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Species diversity and the spread of invasive fish in the Upper Bengawan Solo River, Central Java, Indonesia

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Abstract. *Haqqi MRA, Sholichah DM, Armando MF, Sani MF, Aprianto MK, Dewangga A, Yap CK, Dadiono MS, Setyawan AD. 2024. Species diversity and the spread of invasive fish in the Upper Bengawan Solo River, Central Java, Indonesia. Biodiversitas 25: 4000-4010.* Bengawan Solo is the largest and longest river in Java, Indonesia, and has a major role in supporting the life of communities around it. To understand the quality of the Bengawan Solo River environment, the study can be done from physical, chemical, and biological aspects. This research was carried out to inventory the species and the spread of invasive fish found in the Upper Bengawan Solo River, Central Java, Indonesia. This research was conducted from November to December 2023 and settled on 5 sampling stations located on main body of Bengawan Solo River, including (i) northern spillway of Gajah Mungkur Reservoir, Wonogiri, (ii) Colo Reservoir, Sukoharjo, (iii) Demangan Floodgate, Surakarta, (iv) Tlumpuk, Karanganyar, and (v) Jati, Sragen. Data collection was performed using Visual Encounter Survey (VES) and direct catch with several fishing tools, collected species identified using iNaturalist, and several books such as *Jenis Ikan Introduksi dan Invasif Asing di Indonesia*, *Ikan Air Tawar di Ekosistem Bukit Tigapuluh*, *Ensiklopedia Populer Ikan Air Tawar*, and *Baku Saku Pengolah Data Jenis Ikan*. Identification also carried out by interviewing local people at study area location to match out vernacular names. The results showed 20 species of fish from 12 families were found, dominated by Cyprinidae. The most fish captured is tilapia (*Oreochromis niloticus*), which can be obtained from all the sampling stations. A species with high conservation status according to IUCN Red List was also found, namely *Rasbora lateristriata* with Vulnerable (VU) status. As many as 6 species discovered were categorized as invasive, including snakehead fish (*Channa striata*), red devil fish (*Amphilophus citrinellus*), tilapia (*O. niloticus*), catfish (*Clarias gariepinus*), sailfin catfish (*Pterygoplichthys pardalis*), and guppy (*Poecilia reticulata*). Their invasive characteristics are usually due to their predatory trait, well adaptability, and high population. The introduction of invasive fish in the Upper Bengawan Solo River was caused by several reasons, such as intentional release for stocking population, escaping fish from nearby farms, and wild releases from fish keepers.

Keywords: Bengawan Solo River, diversity, ecosystem, fish, invasive

INTRODUCTION

Bengawan Solo is the largest and longest river in Java, which passes through 17 districts along East Java and Central Java Province, Indonesia (Mirahesti 2016). Bengawan Solo River has a length of about 548.53 km with a total of 2200 tributaries (Fatimah et al. 2023). Bengawan Solo upstream is located in Wonogiri District, Central Jawa, and historically, in ancient times, it flowed to the Indian Ocean, but it stopped due to geological occurrences that caused the Asian and Australian plates to lift. And nowadays, Bengawan Solo used to support the lives of communities along its streams and has become an important part of the socio-cultural development of Javanese people (Himawan et al. 2021). Along with population activity and density, the need for Bengawan Solo River uses is increasing, thus impacting its water quality (Dani et al. 2015). In 2023, Bengawan Solo River was indicated as polluted with both liquid and solid waste, originating from domestic and industrial waste as well as agricultural lands. Waste that enters the Bengawan Solo River affects water quality and made it indecent to be used for daily life (Sulistiono et al. 2023).

Environmental problems that occurred in the rivers can potentially cause changes in composition of natural ecosystem within it. One of the living creatures that can be found in Bengawan Solo River is fish. The presence of fish can be an indicator of the water quality of that river (Khairuddin et al. 2019). The quality of an ecosystem is more directly related to diversity rather than productivity because any process that is naturally needed by living thinks in the ecosystems is driven by biodiversity (Mangunjaya et al. 2014). Fish occupies the first position as the vertebrate with the highest diversity and distribution around the world (Latuconsina 2021). Diversity of fish species describes the entire scope of ecological adaptation

