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Review

An Overview of the Biological Features, Distribution, and Conservation of a Critically Endangered Riverine Catfish, *Bagarius bagarius* (Hamilton, 1822), in the Natural Waters of Bangladesh

Shuva Saha [1], Shamima Nasren [1], Debasish Pandit [2,*] and Sohel Mian [1]

[1] Department of Fish Biology and Genetics, Sylhet Agricultural University, Sylhet 3100, Bangladesh; shuvasahasau@gmail.com (S.S.); snasren-fbg@sau.ac.bd (S.N.); sohelm.fbg@sau.ac.bd (S.M.)
[2] Department of Aquatic Resource Management, Sylhet Agricultural University, Sylhet 3100, Bangladesh
* Correspondence: dpandit.sau@gmail.com

Abstract: *Bagarius bagarius* (Hamilton, 1822) is widely distributed in South and Southeast Asian countries, including Bangladesh. This species is economically important as a game and food fish. The abundance of this fish is declining around the world, especially in Bangladesh, due to a variety of meteorological and mostly anthropogenic factors, which is potentially generating concern among the conservationists. Therefore, this species has already been declared a critically endangered species by IUCN Bangladesh. Although there is no specific conservation initiative for *B. bagarius* in Bangladesh, various measures are there to conserve fisheries resources, which may have an impact on conserving *B. bagarius* in this country. This study reviews the biology and ecology with its distribution throughout the country as well as the world, threats, conservation measures, and finds out the gaps in research on this fish. Moreover, this review suggests a suitable conservation framework to improve the conservation strategy for this critically endangered fish that can be replicated in other countries for the same purpose.

Keywords: catfish; biology; critically endangered; threats; conservation

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1. Introduction

Around 71% of the earth's surface is covered with water, and freshwater ecosystems cover 0.8% of the surface of this planet [1]. Despite their little area coverage, they harbor about 100,000 species [1], among which 15,000 are fish species [2]. The number of endemic species is also surprisingly high in freshwater ecosystems [3]. About 94% of the world's freshwater fisheries are occupied by developing countries, where a huge portion of the world's impoverished people get their livelihoods, nutrition, and food [4]. Although these ecosystems are highly important, very few conservation initiatives have been launched targeting them, and for which, compared to other ecosystems, these freshwater ecosystems have faced an unprecedented deterioration in their species numbers and habitat conditions [3]. In consideration of these global facts, Bangladesh is also following the same trend. Inland capture fisheries production has not increased at a similar rate to culture fisheries production (Figure 1), despite having huge freshwater areas including ponds, lakes, rivers, streams, haors, baors, bogs, marshes, and swamps, which have the potential to support a vast kingdom of aquatic organisms in the wild.

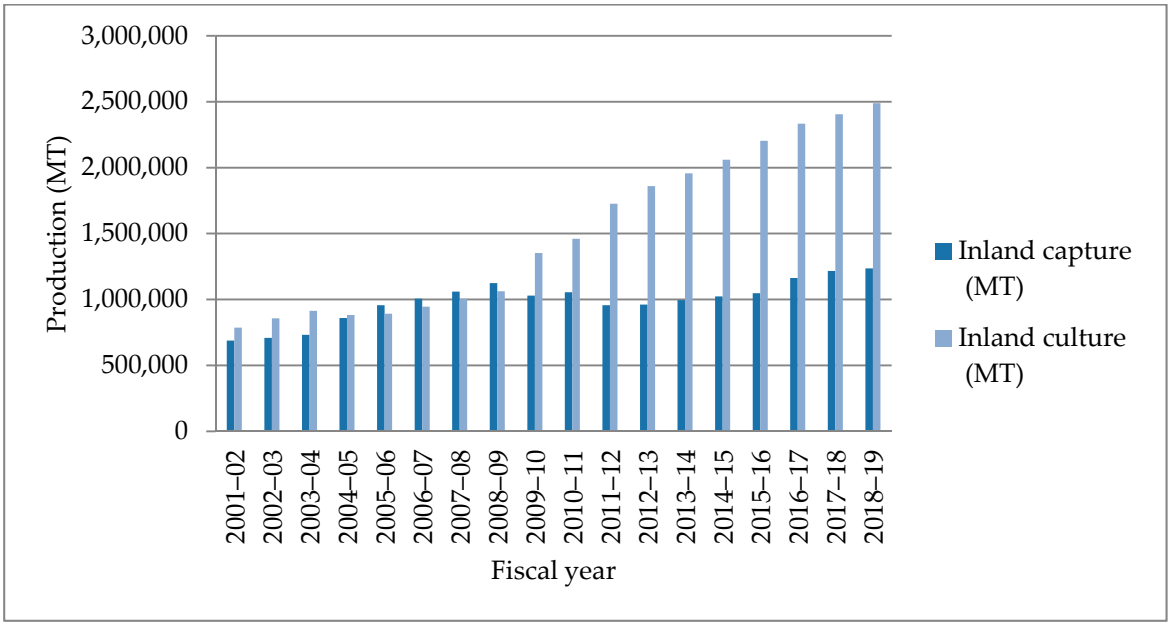

Figure 1. Contribution trend of inland capture and culture fisheries [5,6].

Though capture fisheries production has increased a little, it does not indicate an improved existing stock. Rather, there is a huge possibility of increased fishing pressure that ultimately led to this apparent amelioration. Evidence of extinctions, ramshackle conditions on the verge of extinction [7,8], and the reduced availability of freshwater fishes since 1970s, Paul et al. [4] supports that assumption. Some natural and mostly manmade drivers are responsible for these unexpected changes in freshwater fish diversity [9–13], which indicates the weakness in conservation and management of wild fish populations [9,14–16]. Such a loss of any fish species has both direct and indirect effects on natural stock, ecology, economy, and protein supply [9]. Irrespectively, the last report by IUCN Bangladesh [9] on freshwater fishes of Bangladesh recorded 253 freshwater fish species, all of which have the potential to increase the gross fish production, fulfill national protein demand, and earn the foreign currency of the country.

