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Mitigation of Sources of Threat to the Freshwater Amphidromous Goby Fish Population (Pisces: Gobiidae) in the Cimaja River-Estuary, Sukabumi, Indonesia: The Eco-Biological Concept

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ABSTRACT

Amphidromous is a term used for a group of fish that migrate between freshwater and sea waters without the purpose of spawning. Most of this group of fish come from the Gobiidae family. As a migratory fish, sources of threat to the amphidromous goby fish are spread along their migration route. A study was conducted to map the threats to the existence of the amphidromous goby fish population along the Cimaja estuary, Sukabumi, West Java. A one-year comprehensive study was carried out from December 2020 to December 2021. The findings identified two primary sources of threat to the existence of the amphidromous goby fish population. These threats consist of natural sources related to the fish's life cycle and external threats. Several sub-issues of external threats include the tradition of catching fish larvae and juveniles in the estuary area (nyalawean) and adult fish along the river, stone and sand mining activities in the river body, aquatic pollution, and changes in land use around the Cimaja River Basin. Each threat source is associated with the fish's eco-biology aspect. The mitigation results led to the formulation of an integrated river management plan as a management recommendation that can be implemented. This management scheme aims to reduce existing threats and achieve sustainability of amphidromous goby fishery resources in the Cimaja river-estuary waters, Sukabumi, Indonesia.

INTRODUCTION

Amphidromous is a term first put forward by **Myers (1949)**. Etymologically, the term amphidromous comes from Latin consisting of amphi, which means two and dramein, which implies movement **(Myers, 1949)**. Amphidromous is intended for fish that move between freshwater and seawater to avoid spawning **(McDowall, 2007)**. **Augspurger *et al.* (2017)** stated that the amphidromous fish group is divided into freshwater amphidromous and seawater amphidromous. The seawater amphidromous fish group refers to various types of fish native to the ocean that search for food in estuary areas and river areas at certain stages in their life cycle. Meanwhile, freshwater amphidromous is intended for a group of fish whose larvae are washed into sea waters, and their juveniles will migrate back to freshwater **(Keith, 2003; Keith *et al.*, 2008)**.

Freshwater amphidromous fish broodstock generally spawn in fast-flowing river waters. Eggs are usually laid attached to the rocks of the river bed **(Teichert *et al.*, 2013)**. Newly hatched freshwater amphidromous fish larvae are planktonic. River currents carry early larvae to sea waters. Freshwater amphidromous fish larvae undergo exogenous predation for the first time in seawater to grow and develop. At the juvenile stage, freshwater amphidromous fish move back to freshwater areas through river estuaries **(McDowall, 2007, 2009, 2010; Kwak *et al.*, 2016; Augspurger *et al.*, 2017)**. As migratory fish, sources of threat from amphidromous fish are spread along their migration routes **(Keith, 2003; Iida *et al.*, 2008; Keith *et al.*, 2008; Augspurger *et al.*, 2017; Murase & Iguchi, 2019)**.

Freshwater amphidromous fish are often found in the estuary waters of rivers around Palabuhanratu Bay **(Baihaqi, 2022; Prabowo *et al.*, 2022)**. The Cimaja River estuary is one of the areas that is said to be a hotspot of biodiversity for freshwater amphidromous fish **(Simanjuntak *et al.*, 2021; Baihaqi *et al.*, 2022; Amaliah *et al.*, 2023)**. **Simanjuntak *et al.* (2021)** stated that 20 freshwater amphidromous fish are found in the Cimaja River estuary area. Most freshwater amphidromous fish come from the Gobiidae family **(Amaliah *et al.*, 2023)**.

Although the hotspot status of biodiversity is quite attached to the Cimaja estuary, various sources of threats are quite concerning for the freshwater amphidromous fish **(Baihaqi, 2022; Amaliah *et al.*, 2023; Annida & Baihaqi, 2024)**. Various sources of threats are spread along the migration route of this fish. The sources of threats in question can be internal, such as originating from the physiological adaptation conditions of fish through various environments **(Bell, 2007)**, or external in the form of the influence of human activities that directly or indirectly create threats to the existing amphidromous fish population **(Keith, 2003; Lin *et al.*, 2011; Teichert *et al.*, 2013, 2016, 2021)**. In this study, source of threat was described to freshwater amphidromous fish in the Cimaja estuary, Sukabumi, Indonesia, based on a direct survey linked to the basic concept of fish ecology. The results of this study are expected to be the necessary input in determining the basis for policies in the management of amphidromous fish resources, especially in the southern waters of Java and generally in Indonesia.

