Migratory freshwater fish in Indonesia: Threats and conservation efforts

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Abstract. The process of fish migration is one of the most important biological aspects of the life of certain fish species, including fish species that live in freshwaters. In Indonesia's freshwaters, several types of fish migrate to fulfill parts of their life cycle, such as *Anguilla* spp., *Tor* spp., and *Rasbora* spp., which have economic and ecological values. Fish habitats and migration routes can be affected by many cause changes, including dam constructions, other infrastructure constructions, drainage of wetlands, and floodplain disconnection. Other threats to migratory freshwater fish are overfishing and pollution. In Indonesia, most migratory freshwater fish threats were obstructions to free-flowing rivers, such as dams, and the exploitation of adult fish that migrate for spawning. Some management approaches should conserve and sustain the use of migratory freshwater fish.

1. Introduction

The migration of fish has always been a fascinating phenomenon. Reports of migratory fishes being documented since 20 centuries ago and freshwater fishes also show extraordinary migrations, such as mass migrations of salmonids [1]. Migratory fishes are aquatic species that serve as fishery resources and provide ecosystem services. Hence, they are essential from the ecological, environmental, economic, and social points of view [2].

There are about 8,000 species known to migrate within lakes and rivers [1]. Fish migrate for food daily and also to lay their eggs in places where the quality of water is high, and food is abundant for juveniles. Understanding the migration patterns of freshwater fish is pertinent in fisheries management, as many fish are commercially important [3].

We can classify the type of migration based on the habitats (Figure 1). Migration between two sea water is known as oceanodromous migration [4]. Fishes migrate between freshwater and sea water habitats or from sea to freshwater, known as diadromous fish. There are also amphidromous fish that migrate between sea water and freshwater, not for breeding purposes; this occurs regularly at some other definite stage of their life cycle. Diadromous migration can be separated by fish that migrates from freshwater to sea water (anadromous) or from sea water to freshwater habitats (catadromous), and migrate in two freshwater is known as potamodromous fish [4].

According to McDowall [5], among the listed fish species, approximately 110 are anadromous (48%), 56 catadromous (25%), and 61 amphidromous (27%).

Before entering the river, certain migratory fish stop feeding and using stored body energy, principally fat, to fuel the entire spawning migration, to support the maturation process, and the act of reproduction itself [6]. In Garonne River, France, shads *Alosa alosa* is one anadromous fish that ceased feeding before entering the river [7].

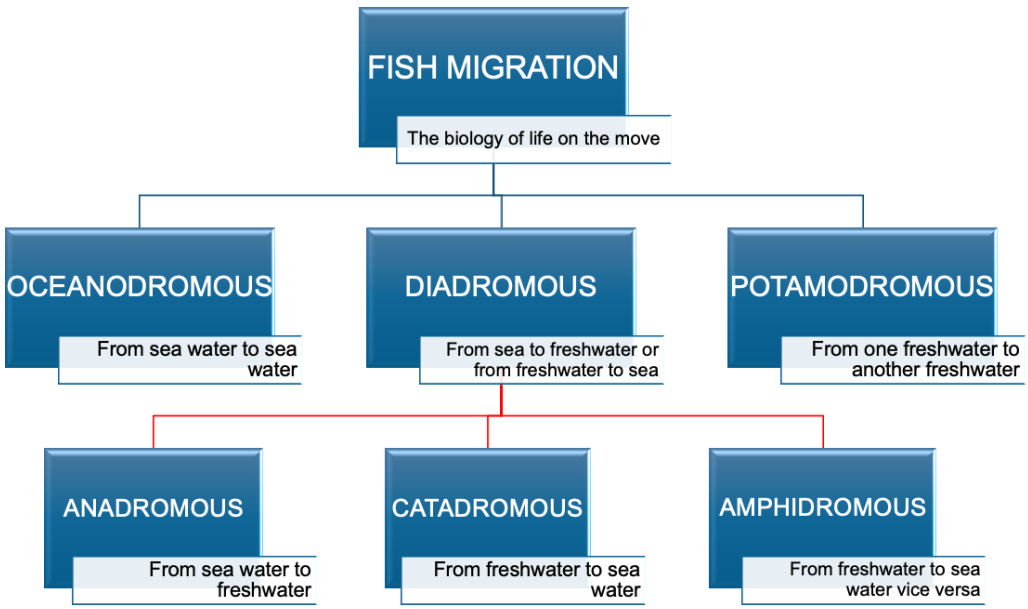

Figure 1. Fish migration pattern (source: modified from Ibrahim [4]).