B. bagarius (Hamilton, 1822) is a fish species that has huge potential as food and game fish in Bangladesh, Bhutan, India, and Nepal [4], but is encountering the threat of extinction in Bangladesh and throughout the world, which can be inferred from its alarming conservation status in Bangladesh [9] as well as throughout the world [17]. It is known as "Baghair" or "Bagh mach" in Bangladesh. In Bangla, the term "Bagh" refers to a tiger. The reason behind such eponym of this fish is the tiger-like black to brown patches on its body. This species has been enlisted as critically endangered (CR) in IUCN red list of Bangladesh, 2000 and 2015. Enlistment of a species as CR in the red list means that the species is facing a very high risk of extinction in nature [9]. In this review, we tried to reveal its physical, ecological, and biological features, along with research gaps about this fish in an accumulated form. The present conservational status of this species in Bangladesh, including its distribution, potential intimidations, and steps taken to support its well proliferation, has been presented in this review. These attributes of this review will assist researchers in their further research on this fish, besides taking necessary specific steps for its conservation by the responsible authorities.

2. Biological Features, Ecology, and Population Trends

2.1. Identification

B. bagarius has an elongated and flat body, and it is flattened up to the pelvics [18]. For convenience, it is divided into three body parts:

a. Head region:

i. It has a large, osseous, and naked head which is greatly depressed, and its snout is sharply conical without pointing [18].
ii. It occupies a ventral, wide, and crescentic mouth [19] with thick lips and sharp, unequal teeth, which are organized into bands on the jaws [18]. They occupy dorso-ventrally flattened buccal cavity and pharynx [20].
iii. Its eyes are small and placed dorsally [18]; a membranous fold separates the closely placed nostrils [21].
iv. It has four pairs of barbells. One pair is maxillary, with stiff and broad bases, one pair is tiny nasal, and the remaining two pairs are mandibular barbell [18,21].
v. Its gill openings are wide [21]; gill membranes are free from each other and attached with the isthmus base [18,21]. It has 4–8 elongated neural spines and 6–9 gill rakers [22].

b. Middle region:

i. They bear no scales but have a myriad of pentagonal epidermal elevations on their skin that give a rough feel on touch [23]. Their skin is also equipped with flask-shaped mucous glands that secrete either acidic or neutral mucopolysaccharides as mucous [23].
ii. Their bodies are attractively light yellowish or greyish in color, with large messy black bands. These bands cover the dorsal and adipose fin bases [21].
iii. Dorsal fin has 1 spine and 6 soft rays [24] where Roberts [22] identified 9–12 pectoral fin rays and Jayaram [18] identified 13 pectoral fin rays with a soft elongation. Pectoral fin also holds a spine with serrated inner edge.
iv. Pelvic fins are equipped with six rays [18]. Kottelat [24] noted 13–14 soft rays, though Jayaram [18] included larger range of 12–15 rays for its anal fin. Its pelvic fin originates in front of the base of the last dorsal ray, and the adipose fin originates behind the anal fin origin [24].
v. It has a complete and simple lateral line [18]. It poses 38–42 vertebrae in total [22,24], where 17–20 are expanded abdominal vertebrae and 19–22 are caudal vertebrae [22].
vi. Its air-bladder is small and enclosed in two bony capsules [18].

c. Caudal region:

Its caudal fin is deeply forked; both lobes of the caudal fin occupy soft filamentous annex with a longer upper lobe [18].

2.2. Records of Length and Weight

In Table 1, data based on length and weight of *B. bagaius* found in different literatures are presented. The total length and weight ranges were 0.21–81.5 cm and 1.35–70 gm, respectively. Some of the literature lacked weight-related data [22,25].

Table 1. Length-weight records of *B. bagarius*.

Length (cm)	Weight (gm)	References
16.1–21 (TL)	20–45	[4]
28.1–42.2 (TL)	70–257	[26]
6.2–81.5 (TL)	1.35–2364	[27]
10.2–41.5 (TL)	-	[26]
4.08–19.2 (SL)	-	[22]

TL: Total length; SL: Standard length.

2.3. Ambiguity with Other Species

B. bagarius has often been confused with *Bagarius yarrelli* (Sykes, 1839). Roberts [22] documented some confusing identification of these two species in some earlier literatures. In Bangladesh, misidentifications of this species have been noted in some literatures [21,28] by IUCN Bangladesh [9]. These two species have been used as synonymous in Alam [21],

but Lashari et al. [29] and Nagarajan et al. [30] confirmed that these two species are genetically distinct from each other. *B. bagarius* and *B. yarrelli* can be differentiated from each other by using some attributes, including the smaller one that lives in streams is *B. bagarius* and the larger one inhabiting large rivers is *B. yarrelli* [9]. Moreover, the pelvic fin of *B. bagarius* originates from a region, anterior from an imaginary perpendicular line from the base of last dorsal fin ray, where in *B. yarrelli* it originates from the posterior of that line [24]. Again, in *B. bagarius* the anal fin origin is advanced from the adipose fin origin on the contrary, *B. yarrelli* has the anal fin origin just beneath or backward from the adipose fin origin [24].

2.4. Food and Feeding Habit

Although a detailed study on the morphology and histology of the digestive tract of *B. bagarius* [20] presents that they are omnivorous fish, a trophic level study of this species shows that they are carnivorous in nature [31]. They forage in the benthopelagic [32], surface, and sub-surface zones [33] for food. They feed both in daylight and in darkness [33]. They are primarily dependent on small and medium sized fishes for food, while insects and crustaceans are their second choice [33]. Among insect food items, they show their preferences for Diptera (Simuliidae), Trichoptera (Glossosomatidae), Ephemeroptera (Heptageniidae), Coleoptera, and Odonata [31]. Frogs, shrimps, and plant matters are also enlisted in their food menu [28,31]. The feeding intensity of this fish was reported to be highest during the winter months and lowest during the monsoon [31].

