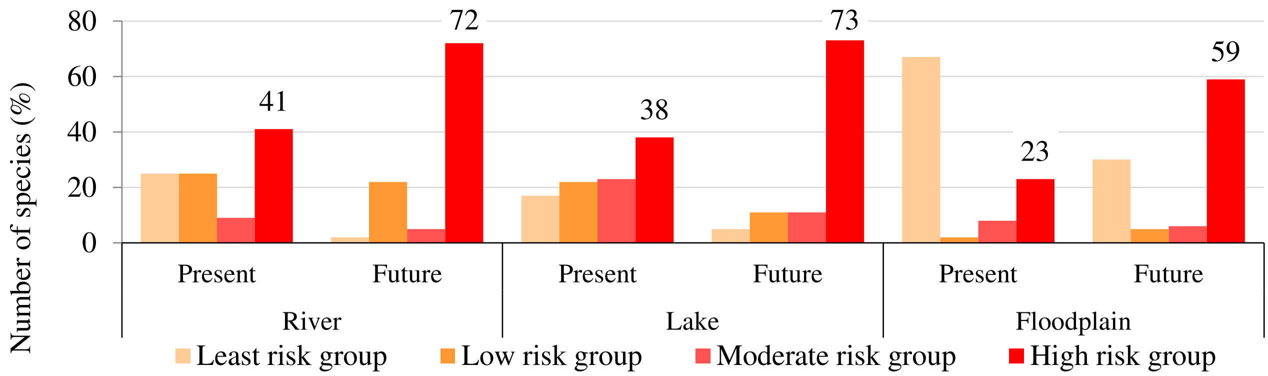

Figure 6. Risk groups were determined based on the percentage of present and future climatically suitable spaces over the different types of habitat categories: the least-risk group, a species having >75% suitable climate within the inland waterbodies; low-risk group, >50 to <75%; moderate-risk group, >25 to <50%; and high-risk group, <25%.

3.6. High Risk Group of Extinction

The Bioclim model projections have identified a concerning scenario for 27 threatened fish species, as they predict that they will have zero future suitable climate habitats within their area of occupancy (AOO). Consequently, these species have been categorized as a high-risk group for extinction, highlighting the urgency of conservation efforts (refer to Table 1). In addition, *Olyra longicaudata* is projected to have a negligible suitable climate habitat (0.026%) within its AOO, with no suitable habitats within the rivers and lakes. *Batasio tengana* is expected to have small future suitable habitats (<2%) within the AOO and no habitats within the rivers.

Table 1. List of species in the high-risk-of-extinction group of the threatened freshwater fish species and their future predicted climate spaces within different habitats.

Species Name	Areas (%) within Future Suitable Climate				
	AOO	River	Lake	Floodplains	Protected Areas
Channa barca	0.00	0.00	0.00	0.00	0.00
Devario anomalus	0.00	0.00	0.00	0.00	0.00
Garra annandalei	0.00	0.00	0.00	0.00	0.00
Labeo boggut	0.00	0.00	0.00	0.00	0.00
Labeo nandina	0.00	0.00	0.00	0.00	0.00
Labeo pangusia	0.00	0.00	0.00	0.00	0.00
Raiamas bola	0.00	0.00	0.00	0.00	0.00
Tor putitora	0.00	0.00	0.00	0.00	0.00
Neolissochilus hexagonolepis	0.00	0.00	0.00	0.00	0.00
Schistura sikmaiensis	0.00	0.00	0.00	0.00	0.00
Schistura corica	0.00	0.00	0.00	0.00	0.00
Neoeucirrhichthys maydelli	0.00	0.00	0.00	0.00	0.00
Sisor rabdophorus	0.00	0.00	0.00	0.00	0.00
Barilius tileo	0.00	0.00	0.00	0.01	0.00
Garra gotyla	0.00	0.00	0.00	0.02	0.00
Lepidocephalichthys irrorata	0.00	0.00	0.00	0.03	0.00
Schistura scaturigina	0.00	0.00	0.00	0.04	0.00