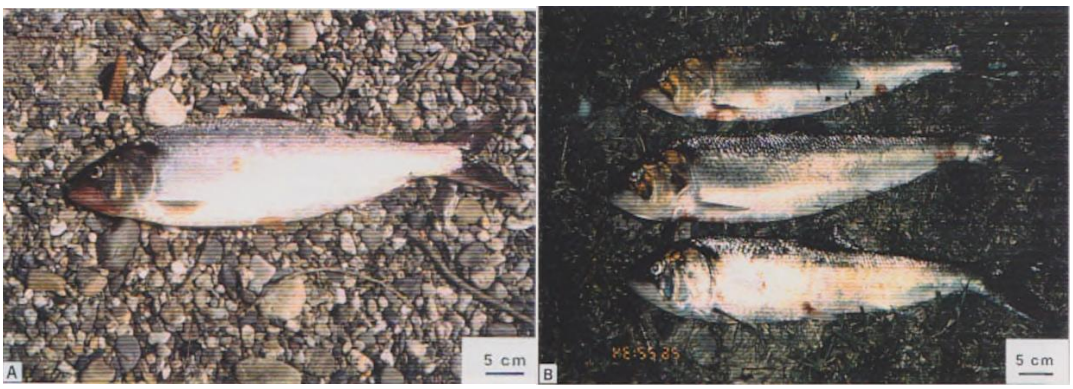

Figure 2. *Alosa alosa* from the estuary of Garonne River (A) and the spawning ground in Lamagistere upstream of Garonne River, France (B) [7].

In the estuary, the body of *A. alosa* looked fatter, and they deposited a large amount of fat in their bodies (Figure 2A). Later, when the fish reach the spawning area, their bodies become thinner (Figure 2B).

At sea and before entering the spawning ground, the shads present the muscle tissue rich in myofibrils closely attached, with a significant lipid accumulation between the myofibrils (Figure 3A1, A2, A3). On the other hand, we observed an alteration of the muscle at the spawning ground, with the less abundant myofibrils with a disorganization of the structure (Figure 3B1, B2, B3) [7]. These fishes mostly die after spawning.

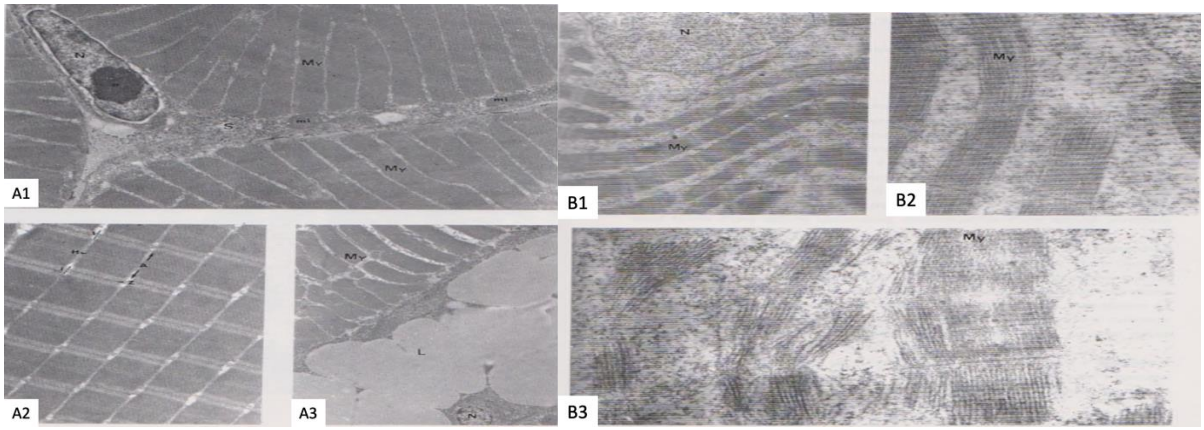

Figure 3. The muscle tissue of shads *Alosa alosa* from the estuary of Garonne River (A1x8700; A2x10500; A3x600) and the spawning ground in Lamagistere, France (B1x 13600; B2 x 3500; B3 x 35000) [7].

2. Indonesian migratory freshwater fish

Indonesia has many rivers, lakes, and swamps with freshwater resources (3,221 billion m^3/year) [8]. According to Hubert *et al*. [9], Indonesia has the most species-rich ichthyofauna, with about 1,218 species (84 families, 630 endemic species). It consists of 1,172 native species and 28 exotic species. However, according to Froese and Pauly [10], the number of freshwater fish is 1,236 species. The number of species will increase along with more exploration and research being conducted in various freshwaters in Indonesia.