and evolution of species to a particular environment. It can be described that each freshwater location has differences in fish diversity from other locations (Syafei 2017). The diversity of fish present in freshwater can be both native and invasive species. Invasive fish are known as species of fish that have not originated from their zoogeographical distributions and can threaten the existence of native fish inhabits (Peronita et al. 2022). Invasive alien fish is the initial process that leads to the extinction of certain species of fish as a result of decreases in biodiversity (Wargasasmita 2005). According to Dina et al. (2022), Java Island has the highest number of alien and invasive fish reported, which mostly came from intentional release for economic purposes and disposal of old pet fish. Alien-invasive fish species were associated with predation on other animals, causing changes in the whole ecosystem by changes in the primary producers, food webs, nutrient status, water clarity, and water quality (Veer and Nentwig 2015).

The presence of invasive fish species along Bengawan Solo River flows was detected in Wonogiri, Sukoharjo, Surakarta, and Sragen from several studies that have been done by Utomo et al. (2006), Cahyono et al. (2018) and Shaleh and Chakin (2018), which on their reports several species of invasive fish were found, such as *Anabas testudineus*, *Barbonymus balleroides*, *Channa striata*, *Clarias batrachus*, *Pterygoplichthys pardalis*, *Oreochromis niloticus*, *Oreochromis mossambicus*, and *Trichogaster trichopterus*. The discovery of several species that are indicated as invasive fish is an important issue that needs to be addressed in order to preserve the river ecosystems. By this time, research concerning the distribution of invasive fish species has not been carried out in the entire Upper Bengawan Solo River. It became the basis of this research, where the aim of this research was to inventory the species diversity and the spread of invasive fish in Bengawan Solo River, Central Java. According to Arif et al. (2015), the main body of the Upper Bengawan Solo River that spans Central Java is located in 5 districts, namely Wonogiri, Sukoharjo, Surakarta, Karanganyar, and Sragen. Therefore, location of this research was focused on those five districts to get data straight from the main body of Bengawan Solo River so that it can increase the validity of the data.

MATERIALS AND METHODS

Study area

This study is conducted from November to December 2023 in the Upper Bengawan Solo River area, Central Java, Indonesia. Sampling points are settled on 5 stations as shown in Figure 1. The first station is located in Wonogiri District; on the northern spillway of Gajah Mungkur Reservoir, second station is located in Sukoharjo District; Colo Reservoir, third station is located in Surakarta City; Demangan Floodgate, fourth station is located in Karanganyar District; Tlumpuk, and fifth station is located in Sragen District; Jati. All of the sampling points are located on the main body of the Bengawan Solo River. The establishment of five study areas was purposely representative of the five districts where the upper Bengawan Solo River is located. The pinpoint of each station was considered for its accessibility and was recommended by local residents.

Data collection

Before data collection was performed, a location survey was conducted to determine the sampling station. Data collection was performed using the active sampling method, which was done by Visual Encounter Survey (VES) and catching with several tools, such as cast nets, lift nets, scoop nets, and hook lines. VES is a rapid and non-manipulative method that has been widely used to assess the presence and abundance of fish in shallow waters. VES enables an assessment with good approximation of fish on their relative density (Tiberti et al. 2022). VES was performed by walking on the side and observing the water along its explorable range. The fish seen and caught are then documented, identified, and determined as an invasive species according to books, journals, and scientific references.

