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Threatened Species Series

Threatened fishes of the world *Anguilla bengalensis* (Gray, 1831) (Order: Anguilliformes) Recommendations for Sustainable Conservation

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ABSTRACT

Anguilla bengalensis, a freshwater eel, contributes significantly to global wild-caught eel production and has a traditional role in aquaculture and trade. It inhabits major rivers including the Padma, Meghna, Jamuna, and Brahmaputra as well as hill streams, reservoirs, and tributaries, migrating downstream to the Bay of Bengal during the rainy season. Valued for its high nutritional content, the species supports both local consumption and international trade in live elvers and adult eels. Despite its broad distribution, populations of *A. bengalensis bengalensis* have declined by approximately 30% over the past decade due to habitat degradation and overexploitation, and it is currently classified as Vulnerable. Although studies have addressed its morphology, growth, reproduction, feeding habits, genetics, and captive breeding, comprehensive documentation remains limited. This review provides a baseline reference to inform effective management and conservation strategies for *A. bengalensis* in Bangladesh. This study aligns broadly with the principles of SDG Goals 14, 15, and 1. These goals emphasize the interconnected roles of aquatic resources, ecosystem conservation, and community livelihoods

Introduction

Freshwater eels belonging to the genus *Anguilla* exhibit a catadromous life cycle and are distributed globally. A total of sixteen species have been identified, including three that are further divided into subspecies. Of these, thirteen are found in tropical regions (Ege 1939; Watanabe et al. 2009). *Anguilla bengalensis* (Gray 1831) a member of the family Anguillidae, belongs to the catadromous group of fishes. This means that eels spend their growth and feeding phase in rivers but migrate back to the sea for spawning (Kardin et al. 2016). They can be cultured in various systems, including earthen ponds, concrete ponds, and floating net cages (Mulis 2015).

A. bengalensis holds high commercial importance owing to strong export demand for both live elvers (eel larvae) and adult eels. The species is widely used as a food fish and is valued for its rich nutritional content (Rahman 1989 and 2005). The species inhibits in several major river systems and hill stream regions of Bangladesh and has been Reported from the Padma, Meghna, Jamuna, and

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Brahmaputra rivers (Sada 2007). It also inhabits the hill streams of Mymensingh and the Chittagong Hill Tracts, as well as the Karnafuli Reservoir in Chittagong and the Kangsha River near Netrokona. During the rainy season, it migrates downstream to the Bay of Bengal (Rahman 1989 and 2005).

Despite its broad distribution, *A. bengalensis bengalensis* has shown an estimated population decline of around 30% over the past decade, primarily due to habitat degradation and over-exploitation for export (Ahmed 2015). Previously, the species was classified as Vulnerable in Bangladesh (IUCN Bangladesh 2015). Given that the existing threats are expected to persist and no specific conservation measures are currently in place, the Vulnerable status for this species remains justified. The taxon has also been considered as Vulnerable (VU) earlier in (IUCN Bangladesh 2000). Several studies have been conducted, including those on morphology, length-weight relationships, length-length relationships, reproduction, feeding habits, genetics, and captive breeding, as outlined in Table 1. Although *A. bengalensis bengalensis* plays a vital ecological role in Bangladesh, comprehensive studies and detailed documentation on the species remain limited. This lack of information hinders the development of effective management and conservation measures. Therefore, the present document seeks to establish a foundational reference to support the formulation of appropriate strategies for the management and conservation of *A. bengalensis bengalensis* in Bangladesh.