Some migratory freshwater fish that live in Indonesia from all types of migration are *Tor* spp., *Anguilla* spp., *Rasbora* spp., bilih fish *Mystacoleucus padangensis*, redtail catfish *Hemibagrus nemurus*, goby fish *Glossogobius giuris*, *Awaous melanocephalus* [11], several anadromous fishes [12], *Polynemus melanochir*, *Pangasius krempfi*, *Arius sumatranus*, and *Boesemania microlepis* (Table 1). Simanjuntak et al. [13] found 13 species of amphidromous fishes in Cimaja River West Java, and provided a list of several amphidromous fish from several regions in Indonesia (Table 2).

Table 1. Several migratory freshwater fish in Indonesia

Scientific Name	Family Name	Common Name/Local name	Migration Type	Economic/ ecological Values
Anguilla bicolor bicolor *A. celebesensis* *A. marmorata*	Angullidae	Eel	Catadromous	+++
Rasbora argyrotaenia *R. lateristriata* *R maninjau* *R. sumatrana*	Cyprinidae	Bada	Potamodromous	+++ Endemic species
Mystacoleucus padangensis	Cyprinidae	Bilih	Potamodromous	+++
Tor tambroides, *T. soro*, *T. Douronensis* *T. tambra*	Cyprinidae	Mahseer	Potamodromous	+++

Scientific Name	Family Name	Common Name/Local name	Migration Type	Economic/ ecological Values
Hemibagrus nemurus	Bagridae	Redtail Catfish	Potamodromous	++
Glossogobius giuris	Gobiidae	Tank goby	Amphidromous	++
Awaous melanochepalus	Gobiidae	nike	Amphidromous	++
Polyphemus melanochir	Polynemidae	Blackhand paradise fish	Anadromous	+
Pangasius krempti	Pangasiidae		Anadromous	++
Arius sumatranus	Ariidae	Goat catfish	Anadromous	++
Boesemania microlepis	Sciaenidae		Anadromous	+

Table 2. Several amphidromous fish from various regions in Indonesia [13].

No	Location	Diversity	Sources
1	Sukabumi Estuary, Pelabuhan Ratu, Sukabumi	13 species, 5 genera, 2 family	Simanjuntak et al. 2021
2	Gorontalo Estuary, Gorontalo Bay	8 species, 5 genera, 2 family	Olii *et al.* (2017, 2019), Pasisingi *et al.* (2020)
3	Leppangan estuary, West Sulawesi	9 species, 6 genera, 2 family	Nurjirana *et al.* (2019)
4	Tondano, Minahasa District, North Sulawesi	8 species, 4 genera, 2 family	Pangemanan *et al.* (2020)
5.	Poigar estuary, Bolaang Mongondow	5 species, 4 genera, 1 family	Pangemanan *et al.* (2020)
6	Luwuk Banggai, Sulawesi	10 species, 7 genera, 2 family	Gani *et al.* (2019)
7	Maro Estuary, Merauke, Papua	7 species, 4 genera, 1 family	Maturbongs *et al.* (2017)
8	Pabean Bay, Indramayu	9 species, 4 genera, 1 family	Khoncara *et al.* (2018)

All these fish have economic and ecological values, and some of them are endemic species. Demand for eels in the international market, from Asia, Europe, America, and Australia, reaches 130,000 tons/year. From 130,000 tons/year global market demand, only 16.8% can be fulfilled from the catch and cultivation [14].

3. Threats and efforts for conservation

The common threat to freshwater migratory fish was obstacles to free-flowing rivers, such as dam constructions, blocking fish from reaching locations required for food or breeding purposes. Habitat connectivity at multiple spatial and temporal scales (river continuum concept) is seen as critical to the integrity of aquatic ecosystems and the communities of fishes and other biotas [15]. Large dams and water diversions for hydroelectricity, agriculture, land reclamation, and human consumption have caused widespread extinctions. About 35% of Pacific salmon stocks are extinct in the Columbia River basin, and 40% are endangered [1]. Some dams have been equipped with the fish passage with various shapes. A fish passage makes it possible for fish to migrate downstream or upstream.

Another threat is overexploitation, such as in unsustainable fishing, either for subsistence or trade. In addition indirect overexploitation occurs when nontarget fishes are killed unintentionally, such as bycatch in fisheries. Pollution can affect a species by making the environment unsuitable for survival. The invasive species compete with native species for space, food, and other resources. It can turn out to be predators for native species or spread diseases not previously present in the environment [16]. In Indonesia, 13 types of alien diseases entered and caused substantial economic losses, such as *Ichthyophthirius multifiliis*, *Lernaea cyprinacea*, white spot syndrome virus, viral nervous necrosis virus, koi herpes virus, and Taura syndrome virus [17].