2.5. Reproduction

Very little literature about its reproduction is available. Adults prefer to live in rocky and torrential, medium to large rivers [34]. Their breeding time starts in the early rainy season [21,34]. However, Akter et al. [35] recorded them breeding in a wide range of months between April and July.

2.6. Habitat and Ecology

B. bagarius is generally found in fast-flowing rivers and takes shelter under stones and bog logs [21]. They are inhabitants of both fresh and brackish water environments and occupy the benthopelagic zone of water bodies [32]. Their migration pattern is potamodromous [32]. They can tolerate the temperature range between 18–25 °C as a tropical fish [36] and a pH range of 6.5–7.8 [32].

2.7. Population Trends

Globally, the population trend of this species is following a declining tendency [17]. In India, their population in southern West Bengal met a significant downfall of about 29.2% within four decades (1960 to 2000) [37]. Its abundance in Bangladesh has declined by a considerable amount since the 1990s [9], and Paul et al. [4] cited about an 80% decrease of this fish in 25 years in Bangladesh.

3. Distribution, IUCN Status, and Economic Importance

3.1. Distribution

It is distributed in South and South-east Asia (Figure 2), including Bangladesh, Cambodia, India, Indonesia (Sumatra, Borneo and Java), Laos, Myanmar, Pakistan [9], Bhutan, Nepal [17], Vietnam [28,38], and also in Thailand [39].

The literature of the last two decades that recorded the distribution of this species in the waterbodies of Bangladesh is listed in Table 2, and district-wise distribution is presented in Figure 3.

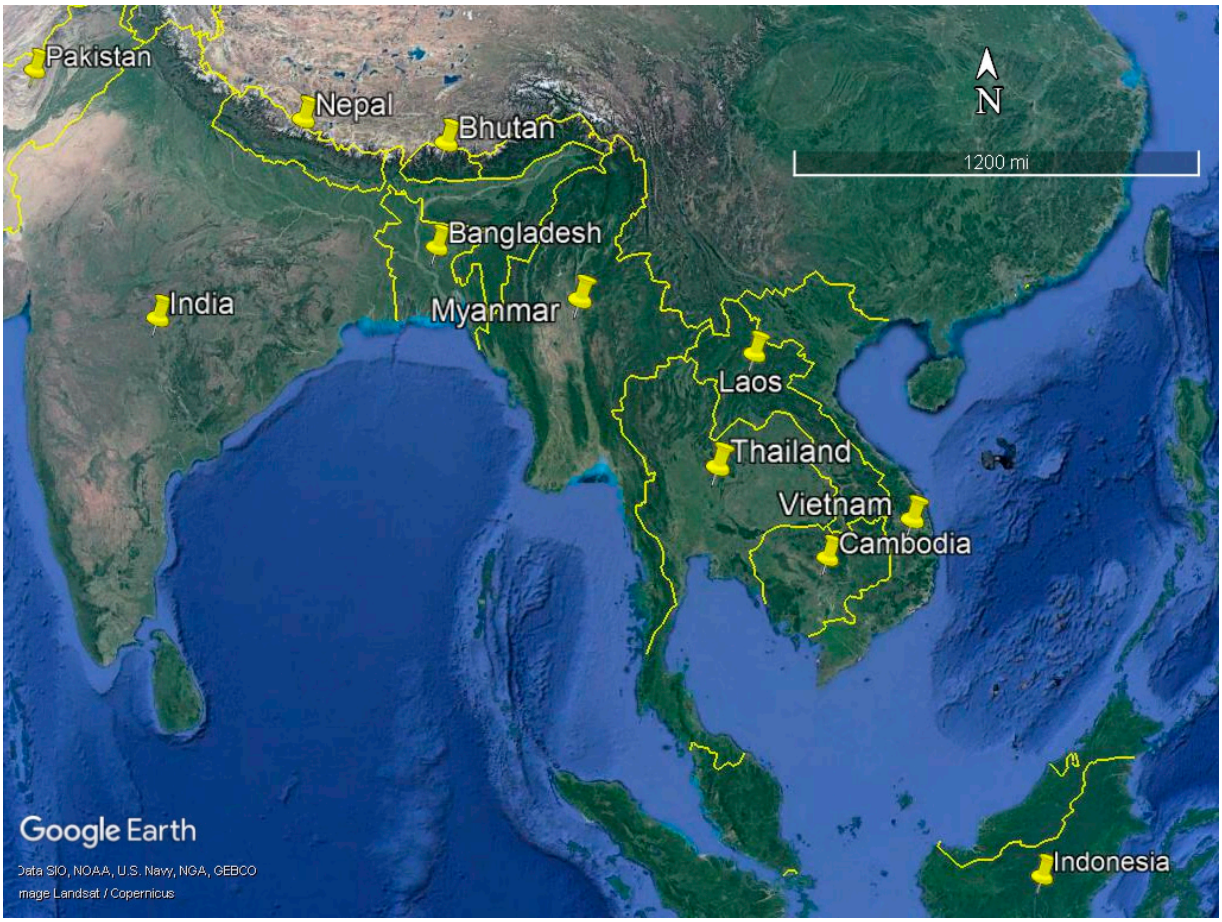

Figure 2. Worldwide distribution of *Bagarius bagarius* (Source: Google Earth Pro).

Table 2. Distribution of *Bagarius bagarius* in Bangladeshi waters.