Table 1. Available studies on *Anguila bengalensis bengalensis* from different countries

Aspects	Country/Region	Reference
Eel cultivation technology	Indonesia	Putra et al. (2023)
Taxonomic characters of genus Anguilla	Japan	Watanabe et al. (2004)
Nutritional content of wild and cultured eel	Indonesia	Wijayanti et al. (2018)
Eel fish resource utilization strategy	Indonesia	Affandi et al. (2005)
Nutritional quality assessment of dried baim fishes	Bangladesh	Hasan et al. (2018)
Biological aspects of eels	Indonesia	Kardin et al. (2016)
DNA barcoding of freshwater eels	Indonesia	Maulidya et al. (2025)
Development of eel conservation strategy	Indonesia	Putra et al. (2023)
Demographics and exploitation of freshwater eels	India	Shanmughan et al. (2022)
Length–weight and length–length of Anguilla bengalensis	India	Sinha et al. (2018)

Taxonomic Classification

Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Anguilliformes
Family: Anguillidae
Genus: *Anguilla*
Species: *A. bengalensis*

Nomenclature and Synonyms

The Indian Mottled Eel, also known as the Giant Mottled Eel or simply Mottled Eel, is locally referred to in Bengali as *Bamosh*, *Banehara*, *Bao Baim*, *Bao Mach*, *Boa Baim*, and *Telkoma*.

Synonyms

Anguilla arracana (McClelland 1844)
Anguilla brevirostris (McClellan 1844)
Anguilla elphinstonei (Sykes 1839)
Anguilla nebulosa (McClelland 1844)
Anguilla variegata (McClelland 1844)
Anguilla bengalensis (Gray 1831)
Muraena labiata (Peters 1852)
Muraena macrophthalmos (Peters 1852)

Morphological Assessment of Freshwater Eels

A. bengalensis bengalensis has an elongated, snake-like body with a dorsally flattened, conical head, tapering gradually toward a moderately compressed tail (Fig. 1). The species possesses small eyes, thick prominent lips, and narrow bands of teeth on the jaws. These teeth are always small, conical, and arranged in multiple rows, forming narrow to broad bands on the jaws and vomer (roof of the mouth). The nostrils are separated, with the anterior nostril being a short, free tube, and the posterior one a simple opening located in front of the eye. The gill opening is nearly vertical, situated before the pectoral fin. The fins lack spines, with the dorsal and anal fins continuous around the tail. The dorsal fin may begin anywhere from the pectoral fin to over the anus, while pectoral fins are always present and pelvic fins are absent. Minute, oval scales are embedded in the skin. The lateral line is present but not highly conspicuous, appearing as a series of small white pores (Mondal and Chakravortty 2019).

Fig. 1. Photo of *Anguilla bengalensis*

Distribution and Habitat Ecology

A. bengalensis is recorded from Bangladesh, India, Myanmar, Nepal, Pakistan, Sri Lanka, and also in southeast Africa (Jacoby et al. 2014). It is reported from the rivers Padma, Meghna, Jamuna and Brahmaputra (Sada 2007). It is also found in the hill-streams of Mymensingh and Chittagong Hill Tracts, Karnafuli Reservoir, Chittagong; and Kangsha River near Netrokona (Talwar and Jhingran 1991). The species inhabits both freshwater and brackish environments, including large rivers, estuaries, and hill streams, and occasionally ventures into the ocean. It occupies diverse habitats within river systems, ranging from quiet, undisturbed muddy areas to deep, fast-flowing rocky pools (Jacoby et al. 2014). This species is semelparous and catadromous, with juveniles feeding primarily on insects and other aquatic invertebrates. During the breeding season, adults migrate to river mouths to spawn in the ocean, after which the juveniles return to freshwater habitats such as large rivers and estuaries (Jacoby et al. 2014).

Food and Feeding habit

A. bengalensis is a nocturnal predator, feeding mainly on crabs, frogs, and other fish (Sada 2007). Adult eels are piscivorous, actively hunting fish at various water levels during the night and also consuming small crabs. Fry mainly feed on small, bottom-dwelling invertebrates, while juveniles consume insects and other small aquatic invertebrates (Okeyo 1998).