Elver and adult eels live in the river and Lake Poso, but in their larval stages, they migrate to the river estuary, river, and lake. The eel catch in Lake Poso Central Sulawesi has been decreasing for the last 20 years, caused by fishing activities, disruption in migration routes, and changes in habitat and environmental conditions. Two significant threats to the eel population in this lake are fishing activity and hydroelectric dam [14]. Lake Poso is located in Central Sulawesi, with its outlet the Poso river flowing into the Tomini Bay [18]. *Anguilla marmorata* is the most caught species and traded for decades [19]. Rainfall or water discharge influences the downstream movement of eels during their migration season [19]. The migration activity of the eels from Lake Poso to the sea will follow the high river discharge during the rainy season, which is the highest in April and May. The eels conserve energy by drifting following the river's current [20].

Fishing for catching silver eels in Lake Poso occurs throughout the year using a fish trap, namely, waya masapi, built along with the river mouth, the lake's outlet. Two hydroelectric dams were constructed in the Poso River. Fishway installations were built in 2012 and 2019 to provide migration routes for eels [14]. The feasibility of the fishway is still being studied to function as expected.. The potential glass eel in Poso Estuary reaches 50 million glass eels/year [14]. However, there is no downstream migration facilities are included in the Poso hydroelectric design.

Threats to *Rasbora* spp. include overexploitation and pollution. In Lake Maninjau, West Sumatra, local people catch *Rasbora* fish using a traditional fish trap, namely, lukah. They place the traps in the stream mouth to catch the fish that migrate from the lake to the stream for spawning. To protect *Rasbora* spp., it is recommended to regulate fishing (types of fishing gears and locations) and maintain the lake and inlets connectivity.

Similar to *Rasbora* fish, *Mystacoleucus padangensis* (bilih fish) is an endemic species that inhabits Lake Singkarak, West Sumatra, and since 2003, these fish have been introduced to Lake Toba, North Sumatra [21]. The local fishermen use ‘alahan’ as a trap for bilih fish that migrate from the lake to the river for spawning. To manage bilih fish in this lake, it is necessary to regulate the fishing activities (location, mesh size of net, and fishing season) of bilih fish around the river. The government of West Sumatra issued regulation no. 81 in 2017 regarding the use of fishing gears in Lake Singkarak to protect fish resources, especially bilih fish (*M. padangensis*), from the threat of extinction.

Indonesia has only four fish passages: Perjaya Dam, South Sumatra; Batang Hari Irrigation Dam, West Sumatra; Wawotobi Weir, South Sulawesi; and Poso Dam, Central Sulawesi [22]. Some examples of the impact of dam construction are the decline in the population of *Chitala* sp. and several native and economical fish species in Kampar River, Riau due to the construction of the Kutopanjang Reservoir and the loss of native fish species in Cincingguling River due to the construction of the Semper Reservoir in Central Java [22].

The Berjaya Irrigation Dam on Komering River, South Sumatra was constructed in 1991, including a fish ladder. Cyprinidae is the dominant family consisting of 15 species, such as *Labeobarbus leptocheilus* and *Crossocheilus* sp. [23]. Accumulation of fish below dams makes fishes more susceptible to exploitation by the fishermen. Furthermore, no fish reached the upstream reservoir. Therefore, it is very important to improve free passage for fish and other aquatic species in rivers in situations where the obstructions cannot, for whatever reason, be removed [24].

Tor spp. usually live fast-flowing rivers and large lakes, and they migrate upstream in rivers to breed [25]. This fish has an economic value; its price ranges up to 100 dollars per kg. Moreover, it has ecological value because of the role of *Tor* species in river ecosystems to maintain the nutritional balance between the river or lake and the stream. The abundance and distribution of *Tor* spp. in their natural habitat have substantially decreased due to overfishing, pollution, and deforestation. For the

conservation of *Tor* fish, in certain areas in West Sumatra, there is a form of *Tor* fish conservation that community groups well manage through local customary and village rules, namely, Lubuk Larangan or protected area.

4. Closing remarks

For conservation and sustainable use of migratory freshwater fish, some management approaches can be made, including fisheries management such as establishing fishing restrictions or fishing regulation, habitat management by restoration of habitat and connectivity, land use regulations, and water quality management, and the establishment of conservation area/sanctuary. Maintaining and restoring habitat connectivity for migratory fishes is very important for completing the life cycle and contributing to natural ecosystem processes [26]. The Ministry of Public Works and Public Housing of Indonesia (PUPR) stated that dam construction in Indonesia will continue until 2024. The target is that by 2024, there will be 61 new dams, the construction of which will be completed in stages. Hydroelectricity is critical for decarbonizing global energy production, but hydropower plants affect rivers' free-flowing and threaten to migrating fish. This puts hydroelectricity production in conflict with efforts to protect threatened species and connectivity ecosystems [27]. Another management approach for managing fish migration is knowledge management by increasing research/study and community/government/ decision-makers awareness. Database management of migratory freshwater fish is necessary and crucial as essential information for sustainable use.

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