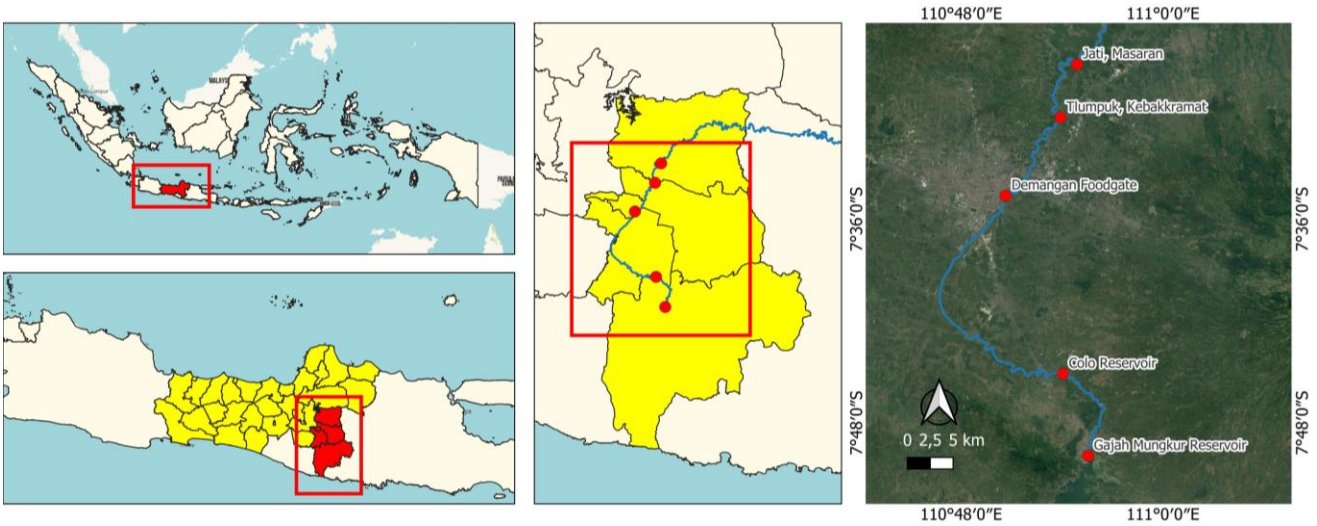

Figure 1. Study area location in the Upper Bengawan Solo River, Central Java, Indonesia

Data analysis

Data analysis were carry out through identification and descriptive analysis. Identification done with the help of software such as iNaturalist and several books such as Kuncoro (2009), Dewantoro and Rachmatika (2016), (Sukmono and Margaretha (2017). Analysis of its invasive character and conservation status was examined by literature review and database from IUCN Red List (www.iucnredlist.org) and iNaturalist (www.inaturalist .org). Descriptive analysis for invasive species was summarized based on literature review, such as journals and research papers that related to freshwater fish found. Analysis references also came from interviews with people who gave an adequate explanation of fish found in the study area location.

RESULTS AND DISCUSSION

Diversity of fish

Based on research conducted, 20 species of fish from 11 families, of which 6 species are considered invasive species, were found in the study area. The diversity of fish on Bengawan Solo River, Central Java, is dominated by Cyprinidae, which consist of 7 species, namely *Barbodes gonionotus*, *B. balleroides*, *Hampala macrolepidota*, *Labiobarbus leptocheilus*, *Rasbora argyrotaenia*, *Rasbora lateristriata*, and *Mystacoleucus marginatus*. Cyprinidae is one of the most speciose of all freshwater teleost fishes with 1700 valid species in at least 200 genera, which is characterized by a protrusible mouth that is actuated by a median bone (the kinethmoid), toothless jaw, and toothless palate. The family has a wide geographical distribution and occurs primarily in freshwater, but some species can tolerate and even breed in saline water (Winfield and Nelson 1991). Collected fishes are mostly captured using cast nets. Based on observations, the utilization of cast nets for fishing in the Bengawan Solo River is quite common. Cast nets are fishing gear that are usually operated in shallow water or open water where the waters are free of bottom obstructions (Seisay 1998). Fish diversity in this research can be seen in Table 1.

The mostly found family was Cyprinidae (35%), followed by Bagridae (10%), Cichlidae (10%), Pangasidae (10%), Channidae (5%), Clariidae (5%), Eleotrididae (5%), Heimramphidae (5%), Loricariidae (5%), Mastacembelidae (5%), and Poeciliidae (5%). According to data on Table 1, Cyprinid fish has the biggest percentage number because it has highest diversity among other taxa. Cyprinid fish can be found almost in all stations besides Station 4. According to Adjie and Agus (2010) and Cahyono et al. (2018), Cyprinid fishes were possessed to be the local fish which being the main inhabitants of the Bengawan Solo River and several fresh waters in Indonesia. The highest number of fish family diversity percentage then followed by Bagridae and Cichlidae. Meanwhile the other family consist of only 1 kind of species. Fish diversity based on its family groups can be presented in diagram form in Figure 2.