Name of the Wetlands with District	References
Padma River, Rajshahi	[40,41]
Meghna River, Bhola, Chandpur	[4,42]
Choto Jamuna River, Naogaon	[43]
Brahmaputra River, Gaibandha	[44]
Old Brahmaputra River, Mymensingh	[45,46]
Khiru River, Mymensingh	[47]
Banar River, Mymensingh	[10]
Teesta River, Lalmonirhat	[48]
Ghaghat River, Gaibandha	[49]
Atrai River, Dinajpur	[50]
Punarbhaba River, Dinajpur	[50]
Turag River, Gazipur	[51]
Kangsha River, Someshwari River, Netrokona	[52]
Someshwari River, Netrokona	[53]
Sangu River, Bandarban	[54]
Lohalia River, Patuakhali	[55]
Andharmanik River, Patuakhali	[56]
Payra River, Patuakhali	[57]
Sibsa River, Khulna	[58]
Rivers of Sundarbans, Khulna, Bagherhat and Satkhira	[59]
Bhairab River, Jessore	[60]
Surma River, Chela River, Katakhali Khal, Mirza Khal, Chhatak, Sunamganj	[11]
Kushiyara River, Maulvibazar	[61]

Table 2. *Cont.*

Name of the Wetlands with District	References
Juri River, Sylhet	[62]
Shari-Goyain River, Sylhet	[63]
Tanguar Haor, Sunamganj	[64,65]
Hakaluki Haor, Moulvibazar	[66,67]
Dekar Haor, Sunamganj	[68,69]
Hail Haor, Moulavibazar	[70]
Chalan Beel, Natore, Pabna, Sirajganj, Naogaon, Bogra	[71,72]
Chinadi Beel, Narsingdi	[13]
Dhanu River, Kishoreganj	[16]
Chapaigachi Beel, Kushtia	[73]

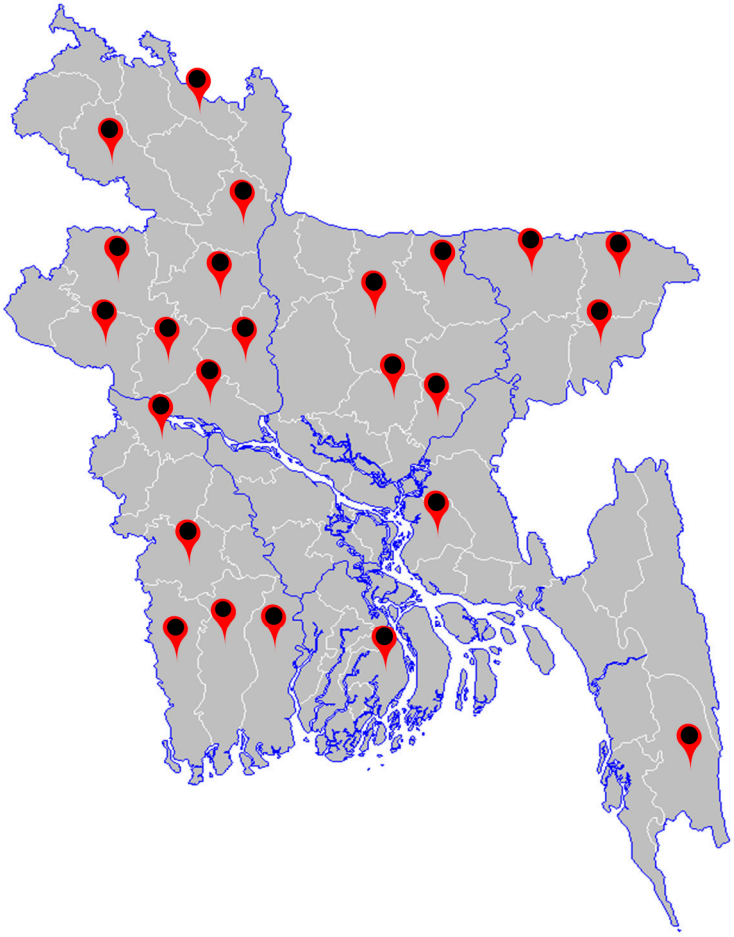

Figure 3. District-wise distribution of *Bagarius bagarius* in Bangladesh.

3.2. Conservation Status

It is in the near threatened category in the world [17] and threatened in India [74] and in Bangladesh. The conservation status of this species is in the critically endangered category [9], though Paul et al. [4] suggested reclassifying *B. bagarius* into a lower threatened status for Bangladesh. However, its population is suffering from various anthropogenic and environmental threats in Bangladesh [16].

3.3. Economic Importance

It is a vital edible fish and manages a high price in the Bangladeshi [75] and Indian [30] markets. It is renowned for its unique taste, flavor, and fewer spines [30,75]. This fish contains 18.05% protein, 8.25% fat, 0.5% ash, and 73.20% moisture as proximate compo-

sition [76]. Sub-adults and juveniles are often used as ornamental fish, while the adults attract recreational anglers [17]. Its meat has a discredit of being spoiled rapidly and that leads to illness of consumer. Alice et al. [75] suggested to use MAP (modified atmosphere packaging) with 50% CO_2 and 50% N_2 for extension of its shelf life.

4. Status of Inland Fish Habitats in Bangladesh

Bangladesh is a country dominated by wetlands, with more than half of its area covered by freshwater and brackish water habitats. Inland fish habitats are diverse and unique, relying on extensive networks of floodplains, large and small rivers, beels (relatively large surface, static water bodies that collect surface run-off through internal drainage channels), haors (back swamps or bowl-shaped depressions between river natural levees), baors (oxbow lakes created by meandering rivers that change course, and two cut-offs from the main course), ponds, lakes, and seasonally cultured waters (Table 3). Ecosystem services from the fisheries resources have long been vital in the economy, culture, tradition, and eating habits of people. From the beginning of time, fish has been an important element of the Bangladeshi people's existence [6]. In both rural and urban parts of Bangladesh, people rely heavily on fish to meet their protein demands. Fish habitats in Bangladesh have been degrading rapidly due to industrial pollution, agro-chemicals, establishment and development of unplanned infrastructures, uncontrolled soil and sand withdrawal, sedimentation, the rise of char (silt bed), lack of rainfall, shallow water depth and flow, deforestation, and climate change [11–16,62,77].

Table 3. The inland fish habitats of Bangladesh and production in 2019–2020.

Name of the Habitats	Area (ha)	Production (kg/ha)
A. Open waters		
i. Floodplains	2,651,567	294
ii. River and tributaries	8,53,863	389
iii. Beels	114,161	903
iv. Kaptai Lake	68,800	185
v. Sundarbans	177,700	118
B. Closed waters		
i. Ponds	404,497	5059
ii. Prawn/Shrimp farms	257,888	1047
iii. Baors	5671	1934
iv. Seasonal cultured water bodies	151,942	1487

5. Major Threats

The fish diversity of Bangladesh, especially the population of *B. bagarius,* is suffering from various anthropogenic and environmental threats in Bangladesh.