MATERIALS AND METHODS

This study was conducted based on direct observation for one full year from December 2020 to December 2021 at the Cimaja River estuary, Sukabumi, West Java, Indonesia (Fig. 1). The temporal observation for one year aims to observe the integrity of the threat conditions of freshwater amphidromous fish resources in all seasons. Sources of threats to the amphidromous fish population are described based on their internal and external origins. Internal sources of threat were identified based on literature studies on vulnerability points during the life cycle of freshwater amphidromous fish. External sources of threat were identified based on direct observations in the Cimaja River Estuary, which can come from human activities, waste disposal, and other things that have the potential to threaten the sustainability of freshwater amphidromous fish. We believe that each source of threat is an essential input in determining the proper management construction to achieve fish resources, especially freshwater amphidromous in the Cimaja River estuary, Sukabumi, Indonesia.

Fig. 1. Research map

RESULTS AND DISCUSSION

Two primary sources of threats were identified to amphidromous fisheries populations in the Cimaja estuary, Sukabumi, Indonesia. The threats were grouped based on their origin. There were internal and external sources of threats.

Internal threat sources

Internal sources of threat emphasize the physiological condition of fish in facing changes in the aquatic environment during the migration process in each life stage of amphidromous fish. In terms of its life stage, the early life history of amphidromous fishes is the life phase with the highest threat level. As illustrated in Fig. (2), five vulnerable points were identified in the life cycle of amphidromous fish.

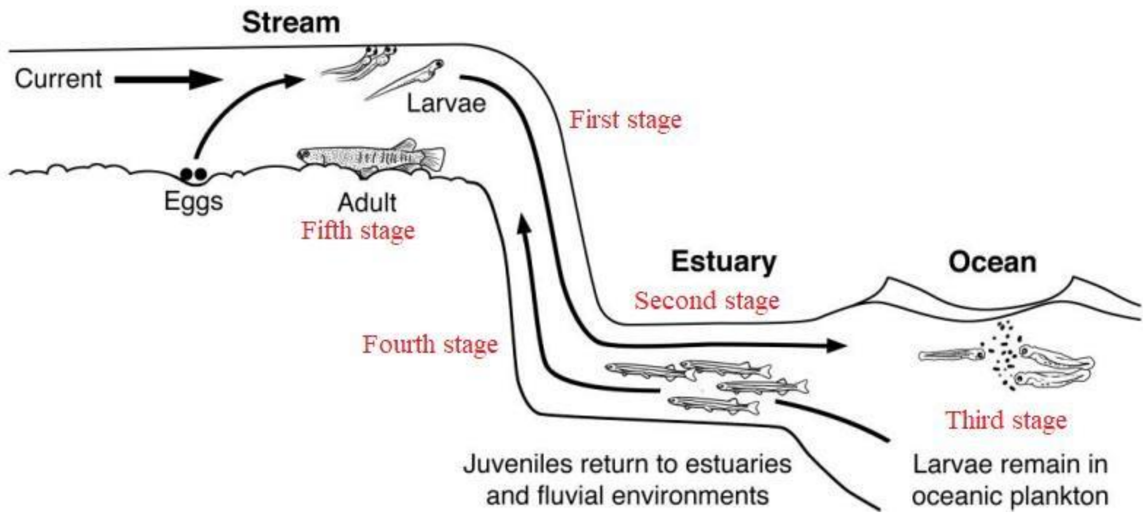

Fig. 2. Sources of internal threats to freshwater amphidromous fish regarding their life cycle **(Augspurger, 2017)**

As one of the diadromous migratory fish that move between freshwater and marine habitats, sources of internal and external threats from freshwater amphidromous fish are spread along their migration path **(Sánchez-Garcés, 2017)**. More specific internal sources of threats can be identified at each stage of migration that involves changes in the physiological processes of the fish **(Kendall *et al.*, 1984; Keith, 2003; Keith *et al.*, 2008)**. From the illustration in Fig. (2), five migration conditions have high internal threat factors.