Maulidya et al. (2025) observed that *A. bengalensis* specimens had total lengths ranging from 23.7 to 44 cm. The eels were characterized by long fins, a plain skin pattern, a black dorsal side, and a silver ventral side. Recorded individuals measured 29.3–35.7 cm in total length, weighed 161–189 g, and exhibited 30–54 pectoral fin rays, 398–438 dorsal fin rays, 318–382 anal fin rays, no ventral fin rays, and 34–68 caudal fin rays, as detailed in the table 2 below (Maulidya et al. 2025).

Table 2. Morphological Assessment of Freshwater Eels

Category	Parameter	*A. bengalensis*
Morphology	Fin length	Long fin
	Skin pattern	Plain skin
	Back color	Black
	Stomach color	Silver
Morphometric	Total length (cm)	29.3–35.7
	Weight (g)	161–189
Meristic	Pectoral fin rays (P)	30–54
	Dorsal fin rays (D)	398–438
	Anal fin rays (A)	318–382
	Ventral fin rays (V)	0
	Caudal fin rays (C)	34–68

Nutritional Profile

Fish is an excellent source of animal protein due to its complete amino acid profile and easy digestibility, making it suitable for people of all ages, from children to adults. Among the nutritious fisheries resources, eel (*Anguilla* sp.) stands out for its high nutritional value (Wijayanti et al. 2018). A comparison of the nutritional profiles of *A. bengalensis* is summarized in Table 3.

Table 3. Nutritional Profile of *Anguilla bengalensis bengalensis* (Wijayanti et al. 2018).

Parameter (%)	Wild Eel (Mean ± SD)	Cultured Eel (Mean ± SD)
Water	62.81 ± 4.05	62.36 ± 2.25
Protein	16.32 ± 1.18	17.51 ± 1.17
Fat	17.92 ± 3.98	17.73 ± 2.47
Carbohydrate	1.39 ± 1.25	0.13 ± 0.21
Ash	1.345 ± 0.28	1.33 ± 0.09
Energy (kcal/100 g)	238.00 ± 35.71	241.84 ± 21.88

Reproductive Biology

A. bengalensis exhibits a typical anguilliform body with a dorsally flattened conical head, small rounded embedded scales, and 106–112 vertebrae. Fin-ray counts are high, with dorsal fins bearing approximately

250–305 soft rays and anal fins 220–250 soft rays (Rahman 1989, 2005). Sexual dimorphism is pronounced, as females are significantly larger than males at comparable maturation stages (Abdul Kadir and Arai 2024). Morphological indices, including eye index, fin index, body length, and body weight, increase progressively with female maturation stages (Arai et al. 2017). Histologically, females show a complete oogenic development from primary oocytes (Stage I) through cortical-alveoli (Stage III), early vitellogenesis (Stage IV), and mid-vitellogenic oocytes (Stage V) (Arai et al. 2017). Males in sampled populations do not reach advanced stages (IV–V); testes contain only spermatogonia, including early type-B (SG-EB) and SG-B spermatogonia (Arai et al., 2017). Gonadosomatic index (GSI) increases with maturation; Stage V females of *A. b. bengalensis* have lower mean GSI (1.62) than those of *A. bicolor* (2.40) (Arai et al. 2017) (Table 4).

Table 4. Biological parameters of *Anguilla bengalensis* at different maturation stages (Arai et al. 2017)

Maturation Stage	No. of Specimens	TL (mm)	Range (mm)	BW(g)	Range (g)	Age (years)	Range (years)
I	1	487	–	257	–	5.5	–
II	6	807±144	637–1011	1038±512	421–1800	6.7±0.8	5.5–7.5
III	3	851±111	726–935	1367±532	772–1800	7.2±0.6	6.5–7.5
IV	4	1116±141	991–1295	2436±1544	2100–5100	7.8±2.1	7.5–10.5
V	3	958±86.3	899–1057	2160±783	1579–3050	7.8±1.5	6.5–9.5

Sex ratio is strongly female-biased. In a field study from northwestern Peninsular Malaysia, 78.8% of sampled individuals were female (Abdul Kadir and Arai, 2024). Similarly, among 54 silver-eel specimens examined by Arai et al. (2017), female dominance was observed, although several individuals' sex could not be determined (Arai et al. 2017). Habitat appears to influence sex distribution: in tropical Anguilla populations, females predominate in freshwater habitats, while males are more frequent in estuarine or brackish zones (Liu 2020).