5.1. Over-Fishing and Indiscriminate Harvesting

Different studies [9,10,13,78,79] showed overfishing as a threat to *B. bagarius* in different water bodies of Bangladesh. The ever-expanding human population and the development of fishing technologies are the primary causes that lie behind the overexploitation of freshwater fish [80]. Besides these facts, the high market price of *B. bagarius* in Bangladesh [75] attracts fishers to capture them regardless of their size and stage in life cycle.

5.2. Habitat Degradation

Fragmentation of water bodies by constructing dams, construction of bridges, alteration of water flow in rivers and canals for hydropower generation and water extraction, light and sound pollution adjacent to the natural water bodies, and use of wetlands for the

route of mechanical water vessels are vital examples of human intervention in the natural habitats of *B. bagarius* in Bangladesh. Construction of roads, dams, and bridges across water bodies creates obstacles to the normal migration of this fish. Rapid urbanization in Bangladesh is also responsible for the degradation of natural habitats for *B. bagarius*. Light and sound pollution are common phenomena of urbanization that are proven as stressors for freshwater fishes [81]. Moreover, encroachment of wetlands for industrial, agricultural, and urban development is continuously destroying their habitats.

5.3. Siltation

As a benthic insectivore and a simple lithophilous spawner, *B. bagarius* is highly sensitive to siltation [82]. Increased deforestation in Bangladesh leads to excessive soil erosion that eventually results in increased siltation in the natural water bodies, which is responsible for decreased depth and increased turbidity in the habitat of *B. bagarius*. In some coastal areas of Bangladesh, people deliberately trap silt for land reclamation. Rapid urban development can also result in a high level of siltation [83]. Many scientists agree that siltation is a threat to *B. bagarius*, as it is ultimately destroying the habitats of this fish [9,10,13].

5.4. Water Pollution

Different point and non-point sources are responsible for surface water pollution in Bangladesh (Table 4). Pollutants from these sources cause significant changes in the thermal, physical, and chemical properties of the bodies of water which make these wetlands unsuitable for *B. bagarius* [84].

Table 4. Sources of water pollution in inland waters of Bangladesh.

Pollutant Type	Point Sources	Non-Point Sources
Pathogens	Raw sewage	Agricultural runoff and waste
	Solid urban waste	Leachate from septic tank, waste of animal
	Excreta of human and animal	
Heavy metals	Industrial discharges mainly from tannery and textile industries	Pesticide runoff
	Mine effluents	Smelting
	Power plants	
	Pharmaceutical wastes	
Organic chemicals	Industrial discharges mainly from tannery and textile industries	Agricultural runoff
	Wastes from urban areas	Runoff from agro farms, pasture, and household wastes
Nutrients	Wastewater of treatment plants	Agricultural runoff
	Excreta of human and animal	Household wastes
Thermal	Electric power plants	
	Effluents from industries	
Sedimentation	Construction related runoff from sites, smaller than 20,000 m^2	Construction related runoff from sites, larger than 20,000 m^2
		Agricultural runoff
		Soil erosion
Radioactivity		Natural occurring radioactivity

Source: Modified from Hasan et al. [84].

5.5. Invasive Fish Species

Among many other drivers of freshwater biodiversity deterioration, invasive species are deliberated as a momentous one [81]. Since the late 1950s, more than 24 exotic fish species have been introduced in the aquaculture of Bangladesh. Deliberate and accidental invasion of these fishes in the natural waters are creating pressure on the native species like *B. bagarius* as most of them are fierce competitor. Moreover, there is evidence of an outbreak of a deadly fish disease named Epizootic Ulcerative Syndrome in the natural water bodies of Bangladesh by an invasive fish named *Barbonemus gonionotus*. Therefore, invasive fishes are treated as threats to *B. bagarius* in some literatures [9,16,40,78,79].

5.6. Climate Change

Climate change has the potential to threaten approximately half of the freshwater fish throughout the globe [85]. Bangladesh has been ranked first among the countries susceptible to the drastic effects of climate change [86]. Therefore, *B. bagarius* in Bangladesh is susceptible to the effects of climate change. Figure 4 delineates the climate change derived impacts on this fish. One of the most important effects of climate change is elevated temperatures. Temperature in Bangladesh has increased by around 0.5 °C over the past 100 years and it was predicted that, by 2100, temperature will increase by 3–3.5 °C [87]. This rise in temperature will increase the water temperature, which will lead to reduced dissolved oxygen, growth of cyanobacterial blooms, and enhancement of the bioaccumulation potential of pesticides and harmful metals [87]. All of these events are clear threats to any freshwater fish species, including *B. bagarius* (Figure 4). Additionally, elevated water temperatures are likely to affect the normal physiology of freshwater fishes. Climate change is changing the rainfall pattern throughout the world. A change in rainfall pattern has the potential to affect the breeding biology of *B. bagarius* as it breeds in the rainy season [34]. Increased temperature is responsible for sea level rise. This raised sea level, lowered freshwater flow in rivers due to reduced depth as a result of siltation, facilitates saline water intrusion in the rivers. As *B. bagarius* occupies freshwater and brackish water regions, saline water intrusion will affect its niche and will shrink its habitat.