The first condition begins with the process of hatching eggs into larvae. Freshwater amphidromous fish spawn and incubate eggs in crevices of rocks on the river bed or under stems, leaves, or roots of aquatic plants that they choose as nests. The male fish makes and guards the nest **(Teichert *et al.*, 2013)**. During spawning, the female parent will enter the nest made by the male fish. The male fish will carry out an assessment process on the female fish that are about to enter its nest. The female fish that are considered suitable will be invited to join the nest and spawn in the nest. The eggs from the spawning are attached to the rocks in the nest. The male fish will protect its eggs during incubation **(Teichert *et al.*, 2013; Tamada, 2024)**. This condition allows the male fish to have very little intensity to leave the nest. In this phase, the male fish will eat food around its nest. However, in conditions of dwindling food sources, male fish can be cannibalistic by eating the eggs they guard. In one nest, there can be ~3,500 eggs of freshwater amphidromous fish. However, the success rate of hatching eggs into early larvae is only 10% of the total number of fertilized eggs. In addition to being re-predated by the male parent, failure to hatch eggs can also occur due to suboptimal egg quality and fertilization quality. In addition, low egg survival can also occur due to changes in water temperature in fast-flowing rivers, which can appear very significantly **(Takahashi & Yanagisawa, 1999; Teichert *et al.*, 2013, 2016, 2021; Watson *et al.*, 2023)**.

After the early larvae are successfully hatched, they will be rheoplanktonic, and river currents carry them to sea waters. Now, we come to the second point of vulnerability. The newly hatched early larvae will immediately face changes in the environmental conditions of the waters, which are different from those previously hypoosmotic in fresh water to being more hyperosmotic in sea waters **(Ellien *et al.*, 2016; Simanjuntak *et al.*, 2021)**. **Bell (2007)** even predicted that only 4% of the hatched larvae could survive during this process.

Some larvae that survive and adapt in sea waters will live as ichthyoplankton that are swayed by the hydrodynamic conditions of the waters. Their food reserves in the form of yolk cells will become increasingly depleted at this stage. The larvae need to adapt harder by carrying out their first predation in seawaters with prey targets in the form of other planktonic organisms, both phytoplankton and zooplankton. At this stage, some larvae can die due to starvation because they do not get food. This point is another source of internal threats with critical conditions coupled with predators in sea waters **(Iida *et al.*, 2010; Yamasaki *et al.*, 2007; Urbina & Glover, 2015)**.

Some larvae that successfully obtain food will experience the development of the juvenile stage. Amphidromous fish will have better locomotion and are no longer planktonic at this stage. The olfactory system of amphidromous fish will also develop very well. Amphidromous fish use this sense of smell to detect the direction of fresh water. After successfully detecting the direction of fresh water, amphidromous fish juveniles will approach the coast and river estuaries and swim as benthopelagic fish. Amphidromous fish juveniles generally wait for high tide as the most suitable momentum to enter fresh water through river estuaries **(Maeda & Tachihara, 2005; Murase *et al.*, 2020)**.

At the recruitment stage of amphidromous fish juveniles to freshwater areas through river estuaries, this phase is also identified as one of the stages with a high threat source. This is because juvenile fish will adapt again to changes in the freshwater environment. Failure to adjust the body's osmoregulation system, as well as the factor of running out of energy while moving against the river current, can impact the failure of the recruitment process and death. In addition, amphidromous fish juveniles that experience a drastic decrease in energy in estuary waters to rivers will become an easy prey for various predators that have been waiting for their presence **(Keith, 2003; Lin *et al.*, 2011; Teichert *et al.*, 2013, 2016, 2021)**.

Amphidromous juveniles that successfully move back home to freshwater areas will develop into adult fish. During this phase, amphidromous fish also have several sources of internal threats such as predation by predators, failure to compete for territory/nests, failure to obtain mates, and failure to adapt to changes in the dynamic river water environment **(McDowall, 2007; Lin *et al.*, 2011)**.