Size at sexual maturity also differs between sexes. Female *A. b. bengalensis* reach advanced maturation stages (IV–V) at a mean total length of ~881 mm (range: 573–1022 mm), whereas males attain early stages (I–II) at smaller sizes (mean ~422–480 mm) (Arai et al. 2017; Abdul Kadir and Arai 2024). Age at maturation is estimated at 6.5–10.5 years.

A. bengalensis is catadromous, migrating from freshwater to the sea to spawn (Arai et al. 2017). Peak maturation and potential spawning are observed primarily from April to September, although mature individuals can occasionally be found outside this window, suggesting opportunistic spawning rather than strict seasonality (Arai et al. 2017).

Fecundity in Stage IV–V females ranges from 0.33 to 1.72 million eggs, showing a positive correlation with body size; larger females produce more eggs (FAO 2015). Therefore, these reproductive traits female-biased sex ratio, large female body size, extended maturation period, and opportunistic spawning reflect the life-history strategy of this tropical anguillid eel.

Growth Pattern

Sinha et al. (2018) reported highly significant length–length relationships in their study, with multivariate regression analysis revealing a strong linear association between body weight and both dorsal length and total length (r^2 = 0.9610, F-test significant). These results similar with previous studies by Moutopoulos et al. (2002), Mousavi-Sabet et al. (2013), and Moradinasab et al. (2012). The growth coefficient '*b*' indicated the pattern of growth, where a value of 3.0 signifies isometric growth, and values markedly above or below 3.0 indicate positive or negative allometric growth, respectively. Similar observations were also reported by Ricker (1975) and Wooten (1998).

Ye et al. (2007), Subba et al. (2009), and Mousavi-Sabet et al. (2013) reported negative allometric growth ($b < 3$) in various fish species. In contrast Subba and Adhikaree (2011), and Moradinasab et al. (2012) observed positive allometric growth in different species. According to Allen (1938), ideal fish that follow the "cube law" should have a growth coefficient ('*b*') of 3. However, Martin (1949) noted that '*b*' typically ranges between 2.5 and 4.0, and in most cases, it does not equal exactly 3.

Conservation Status

Information on the total population of *A. bengalensis* is not currently available. The population of the species has probably declined by 30% throughout its habitat ranges in Bangladesh due to overexploitation and habitat degradation over the last ten years (Ahmed

2015) also noted a significant decline in its population. Previously, this species was classified as *Vulnerable* in Bangladesh. Since the existing threats are expected to continue in the near future, and no specific conservation measures have been implemented, the *Vulnerable* status of the species remains unchanged (IUCN 2015).

Shanmughan et al. (2022) conducted a detailed demographic and exploitation study on *Anguilla bengalensis* and *A. bicolor* in small-scale subsistence fisheries along coastal river systems in the Western Ghats of southern India, reporting computed annual catches of up to 0.30 t for *A. bengalensis* and employing virtual population analysis to reveal a drastic decline in length classes > 45 cm, indicating that many individuals are unlikely to reach their asymptotic (maximum) size (Shanmughan et al. 2022). Their analysis also concluded that current exploitation rates are unsustainable, with significant risk of recruitment failure and high mortality among spawning (migratory) adults (Shanmughan et al. 2022). In a separate regional assessment from West Bengal, India, a 2025 ecological study classified *A. bengalensis* as Near Threatened (NT), but noted the population trend is "unknown", underscoring continuing uncertainty about its long-term viability (Chini et al. 2025).