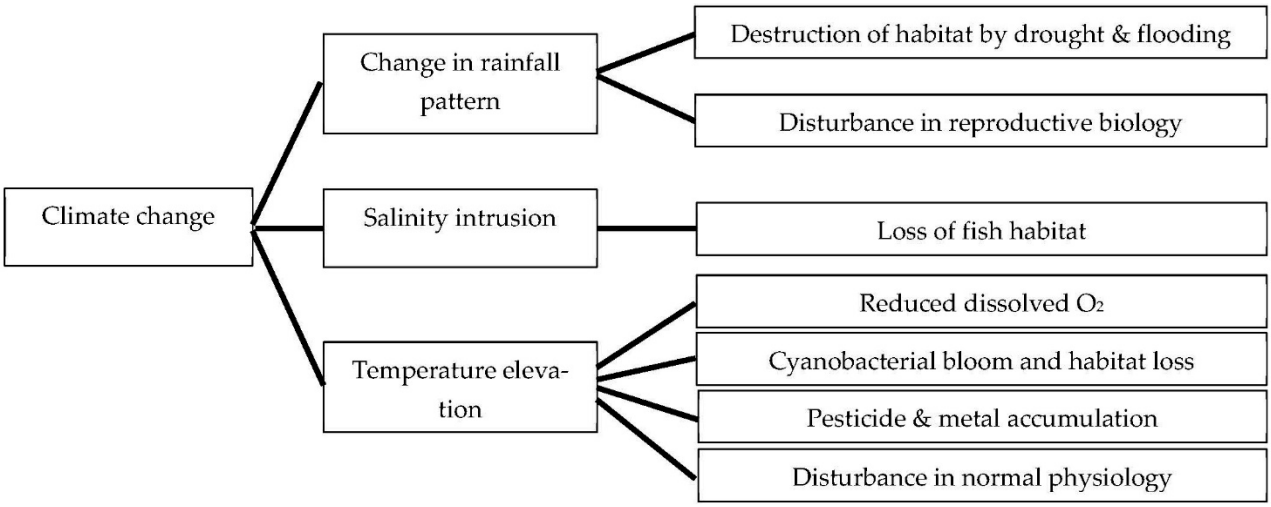

Figure 4. Effects of climate change on *B. bagarius*.

6. Management and Conservation Aspects in Bangladesh

6.1. Actions Taken

Currently, there is no specific conservation effort for this species. However, the government and various non-government organizations (NGOs) have taken various steps to conserve freshwater fisheries resources in Bangladesh that support the conservation of *B. bagarius* and many other species in the natural waters of Bangladesh (Figure 5). Efforts that support the conservation of this fish include:

1. Employment of different acts and rules related to fisheries,
2. Implementation of different fisheries projects for enhancing inland fish stocks and their conservation,
3. Establishment of fish-friendly structures, and
4. Habitat restoration program.

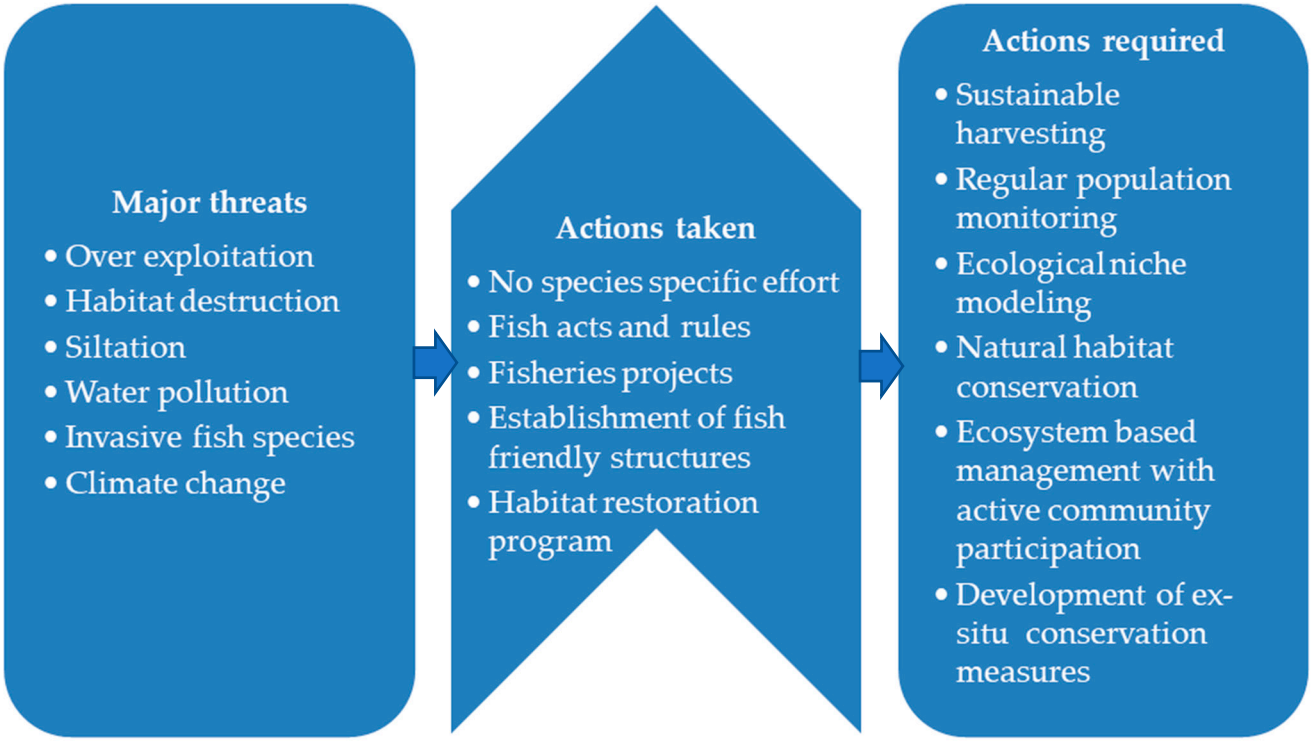

Figure 5. A schematic diagram depicting the major threats, actions taken, and actions required for *B. bagarius* conservation in the inland waters of Bangladesh.

6.1.1. Acts and Rules Related to Fisheries

The "Protection and Conservation of Fish Act, 1950" was the first law enacted in Bangladesh (East Pakistan) to conserve fisheries resources. Since then, extensive acts and policies for the management, conservation, and development of fisheries resources have been drafted and adopted (Table 5).

Table 5. List of major acts, ordinances, and regulations related to inland fisheries development and conservation, implemented in Bangladesh over time [8,88].