Cyprinidae is a family of fish that commonly found in Indonesian waters and has a various types of habitat distribution, such as ponds, swamps, lakes, creeks, to rivers, including Bengawan Solo River. But in this research, the encounter of fish species from Cyprinidae on Station 4 was not happened. It is still unclear but we presume that environment factor and its dispersal pattern is the key for its absence. Water quality conditions in Bengawan Solo River was studied by Aida et al. (2022), resulting poor water quality in Bengawan Solo River of Karanganyar District (low O_2 and transparency, high CO_2, conductivity, TDS, phospor level) due to large number of industrial areas. According to Reichard and Juradja (2007), Cyprinid fishes population dynamics in riverine ecosystems were related to its drift, while those drifting itself affected by fish swimming capacity, density-dependent response to high competitor density of low food abundance, and adaptation to the riverine conditions. Based on observation, Station 4 water conditions was relatively poor compared to other stations which may presumed to be supporting factor on its lowest fish diversity.

Fish diversity along Bengawan Solo River stream also studied by Utomo et al. (2006), which investigating from Gajah Mungkur Reservoir, Wonogiri District, to Cemeng Village, Sragen District. According to their data, several fish families indicate similarity with this research, namely Anabantidae, Belontiidae, Chanidae, Gobiidae, Siluridae, Synbranchidae, and Notopteridae. Meanwhile, their study does not find species from Hemiramphidae, Poeciliidae, and Schilbeidae families. Based on their research, it is known that Bengawan Solo River stream on Sragen District was indicated as seriously polluted since 2006 and it is made worse when polluted water also comes from previous area after rain, which caused fish diversity on those area was low.

Several years later, Cahyono et al. (2018) studied fish diversity in Colo Reservoir, Sukoharjo District. Compared with their research, the results of this research show both similarity and differences in the types of fish that observed on those location. Species of *M. nemurus*, *O. niloticus*, *B. gonionotus*, *B. balleroides*, *H. macrolepidota*, *L. leptocheilus*, and *P. djambal* were found in both research while *R. argyrotaenia* and *R. lateristriata* only found in this research. According to them, the differences of fish diversity can be caused by habitat suitability, seasonal changes, physical conditions of river, and distribution of fish species from upstream. Aida et al. (2022) also studied fish diversity along upstream zone (Gajah Mungkur Reservoir, Wonogiri District) to downstream zone (Kabalan Village, Bojonegoro District). Similar fish species that found along Bengawan Solo River stream from Wonogiri District to Sragen District on their research was *B. gonionotus*, *O. marmorata*, *C. striata*, *C. gariepinus*, *O. niloticus*, *H. macrolepidota*, *P. pardalis*, *M. aculeatus*, *M. nemurus*, *M. marginatus*, and *R. lateristriata*. Research of Aida et al. (2022) shown that tilapia (*O. niloticus*) being dominant species along Wonogiri to Sukoharjo District due to stocking activites occur oftenly, while sailfin catfish (*P. pardalis*) being dominant species along Surakarta city to Sragen District due to its adaptability to heavily polluted water. The findings from their research show aligned evidence where in this study tilapia and sailfin catfish can be found in relatively large numbers compared to other species. Both similarity and differences of fish diversity from previous research proven that population dynamics of fishes occur in the upper Bengawan Solo River.