External threat sources

In addition to threats originating from internal factors of amphidromous fish life, other sources of threats are more external. External sources of threats are emphasized in the presence of disturbances from human activities that directly or indirectly hurt the lives of freshwater amphidromous fish. In general, three main factors of human activities were identified as sources of external threats to amphidromous fish in the Cimaja River, Sukabumi, West Java.

The first external source of threat is mining river sand and rocks. The surrounding community mines river sand and rocks. The rocks and sand obtained are used as the primary material in the construction of residential areas. As previously stated, the gaps in riverbed rocks are used by freshwater amphidromous fish as nests and places to lay eggs **(Teichert *et al.*, 2013)**. Mining of riverbed sand and rocks has the potential to directly reduce the population of amphidromous fish as a result of a decrease in the number of nests, an increase in the risk of failure of parent spawning and egg hatching, and changes in the ecological structure of river waters which are the primary habitat for this fish.

Fig. 3. Changes in the condition of the Cimaja River resulting from sand and rock mining

Fig. (3) accurately illustrates changes in river habitat conditions before and after sand and river rock mining was carried out. These changes occurred only within 14 days after the sand and rock mining activities. Both images are in the exact location and characterized by macrophyte vegetation in the form of rows of the same coconut trees around the river boundaries. In the left image (conditions before mining), a natural river structure is seen with good flow direction, and bedrock structures are adequately arranged. The conditions on the right illustrate after mining activities where large rocks were lifted. Miners took small stones and sand at the bottom of the river. The river construction changed drastically, the river flow was disrupted, and the presence of several amphidromous fish that had lost their nests was indicated.

The next source of external threat is the tradition of catching larvae and juveniles of coastal fish, which is commonly carried out around the Cimaja estuary and several other large estuaries in the waters of the southern coast of Java, Sukabumi, and West Java. This tradition is known as *nyalawean* (Fig. 4). Judging from its origin, *nyalawean* comes from the word *selawe*, which means 25 in Japanese. This refers to the date of this activity, which is every 25th of each month on the lunar calendar (Hijri) **(Simanjuntak *et al.*, 2021; Baihaqi *et al.*, 2022; Amaliah *et al.*, 2023)**. This fishing activity is carried out massively by all coastal communities from all groups. Fishing is generally carried out with the help of fishing gear in the form of a rectangular lift net and a triangular scope net **(Annida *et al.*, 2021; Simanjuntak *et al.*, 2021)**. The community obtains various types of catches in the form of larvae and juvenile fish during the *nyalawean* procession. **Baihaqi *et al.* (2022)** stated that most of the larvae and juvenile fish obtained were freshwater amphidromous fish. This is because the peak recruitment pattern of this fish in moving from the sea to fresh water through the river estuary in the juvenile phase also occurs between 23-27 Hijriah. The highest recruitment peak was on 25 Hijriah **(Baihaqi, 2022)**. This fact shows that in addition to the internal threat from changes in the osmoregulatory system of amphidromous fish juveniles during recruitment, the next threat is a large number of coastal communities ready to wait and catch this fish. Of course, the source of death from this fishing route adds to the list of threats to the freshwater amphidromous fish population in the Cimaja River, Sukabumi, West Java.

Fig. 4. The tradition of catching larvae and juvenile fish (*nyalawean*) around the coast and estuary of Cimaja, Sukabumi, West Java

Another source of external threats that we have successfully identified is water pollution from household waste runoff and chemicals from plantations and agriculture. Cimaja is one of the large rivers flowing into Palabuhanratu Bay. This river stretches 34.72km and is connected to more than 15 tributaries in the upstream area around the Gunung Halimun National Park area. Along this stretch of the area, various human activities that directly or indirectly affect the quality of the Cimaja River waters are also carried out. One of the detrimental activities is the disposal of anthropogenic waste that pollutes the river. The dominance of plastic waste is often seen piling up in the coastal area around the Cimaja River estuary at certain times (Fig. 5).