Name of Act, Ordinance and Regulations	Applicable Area	Major Scopes
East Bengal protection and conservation of Fish Act 1950	East Pakistan	Protects all types of aquatic organisms and water bodies.
The Bangladesh Fisheries Development Corporation Act, 1973	Bangladesh	Fisheries Development Corporation was created under this act.
The protection and conservation of fish (amendment) ordinance, 1982	Bangladesh	This amendment was brought to make the previous acts more effective.
The protection and regulations for conservation of fish rules, 1985	Bangladesh	Fisheries conservation.

Table 5. *Cont.*

Name of Act, Ordinance and Regulations	Applicable Area	Major Scopes
The new fisheries management policy, 1988	Bangladesh	Provides provisions for leasing Fisheries resources to real fisherman.
National Environment Policy, 1995	Bangladesh	Restoration of aquatic waterbodies
Aquatic environment protection law	Bangladesh	Protects habitats of aquatic organisms.
National Fisheries Policy, 1998	Bangladesh	Development of fisheries sector through various conservation efforts including maintenance of biodiversity and ecological balance.
National Water Policy, 1999	Bangladesh	Ensuring suitable environment for fishes and other aquatic organisms.
National Land Use Policy, 2001	Bangladesh	Protection of decaying inland water bodies.

6.1.2. Fisheries Projects Targeting Inland Fish Conservation

To date, various fisheries projects have been implemented in this country. Some of these projects directly or indirectly played a vital role in the conservation of *B. bagarius*. The durations, scales, and scopes of these projects in *B. bagarius* conservation are briefly described in Table 6.

Table 6. List of the major projects for the conservation of inland fisheries [88].

Project Name	Duration	Scale of Project	Major Scopes
Community Based Fisheries Management (CBFM) Project	1995–2007	10 rivers (partly), 7 beels and two baor sites in east, north, south and central Bangladesh	1. Involving local fishers in fisheries conservation 2. Creating alternative income sources for the fishers that lowers fishing pressure
Fourth Fisheries Project (FFP)	1999–2004	49 sites covering 33 of the 64 districts in Bangladesh	1. Fish sanctuary establishment 2. Restoration of habitat by re-excavation of canals and beels 3. Establishment of fish passes for easier migration of fish
Management of Aquatic Ecosystem through Community Husbandry (MAECH) Project	1998–2003	Kangsha-Malijhi site from the north-central, the Turag-Bangshi site from the central and the Hail Haor from the northeast part of Bangladesh	1. Establishment of 63 sanctuaries 2. Excavation of 57 ha of beel wetland and 31 km of water channels

6.1.3. Fisheries Friendly Structures

Fish Sanctuaries

Sanctuaries work as powerful tools for the conservation of natural fish stock in Bangladesh [89]. Since 1960, the Bangladesh Government and different NGOs have established a considerable number of fish sanctuaries at different strategic points of open water bodies. Ali et al. [90] recorded 464 fish sanctuaries throughout the country, which cover an area of 1745.61 ha. These sanctuaries may have the potential to facilitate the successful proliferation of *B. bagarius* and other inland open water fishes, as they provide protected areas for feeding, breeding, and nursing grounds to them.

Fish Migration Friendly Structures

Construction of levees, bridges, etc. has been creating obstacles to fish migration in Bangladesh for a long time, while fish migration-friendly structures like fish passes and other fish-friendly regulators are solving this issue by facilitating the easy migration of fish through their migrating routes. Moreover, such structures are helping to reduce the mortality rate of fish larvae to a significant level, ensuring a smooth connection between floodplain and rivers and providing enough depth and flow of water to attract fishes to migrate within rivers and floodplains [88]. As *B. bagarius* is a potamodromous fish, such migration-friendly structures in freshwater bodies are acting as blessings for their migration. There are four such structures in Bangladesh, enumerated with their locations in (Table 7).

Table 7. Fish migration friendly structures in Bangladesh.

Name of Structure	Water Body	District
Sariakandi fish pass	Between Jamuna and Bangali River	Bogra, Rajshahi
Kasimpur regulator and fish pass	Manu River	Moulovibazer, Sylhet
Jugini regulator and fish pass	Lohajong River	Tangail, Dhaka
Moricherdana fish pass	Mohanonda River	Chapainawabganj, Rajshahi

6.1.4. Habitat Restoration

Habitat destruction is a major threat to this fish. Therefore, fish habitats are trying to be restored by the Bangladesh government through re-excavation of silted up water bodies and the connecting tributaries among them, planting water-tolerant trees, raising awareness, and motivating local communities to restore the fish habitats [88]. Hossain [88] documented that by 2000, 8300 ha of water area had been excavated by the Department of Fisheries, Bangladesh. As *B. bagarius* loves to take shelter in fast-flowing rivers and under bog logs, such restoration activities are crucial for this fish.

6.2. Research Gaps and Actions Needed

To date, various aspects of *B. bagarius* have been revealed through different research works around the world. Intents of these existing research activities on this fish are enlisted in Table 8.

Table 8. Existing studies on *B. bagarius* around the world.

Research Activities	References
Details about the keratinization of its skin	[91]
Origin, form and network of cranial nerves	[92]
Identification of 3-Hydroxyretinol (Vitamin a3), a chromogen in the liver oil of *B. bagarius*	[93]
An insight of its skin	[23]
Some of its morphometric and meristic characteristics and its comparison with some other species of genus *Bagarius*	[22]
A detail on the morphology and histology of its digestive tract	[20]
Study on some deformities of this species from Nepal	[94]
Food and feeding habit	[31,33]
Length-weight relationship from Indus River, Pakistan, Ganga River, India and Ravi River, north-western India	[25–27]
Studies on its genetics	[29,30,95]
Post-harvest processing	[75]

Table 8. *Cont.*

Research Activities	References
Morphometric and meristic features of this fish	[18]
Features and status in Bangladesh	[21]
Its availability status in the Padma and Meghna river, Bangladesh	[4]
Effects of organochlorine and organophosphate pollution on its reproductive physiology	[96]