The management of eel fisheries should not rely solely on government regulations or fishing restrictions. It must also be supported by comprehensive information on key aspects such as ecology (habitat distribution), biology (feeding habits, growth, and reproduction), and social factors (Fekri et al. 2019). To ensure environmental sustainability, management strategies should include the assessment of ecological criteria, such as evaluating the water quality index (Simoes et al. 2008). Effective and rational eel management, along with active participation from all stakeholders, is essential to maintain the long-term sustainability of eel populations and promote responsible utilization of eel fishery resources (Gollock and Walker 2018). Therefore, this study aims to analyze eel resource management strategies in the Cimandiri River based on developmental stages.

Threats

Plain eels are more preferred in the Japanese market than the mottled species *A. bengalensis*; however, the demand for mottled eels has been steadily increasing in China (Mondal et al. 2019). In Nepal, *A. bengalensis* is exposed to threats similar to those faced by many other freshwater fish species, such as pollution, destructive fishing practices, habitat modification, environmental degradation, and the barrier effects of dams (Mondal et al. 2019).

A. bengalensis has been reported to accumulate pollutant levels that may be harmful to human health. For instance, in the Ganges River, West Bengal, specimens of *A. bengalensis* found to contain methyl mercury concentrations exceeding the permissible limits for human consumption established under the Prevention of Food Adulteration (PFA) Act (Pal et al. 2012). Furthermore, *A. bengalensis* is also threatened by habitat degradation, overfishing, and game fishing pressure, particularly from hook-and-line capture and poisoning (Mondal et al. 2019).

Impact of Environment and Climate

Environmental change and climate variability increasingly influence the distribution, migration, and recruitment of *Anguilla bengalensis* (Jacoby et al. 2014; Gollock and Walker 2018). Altered river hydrology due to erratic rainfall, droughts, and upstream water abstraction disrupts longitudinal connectivity, directly affecting catadromous migration between freshwater habitats and marine spawning grounds (Arai et al. 2017). Rising water temperature and changes in salinity regimes can modify metabolic rates, growth patterns, and sex differentiation, potentially altering population structure (Liu 2020). Habitat degradation driven by sedimentation, riverbank erosion, dam construction, and land-use change further reduces the availability of suitable feeding and refuge habitats (Mondal and Chakravortty 2019). Climate-induced sea-level rise and estuarine salinity intrusion may negatively affect glass-eel recruitment and early life-stage survival in coastal river systems (Jacoby et al. 2014). Together, these environmental and climate-related pressures are likely to exacerbate existing threats from overexploitation, increasing extinction risk in the absence of adaptive, ecosystem-based management (Gollock and Walker 2018).

Conservation Action

Putra et al. (2023) conducted a SWOT analysis of eel fisheries in the Cimandiri River and proposed several strategies for sustainable environmental management. They recommended that governments implement sustainability-focused programs or policies, such as requiring eel collectors and farming companies to release a portion of their reared eels into natural habitats. This practice would enable the eels to migrate to the sea for spawning, helping to maintain and restore eel populations. To prevent destructive practices in eel fishing that may threaten the species' sustainability, it is essential to raise community awareness about the ecological and economic importance of eels and to promote the adoption of eel aquaculture techniques (Fekri et al. 2019). Key factors contributing to the success of eel farming include the use of appropriate technologies for rearing and growing eels from the glass eel and juvenile (elver) stages to marketable sizes ranging from 200 to 350 grams (Putra et al. 2023).