Table 1. Diversity of fish species found in the study area

Family	Scientific name	Vernacular name	Station					Status	Nativity	Conservation status (IUCN)
			1	2	3	4	5			
Bagridae	*Hemibagrus nemurus* (Valenciennes, 1840)	*Sogo/baung*	+	+	-	-	-	Non-invasive	Java	LC
	Mystus nigriceps (Valenciennes, 1840)	*Ndaringan/keting*	+	-	-	-	+	Non-invasive	Java, Sumatra	LC
Channidae	*Channa striata* (Bloch, 1793)	*Kutuk/gabus*	+	-	-	-	+	Invasive	Non-native	LC
Cichlidae	*Amphilophus citrinellus* (Günther, 1864)	*Red devil*	-	-	+	+	+	Invasive	Non-native	LC
	Oreochromis niloticus (Linnaeus, 1758)	*Nila*	+++	++	+	+	+	Invasive	Non-native	LC
Clariidae	*Clarias gariepinus* (Burchell, 1822)	*Lele*	-	-	+	-	-	Invasive	Non-native	LC
Cyprinidae	*Barbodes gonionotus* (Bleeker, 1849)	*Tawes*	+	+	-	-	-	Non-invasive	Java, Sumatra, Kalimantan, Sulawesi, Bali	LC
	Barbonymus balleroides (Valenciennes, 1842)	*Bader*	+	++	-	-	+	Non-invasive	Java, Sumatra, Kalimantan	LC
	Hampala macrolepidota (Valenciennes, 1842)	*Palung/hampala*	+	-	+	-	-	Non-invasive	Java, Sumatra, Kalimantan	LC
	Labiobarbus leptocheilus (Valenciennes, 1842)	*Lukas*	+++	++	-	-	+	Non-invasive	Java, Sumatra, Kalimantan	LC
	Rasbora argyrotaenia (Bleeker, 1849)	*Wader pari*	++	-	-	-	-	Non-invasive	Java, Sumatra, Kalimantan, Lombok, Bali	LC
	Rasbora lateristriata (Bleeker, 1854)	*Putihan/wader*	++	+	+	-	+	Non invasive	Sumatra, Kalimantan, Bali, Java, Lombok	VU
	Mystacoleucus marginatus (Valenciennes, 1842)	*Keprek*	-	++	+	-	+	Non-invasive	Java, Sumatra	LC
Eleotridae	*Oxyeleotris marmorata* (Bleeker, 1852)	*Betutu/kembo*	+	-	-	+	+	Non-invasive	Non-native	LC
Hemiramphidae	*Dermogenys pusilla* (Kuhl & van Hasselt, 1823)	*Jarum/Julung*	-	-	-	+	-	Non-invasive	Non-native	LC
Loricariidae	*Pterygoplichthys pardalis* (Castelnau, 1855)	*Sapu-sapu*	+	-	++	+	+	Invasive	Non-native	LC
Mastacembelidae	*Macrognathus aculeatus* (Bloch, 1786)	*Sili*	-	-	+	-	-	Non-invasive	Non-native	LC
Pangasidae	*Pangasius djambal* (Bleeker, 1846)	*Jambal*	+	+	+	+	-	Non-invasive	Java, Sumatra, Kalimantan	LC
	Pseudolais micronemus (Bleeker, 1846)	*Jendil*	-	-	+	-	+	Non-invasive	Non-native	LC
Poeciliidae	*Poecilia reticulata* (Peters, 1859)	*Cetol*	-	-	+++	++	++	Invasive	Non-native	LC

Note: +: Less than 50, ++: 50-100, +++: More than 100

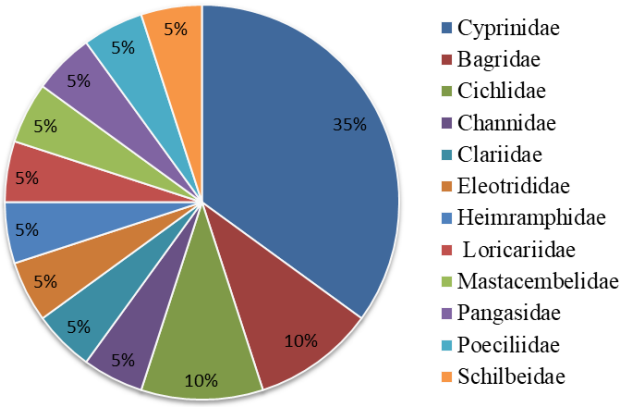

Figure 2. Study area location: main body of Bengawan Solo River in Central Java, Indonesia