There is a clear lack of research on this species in Bangladesh. The only existing research aimed at this fish was on its availability status in the Padma and Meghna Rivers of Bangladesh, carried out by Paul et al. [4]. Multiple research on this species should be carried out in order to successfully revitalize not only this fish, but also all other fish facing similar threats, because knowledge about one species and its habitat has the potential to result in holistic conservation of species from similar habitats (Figure 6). Its absolute stock, mortality rates, growth, age, spawning locations, patterns of movement should be assessed for preparing a well-planned management strategy. For ensuring their successful proliferation, their ecological niche modeling and breeding biology should be studied. Regular population monitoring, besides weighing the extent of threats to this species in different waterbodies, should be done to understand its fitness in the habitats of Bangladesh. Their natural habitats should be conserved by establishing more protected areas like fish sanctuaries in selected locations. Use of illegal fishing gears and methods and overfishing should be strictly checked by enhancing law enforcement. Besides, mitigating the previously identified threats to this species, new and hidden threats should be identified. Moreover, the development of ex-situ conservation measures like cryopreservation can be a good step toward its conservation. In taking these multidimensional steps, active community participation should be confirmed. If this ecosystem-based management with active community participation is implemented, it will play a vital role in conservation of the multiple freshwater fish species in the wetlands of Bangladesh. Finally, more and more awareness programs should be performed in Bangladesh to draw the attention of the policy makers towards the survival of this species and effective implementation of its conservation measures.

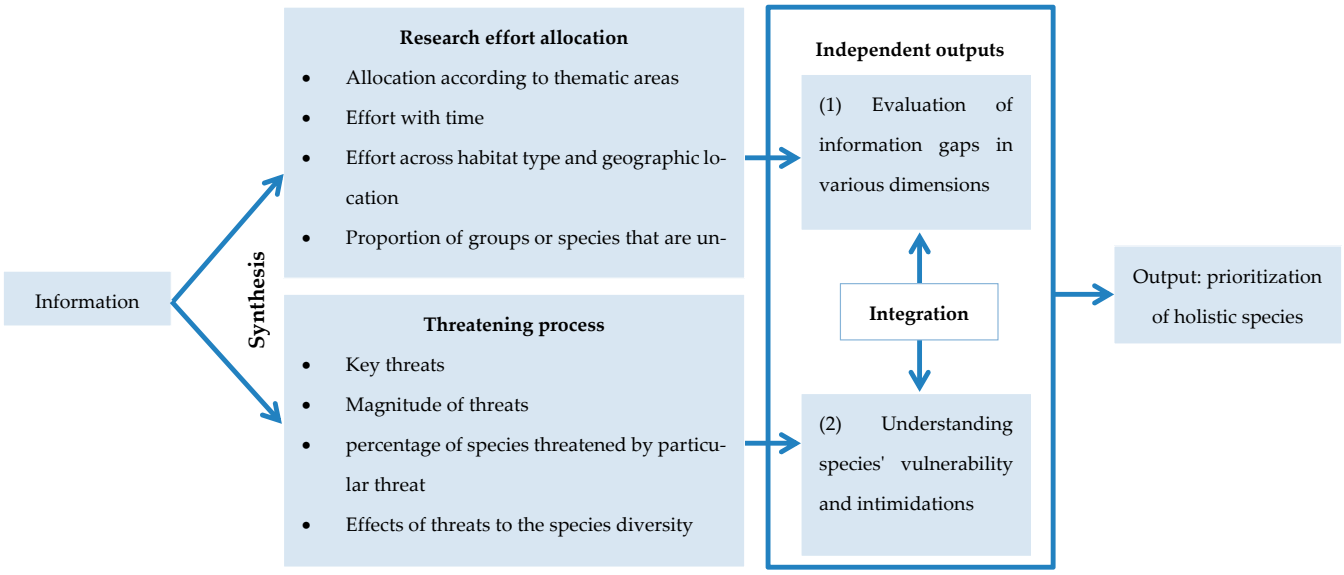

Figure 6. A proposed framework of leading information about one species to a holistic conservation of freshwater ecosystems (modified from Tanalgo and Hughes [97]).

6.3. Future Possible Impacts of B. bagarius Conservation Efforts

Different conservation initiatives have increased the production and biodiversity of catfishes, carps, minnows, eels, barbs, and perches in the wetlands of Bangladesh, besides contributing to the socio-economic development of the people at the conservation sites [88]. There are some species-specific conservation measures throughout the world which have improved the adjacent ecosystems, and the targeted species have acted as umbrellas for other species in the ecosystems. For instance, hilsa (*Tenualosa ilisha*) conservation in Bangladesh [6] and coho salmon (*Oncorhynchus kisutch*) conservation in British Columbia, Canada [98] increased the abundance of not only the surrogate species but also other fishes. Interestingly, Rahman et al. [99]) recorded a remarkable increase in the abundance of *B. bagarius* due to hilsa (*T. ilisha*) conservation in Bangladesh. Similarly, if such conservation efforts are applied to *B. bagarius*, then it will help the conservation of the total freshwater ecosystems adjacent to their habitat and to improve the socio-economic condition of the population dependent on these freshwater ecosystems.

7. Conclusions

This study is the first comprehensive description of the species *B. bagarius*. In this review it was attempted to compile all the information about this species that is currently available. Its availability is declining throughout the world, especially in Bangladesh. Furthermore, the causative agents of this deterioration are mostly anthropogenic. Therefore, this review recommends efficacious conservation measures for this fish, some of which are already at a rudimentary stage in this country. Successful execution of these recommendations will not only rejuvenate this species but also improve total aquatic biodiversity and fisheries production in the inland waters of Bangladesh. Thus, this species may act as an efficient umbrella for a broader ecological community. Therefore, this prescribed ecosystem-based management, accompanied by the participation of local people, can be a charismatic approach towards the conservation of the total freshwater fish community in Bangladesh, which should be implemented following an updated priority list. As the conservation status of *B. bagarius* is not that reassuring throughout the world, a simultaneous implementation of this conservation approach with some country specific ones will probably be able to return them to their heyday on this planet.

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