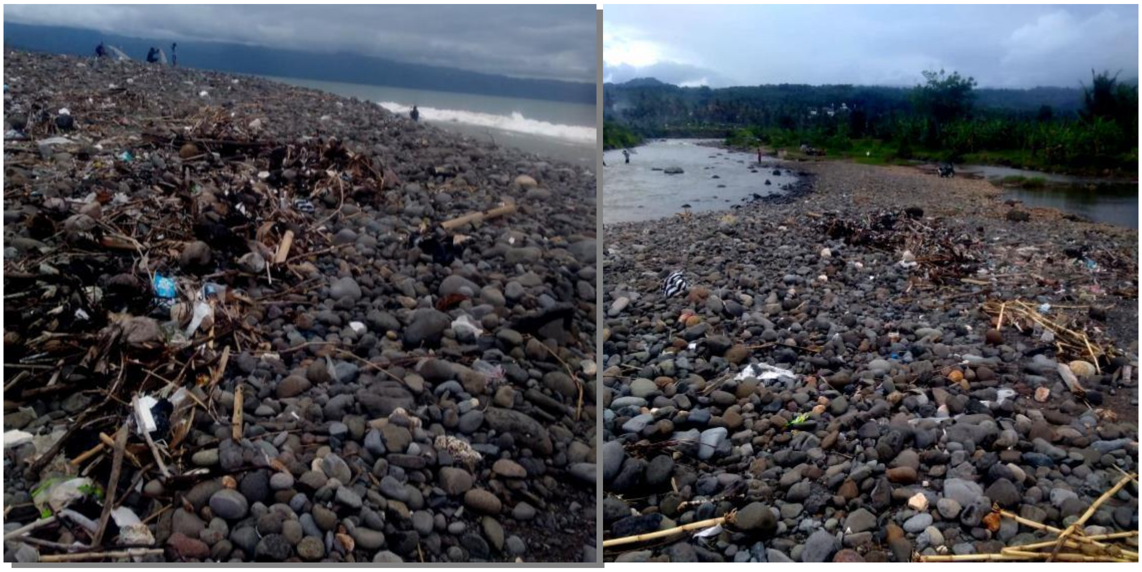

Fig. 5. The presence of anthropogenic waste around the Cimaja River estuary

The presence of plastic waste can affect the health and safety of the Cimaja aquatic environment as a habitat for amphidromous fish. Existing plastic waste, especially microplastic, has the potential to be consumed by amphidromous fish and disrupt the health of their digestive organs **(Primus & Azman, 2022)**. Through the biomagnification pathway, this can also endanger human health if they consume amphidromous fish contaminated with plastics **(Hasan *et al.*, 2023)**. Meanwhile, detergent waste can cause an increase in organic pollution, such as phosphorus and chemicals, which can increase the acidity level of alkaline. Excessive phosphorus pollution in the aquatic environment can cause an increase in the rate of eutrophication around Palabuhanratu Bay and has the potential to lead to HABs **(Heisler *et al.*, 2008)**.

In addition to domestic waste runoff, other potential sources of waste that pollute the Cimaja River come from agricultural and plantation activities. The use of pesticides from agricultural and plantation activities around the River Basin Area will eventually reach the Cimaja River. The composition of pesticides often contains various hazardous substances such as toxic salts, namely arsenate, fluoride, chlorine, copper sulfate, and so on. Each of these substances can be toxic to the life of aquatic organisms, causing reproductive failure, thinning of the dermis layer of eggs, decreased immune system, and abnormal events in the development of the fish body **(Werner *et al.*, 2021; Islam *et al.*, 2022; Ray & Shaju, 2023)**. Therefore, this waste is also a threat that needs to be considered for the survival of amphidromous fish in the Cimaja River.

Mitigation efforts for sources of threats and management

From all the sources of threats that we have put forward, both internal and external, we realized the importance of mitigation efforts to manage each source of threat and minimize the negative impacts on the lives of amphidromous fish in the Cimaja River.