Figure 3. Tilapia (*Oreochromis niloticus*) which mostly found

The most captured fish was tilapia (*O. niloticus*) as in Figure 3, which can be obtained from all of the sampling stations in relatively high numbers. Tilapia, or *nila* in Indonesian, is one of the cichlid fishes that have good adaptability and occupy shallow inshore waters purposely as feeding and reproductive grounds (Yongo et al. 2021). Historically, the advent of tilapia in Indonesia started in 1969 when introduced by the Freshwater Fish Research Center Bogor. Those tilapias were then distributed to local farmers all over the country after some research and an acclimatization period (Arfiati et al. 2022). Tilapia are popularly cultivated for consumption as their taste and appearance are similar to red snapper (*Lutjanus campechanus*) (Arifin 2016). Besides being raised for consumption and commercial purposes, tilapia is often used as ornamental fish. It can be found in various freshwater such as lakes, ponds, and rivers. Most of the tilapias caught are the black strain, while the others are the red strain. Black strain tilapia is the result of the hybridization of *O. nilotica* and *O. aureus*. Meanwhile, the red strain tilapia that appear in Indonesia are tetra hybrid from 4 different *Oreochromis* species i.e.; *O. mossambicus*, *O. niloticus*, *O. honorum*, and *O. aureus* (Ghufran 2010). According to several people in the research location, tilapia is the most dominant fish along the Upper Bengawan Solo River. It was comparable to the research by Adjie and Agus (2010), that the upstream parts of Bengawan Solo River are dominated by tilapia (*O. niloticus*) and *jambal* (*P. djambal*). Research by Cahyono et al. (2018) also mentioned that tilapia is the most dominant fish on Colo Reservoir.

In addition, at the research location a species of fish with high conservation status is also found, i.e. *wader* or *putihan* (*R. lateristriata*). According to IUCN (International Union for Conservation of Nature) Red List, *R. lateristriata* are listed in vulnerable endangered (VU), and this indicates that *R. lateristriata* will be at risk of becoming extinct in the future. The *R. lateristriata* is a native Indonesian freshwater fish that belongs to Cyprinidae family and Rasborinae subfamily. The main habitat of this fish is in a riverbed that has a weak current. This fish lives in tropical water at temperatures of 22-24°C and pH of 6,0-6,5. Usually, these fish swim on flowing water and stagnant water within their group. Their grouping behavior also correlated with their spawning, which can happen in several days (Sentosa and Djumanto 2010). The *R. lateristriata* is considered an endangered species due to overfishing and environmental pollution, such as pesticides, which affect the availability in nature (Azhar et al. 2022). The *R. lateristriata* fishing is also seen in Station 1, where local residents are using traditional lift nets to catch the fish along the waterways of Gajah Mungkur Reservoir's northern spillway. The threat for endangered fish like *R. lateristriata* also is more severe because of the existence of invasive fish.

Invasive fish found

Invasive fish are known as species of fish that have not originated from their zoogeographical distributions and can threaten the existence of native fish inhabits (Peronita et al. 2022). Invasive alien fish is the initial process that leads to the extinction of certain species of fish as a result of decreases in biodiversity (Wargasasmita 2005). Invasive fish tend to be efficient predators and can reduce the number of native fish species, aquatic animals, and other organisms that are present in an ecosystem (Rudiyant 2023). The introduction of invasive fish species into an ecosystem can occur in various ways, such as accidental mobilization or purposive releases for cultivation (Ramadian and Muthmainnah 2023). Based on the study, invasive fish found in the study area consist of 6 species as shown in Figure 4, namely snakehead fish (*C. striata*), red devil fish (*Amphilophus citrinellus*), tilapia (*O. niloticus*), catfish (*Clarias gariepinus*), sailfin catfish (*P. pardalis*), and guppy (*Poecilia reticulata*).

The invasive fish species are commonly found in freshwaters in Indonesia (Irmawati et al. 2018; Andriyono and Mirna 2021; Putri et al. 2022; Akhdiana et al. 2023; Mulyani et al. 2023). From the results of interviews with several residents around the Bengawan Solo River stream, the introduction of invasive fish on the Bengawan Solo River mostly occurred due to human activity. The invasive fish species found are also types of fish that tend to have a high adaptation rate to environmental changes in waters. Previously, the presence of some potential invasive fish species can be seen in several studies related to the types of fish that can be found along the Bengawan Solo River