Conservation Recommendation

Conservation of *A. bengalensis* requires an integrated approach. In open waters, fishing pressure should be regulated through size- and season-specific restrictions to protect larger, sexually mature individuals, while freshwater and estuarine habitats should be designated as protected areas to safeguard migration routes and spawning grounds. Regular population monitoring and maintenance of habitat connectivity are essential to ensure population sustainability. In terms of culture-based conservation, development of captive breeding protocols and induced breeding techniques can support restocking programs and sustainable aquaculture, reducing pressure on wild populations while providing livelihoods. Finally, effective conservation demands active participation of local communities, supported by NGOs and research institutions, through awareness campaigns, habitat restoration, community-based monitoring, and policy advocacy. This combined strategy protecting wild habitats, promoting aquaculture, and engaging communities offers the most effective pathway to ensure the long-term survival of *A. bengalensis*.

Improving human resource capacity is crucial for effective conservation efforts, which require collaboration among various stakeholders, including local communities (eel fishermen), collectors, eel farming companies, NGOs, research institutions or universities, and local governments. To achieve this, a Forum Group Discussion (FGD) among stakeholders should be established to focus on strengthening the skills of eel fishermen and raising awareness about the importance of protecting river ecosystems from upstream to downstream. Collaborative programs may include guidance and training on eel cultivation and enlargement techniques (Putra et al. 2023).

Stakeholders hold a crucial position in ensuring the success and sustainability of economic management as well as the optimal use of available resources. In the context of eel fisheries, this includes government agencies, local communities, eel fishermen, collectors, and private sector actors involved in eel cultivation and trade. Among these, eel fishermen are the most directly dependent on eel resources for their daily income and livelihood. Because of this dependence, they are highly responsive to government initiatives and policies that aim to enhance their economic stability and promote sustainable practices. When government programs focus on improving fishermen's welfare through financial support, training, access to markets, and sustainable resource management fishermen are more likely to comply with and actively participate in these efforts. Therefore, building strong relationships and cooperation between stakeholders is essential for creating a balanced approach that supports both economic growth and the long-term conservation of eel populations.

Non-governmental organizations (NGOs) and research institutions play a pivotal role in supporting sustainable resource management and environmental conservation. Their expertise allows them to conduct comprehensive studies on ecological conditions, habitat quality, and biodiversity, as well as to analyse the social and economic aspects that influence how communities interact with their surrounding environment. Through such interdisciplinary research, they can identify key environmental challenges, evaluate the effectiveness of existing management practices, and propose evidence-based solutions.

In addition to their research functions, NGOs and academic institutions often act as vital mediators and facilitators between local communities, stakeholders, and government authorities. They help bridge communication gaps, ensuring that the concerns and traditional knowledge of local stakeholders such as eel fishermen and river-dependent communities are heard and incorporated into policy-making processes. At the same time, they translate government regulations and conservation objectives into practical guidance that communities can implement.

By fostering dialogue, organizing workshops, and providing technical support, these organizations strengthen cooperation and trust among all parties involved. Their involvement ensures that conservation and management policies are not only scientifically grounded but also socially inclusive and sustainable in the long term.

Conservation of *Anguilla bengalensis* requires an integrated approach aligned with the United Nations Sustainable Development Goals (SDGs). In open waters, fishing pressure should be regulated through size- and season-specific restrictions to protect larger, sexually mature individuals, and freshwater and estuarine habitats should be designated as protected areas to safeguard migration routes and spawning grounds, contributing to SDG 14: Life Below Water. Regular population monitoring and maintenance of habitat connectivity support ecosystem sustainability and biodiversity (SDG 15: Life on Land). Culture-based conservation through captive breeding and induced spawning can facilitate restocking programs and sustainable aquaculture, reducing pressure on wild stocks while supporting livelihoods (SDG 1: No Poverty, SDG 2: Zero Hunger, SDG 8: Decent Work and Economic Growth). Active involvement of local communities, NGOs, and research institutions in awareness campaigns, habitat restoration, community-based monitoring, and policy advocacy strengthens governance and inclusive participation (SDG 16: Peace, Justice, and Strong Institutions). This integrated strategy ensures the long-term survival of *A. bengalensis* while promoting sustainable development and resilient ecosystems.

Conflict of Interest

There is no competing interest that might influence the research work.

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