Table 1. *Cont.*

Species Name	Areas (%) within Future Suitable Climate				
	AOO	River	Lake	Floodplains	Protected Areas
Sicamugil cascasia	0.00	0.00	0.00	0.14	0.11
Ompok pabo	0.00	0.00	0.00	0.45	0.02
Labeo ariza	0.00	0.00	0.00	0.55	0.08
Osteochilus hasseltii	0.00	0.00	0.00	1.02	1.04
Labeo boga	0.00	0.00	0.30	1.37	0.00
Botia lohachata	0.00	0.00	0.00	1.37	0.67
Amblyceps laticeps	0.00	0.00	0.00	4.04	2.77
Eugnathogobius oligactis	0.00	0.13	0.20	2.14	0.73
Awaous grammepomus	0.00	0.19	0.10	3.97	1.91
Tor tor	0.00	1.40	2.20	17.33	1.82
Olyra longicaudata	0.26	0.00	0.00	4.70	3.29
Batasio tengana	2.00	0.00	0.15	2.57	0.30

Notably, among these species, 13 have no alternative suitable habitats predicted in the future, exacerbating the risk to their survival. Four species (*Barilius tileo*, *Garra gotyla*, *Schistura scaturigina*, *Lepidocephalichthys irrorata*) have <1% alternative habitats only within the floodplains. It is important to mention that seasonal floodwater may provide alternative habitats for 16 species of the high-risk-of-extinction group.

4. Discussion

The threatened freshwater fish species in Bangladesh are expected to experience a significant reduction in climatically suitable habitats within the existing hydrographic networks of the country in the near future. Fish species at high risk like *Awaous grammepomus*, *Barilius tileo*, *Labeo boga*, *Neolissochilus hexagonolepis*, and *Batasio tengana* may face extinction due to the lack of suitable habitats in the current aquatic environments in Bangladesh. The species distribution model indicates a potential shift in suitable habitat distribution towards the hill tracts, suggesting a migration of suitable climate zones from the plains to higher elevations to accommodate temperature changes [8,38]. In the anticipated timeframe, it is suggested that existing high-altitude freshwater bodies, like the Kaptai Lake, the largest man-made lake in Bangladesh, could serve as alternative habitats to safeguard these threatened species in future climate scenarios. However, the physical barrier posed by hilly terrains may limit the migration of fish to these elevated suitable habitats [39–41]. Simultaneously, the quality of freshwater fish habitats in the plains is gradually declining due to rising surface water temperatures, shifts in precipitation patterns [42,43], and anthropogenic interference [44,45]. The proper conservation and management of high-elevated water bodies and freshwater bodies in plains may facilitate the future protection of threatened fish.

Most of the rivers in Bangladesh originate from the Indo-Himalayan mountain and flow through Bangladesh towards the Bay of Bengal [46]. Rivers constitute the primary elements of the hydrographic network, connecting through numerous small-to-large canals [47], and are suitable for 32 species at present, but may be suitable for only 15 species in future climate scenarios. These waterways undergo temporary disconnection during the dry season and reconnect during the wet season [48]. However, these lotic habitats are experiencing shallowing, narrowing, and fragmentation due to siltation [49] and unplanned development activities [18]. In addition, small ponds and lakes are rapidly transforming into controlled fish farming ponds. This transformation further diminishes the availability of freshwater habitats for native fish species. Therefore, it is imperative to maintain connections within both lotic and lentic components to ensure the protection of threatened freshwater fish in Bangladesh.

The heavy rainfall in the monsoon causes floods in low-elevated countries like Bangladesh, and that floodwater connects the lentic and lotic water bodies for a few months [50]. In the current climate scenario, floodwater appears to be one of the noteworthy habitats for freshwater fishes and has also been found to be highly suitable for threatened fishes in the future. Most of the native fishes depend on seasonal flooding for spawning cues and larval development [51]. Brood fishes move from deep to shallow waters for their reproduction during the monsoon, and flood-connected hydrographic networks provide travel ways for their breeding migration [52,53], allowing the population to mix up [50]. Floodplains and their ecological association with freshwater fishes have long been acknowledged [54] for their reinforcement in reproduction and food [55,56]. Around 80% of the surfaces of Bangladesh are considered floodplains [57,58] and 25–33% (maximum 57%) of the entire country [59] remains submerged for four-to-six months as a result of heavy monsoon rains and snow melt in the mountains [50,60]. Although inundation depth and duration vary spatially, but temporally, depending on the relief and soil type [61], flood flow increases the distribution of freshwater fish species around the floodplains to claim more suitable habitats [62,63]. To maintain the dispersal ways of threatened fish species over a suitable habitat, the establishment of inland water bodies and the management of seasonal flooded areas may play a vital role.