Internal sources of threat have been present as a form of natural selection. Each organism has a unique form of adaptation and life strategy to deal with this. Amphidromous fish also possess this adaptation strategy. Amphidromous fish have several adaptation strategies in dealing with the high sources of internal threats in their life cycle. Some examples of existing adaptation strategies are (1) Maximizing the number of eggs produced to increase the potential number of young fish that can maintain the existence of their population **(Closs *et al.*, 2013)**; (2) Optimizing the diameter of the eggs to maximize the amount of yolk as a food reserve for larvae to avoid starvation during life as ichthyoplankton **(Iida *et al.*, 2017)**. (3) Making nests for egg spawning in fast-flowing rivers near estuaries to accelerate the distribution of larvae to sea areas, where amphidromous fish larvae have a faster growth rate in sea areas **(McRae, 2007; McDowall, 2009)** is an additional strategy. In line with those adapation methods, (4) utilizing tidal energy for the process of re-migrating juvenile fish to river waters through estuaries **(Maeda & Tachihara, 2005; Murase & Iguchi, 2019; Simanjuntak *et al.*, 2021; Baihaqi *et al.*, 2022)** forms a further step. (5) Several species are known to re-recruit to river waters in the juvenile phase at night and/or when the water is more turbid to avoid predator visibility **(McDowall, 2007)**. Notably, (6) in several species of the Gobiidae family, the pelvic fins are structured like discs that can stick to rocks on the river bed and are used to maintain position when moving against the river current **(Cullen *et al.*, 2013; Barbeyron *et al.*, 2017; Christy & Maie, 2019)**.

Reviewing the existence of adaptation forms and life strategies of amphidromous fish in responding to the high internal sources of threat, the focus is on mitigating and managing efforts to overcome more external sources of threat. With full awareness of viewing a river system as an integral part of and influencing it from upstream to downstream, an integrated form of Cimaja River management is recommended. An integrated river management system is not new; it is a concept that has long been developed and widely applied in several river areas worldwide. This concept is recommended to be used with an awareness of the dependence of amphidromous fish on a river system that is running well and minimally disrupted with negative impacts.

In optimizing the implementation of the integrated Cimaja River management concept and supporting the life of fishery resources in the Cimaja River, including amphidromous fish, eight basic regulations were formulated that need to be adequately implemented. The eight basic regulations in question are: (1) Prohibiting sand and river rock mining efforts, especially within a distance of 10km from the river mouth which is a potential area for amphidromous fish nests; (2) Conducting supervision and enforcement efforts against violations of sand and river rock mining activities within a distance of 10km from the Cimaja river mouth; (3) Conducting a review of development activities around the Cimaja river boundaries that have the potential to disrupt the quality of the health of the river ecosystem based on building permit documents for settlements and Environmental Impact Analysis documents for industry; (4) Implementing a ban on the disposal of household waste and industrial waste into the river body as stipulated in the general regulations in the Republic of Indonesia Law No. 18 of 2008 concerning Waste Management and regional instructions from the Sukabumi Regional Government No. 37 of 2023 concerning the prohibition and handling of violations of waste disposal in tributaries, main rivers, river estuaries, and beaches in Sukabumi Regency, West Java; (5) Conducting socialization to farmers regarding the prohibition of the use of hazardous pesticides that can increase the risk of food safety and can pollute the river water environment; (6) Implementing regulations on the time period for which and when catching larvae and juvenile fish in the Cimaja river and estuary is permitted for the nyalawean tradition; (7) Implementing periodic monitoring and evaluation of each regulation that is implemented; (8) Providing a symbolic form of appreciation to every individual, group, and/or community organization that actively takes real action in maintaining and managing the river ecosystem, especially the sustainable Cimaja. Through these seven principal regulations in implementing the integrated Cimaja River management system, we believe it can be a positive mitigation effort against the source of threats to the amphidromous fish population in the Cimaja River, Sukabumi, Indonesia.

CONCLUSION

There are various threats to the existence of amphidromous fish resource populations in the Cimaja river, which are grouped based on their internal and external origins. Amphidromous fish have a form of adaptation strategy in responding to internal sources of threats, which is more of a form of natural selection. Meanwhile, external sources of threats can be minimized by integrated management of the Cimaja River from upstream to downstream. The concept of integrated river management by implementing regulations, prohibitions, controls, monitoring, and evaluations is believed to be able to minimize external sources of threats and maintain the existence of sustainable amphidromous fishery resources in the Cimaja River, Sukabumi, Indonesia.

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