There are some small, seasonal, and temporary protected areas, known as fish sanctuaries, which are not providing support for long-term conservation [64]. Meanwhile, none of the permanent protected areas dedicated for wildlife conservation in Bangladesh are for fish [65]. Moreover, aquatic bodies in those protected areas provide a present suitable habitat for threatened fish species; however, there will be no suitable habitats in the future. This clearly indicates the necessity of permanent protected areas dedicated to freshwater fish conservation [66]. We strongly suggest the establishment and conservation of available aquatic habitats and the creation of new water bodies in predicted suitable climate spaces to interconnect the hydrographic networks and to expand and sustain their existence in the altered climate conditions.

Despite the habitat viability, the sustainable harvest of fishery resources depends on the management of fishing pressure to be maintained at the minimum level [67]. Our analyses revealed that uncontrolled and unsupervised fish capture from open water, particularly from rivers and floodwaters, exceeds fish harvest from any other sources by multiple times. The capture of broods, fries, and migrating fish during spawning season induce pressure on the communities of threatened fish [68,69]. Therefore, inadequate knowledge about threatened species among the native fishermen leads to an unsustainable harvest, driving threatened fish towards extinction [67]. In Bangladesh, in the recent past, the amount of fish captures has been increasing in most fish habitats in the open inland waters. Nevertheless, the conversion of ecologically complex aquatic ecosystems into monotypic fish farming ponds for fish farming ruins opportunities for habitat choice and invites inconceivable threats for threatened species [23]. Moreover, some exotic fish have recently become popular in the fish farming industry, with potential threats to them in the wild [70]. There should be a concise and outlined guideline for fishermen mentioning the fishing species, identity of threatened fish, harvesting areas, fishing time and duration, and types of fishing trawls to raise public consciousness.

Because the available climate niches in the rivers and floodplains are decreasing, they are not legally protected, and habitats in the hill tracts are not easily accessible, about half of the studied threatened fish species have been re-evaluated as belonging to the high-risk-of-extinction group. Among them, only 12 species (CR: Tila Shol, one variety of Mohashol, Bhangon Bata, Nandi, Baghair, and Chenua; EN: another type of Mohashol, Ghora Muikha, Rita, Bhool, Joya, and Rani) are declared as protected in Bangladesh under the Wildlife Act 2012, but no conservation policy has been developed for other high-risk species. Despite their economic importance for nutritional demands, ecological significance in the trophic equilibrium, and ornamental value in aquarium culture [71], freshwater fish are mostly overlooked by conservationists. Considering the potential impact of climate change, legal protection for threatened species, regular monitoring, a schedule awareness program, and the implementation of laws can be instrumental for the protection of threatened fish.

5. Conclusions

Our analysis confirmed the impact of the changing climate on the suitability distribution of the habitat of 64 threatened freshwater fishes. Most of these fish may lose their maximum current suitable habitats in lotic and lentic waterbodies in the predicted future. Moreover, currently, there is no permanent protected area dedicated for fish protection and no monitoring of the fish harvest from any of the freshwater bodies. The flood zone that remains underwater connects all lotic and lentic habitats during the monsoon and post-monsoon for almost half a year, allowing different populations to mix up and contributing to the breeding of threatened fishes. The conservation and sustainable management of this floodwater may assist in protecting these species from early extinction. The habitat connectivity and legal protection of fish, at least during the spawning season, are essential to ensure safe breeding migration and population mix-up. Moreover, the declaration of permanent protected areas for fish; regulated harvest from inland water bodies, especially during flood; zero capture of threatened species; and the management of hydrographic networks should be considered when designing conservation policies for threatened freshwater fish.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ecologies5020010/s1, Supplementary Table S1: Threatened freshwater fish species of Bangladesh source: [27].

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