stream. Purnomo (2000) studied the fish community structure of Gajah Mungkur Reservoir, Wonogiri, which is upstream of Bengawan Solo River, and the type of invasive fish found was tilapia (*O. niloticus*). Sriwidodo et al. (2013) studied fish diversity in the inlet and outlet of Gajah Mungkur Reservoir, Wonogiri, and it is known that there are 2 species of invasive fish, namely snakehead fish (*C. striata*) and tilapia *(O. niloticus*). Cahyono et al. (2018), studied the diversity of fish in Colo Reservoir, Sukoharjo, found 11 invasive fish, namely climbing perch (*A. testudineus*), snakehead fish (*C. striata*), tilapia (*O. niloticus*), Mozambique tilapia (*O. mossambicus*), Buenos Aires tetra (*Hyphessobrycon anisitsi*), Asian catfish (*C. batrachus*), catfish (*C. gariepinus*), common carp (*C. carpio*), sailfin catfish (*P. pardalis*), guppy (*P. reticulata*), and blue panchax (*A. panchax*). Aida et al. (2022), which studied distribution of fish species in Bengawan Solo River from Gajah Mungkur Reservoir, Wonogiri, to Kabalan Village, Bojonegoro, found a total of 6 invasive fish species, namely climbing perch (*A. testudineus*), snakehead fish (*C. striata*), catfish (*Clarias* sp..), Mozambique tilapia (*O. mossambicus*), tilapia (*O. niloticus*), and sailfin catfish (*P. pardalis*). From those studies, it is known that tilapia (*O. niloticus*) presence along the Upper Bengawan Solo River was constant and tends to be the most dominant invasive species today.

The spread of tilapia can be found in all stations, but the first station (Gajah Mungkur Reservoir, Wonogiri) has the largest number. According to interviews from local residents, tilapia is occasionally released into Gajah Mungkur Reservoir for cultivation purposes. The next most widespread invasive fish species was sailfin catfish, which can be found in almost all stations except Station 2. The presence of sailfin catfish on Station 2 was recorded by Cahyono et al. (2018) before, but in this study, these fish were not found. The absence of other invasive fish in this study could be caused by several reasons, such as mobilization and population decrease due to fishing activities. Overall, the spread of invasive fish occurred in all parts of Bengawan Solo River, Central Java. The description of each species is as follows:

Channa striata (Bloch, 1793)

Also called snakehead fish, *C. striata* is classified in the order Perciformes, sub-order Channoidei, family Channidae, which can be found in freshwater of tropical regions such as Africa, South Asia, South-East Asia, and East Asia (Muslim 2007). In Indonesia, snakehead fish can be found in Kalimantan, Sumatra, Java, Sulawesi, and Papua (Sinaga 2018). Snakehead fish has many economic and health benefits because it contains essential amino acids such as leucine, lysine, and phenylalanine (Fitriyani et al. 2020). In their small size (juveniles), snakehead fish look exotic, so they are often used as ornamental fish in aquariums (Listyanto and Andriyanto 2009). Snakehead fish's body is long, round, cylindrical, and slimy. It is greyish green in color, and the ventral side is faint yellow with white or reddish flings. Black oval blotches appear below the lateral line. Dorsal and anal fin has greyish color with irregular small white spots. Pectoral fin is pale with reddish tinge (Sinha and Jamal 2015). The main characteristic of *C. striata* is snake-shaped heads that are covered with scales. Therefore, this fish is commonly named snakehead fish (Alviodinasyari et al. 2019). Channidae fishes are able to breathe oxygen from the atmosphere because their gills have additional features. Hence, *C. striata* has a nice adaptability in waters with low oxygen levels, such as swamps, rivers with small flows, and even waters with high humus content derived from peat (Sinaga 2018). The *C. striata* is carnivorous and has an allometric growth pattern, which is correlated to its aggressiveness in seeking food that consists of small fish, insects, and all kinds of other aquatic animals, including tadpoles and frogs (Listyanto and Andriyanto 2009). The predatory effect of *C. striata* would decrease abundance, restrict spatial distribution, and alter species composition and food webs (Li et al. 2016). The threat of *C. striata* as an invasive fish can be seen in the study of Omar et al. (2023), which mentioned that *C. striata* has high risk impact value for predator fish that threaten endemic fish at Mahalona Lake, South Sulawesi, Indonesia such as *Dermogenys megarrhamphus*, *Telmatherina prognatha*, and *T. celebensis.*

Amphilophus citrinellus (Günther, 1864)

The *A. citrinellus*, commonly called red devil fish, is a species of fish originating from Central America (Nicaragua and Costa Rica), which is distributed around Lake Masaya, San Juan River and Lake Nicaragua. This species lives in tropical waters with a temperature of 21-26°C and a pH between 6-8 (Umar et al. 2015). Red devil fish belong to the Cichlidae family. The red devil fish has a slender body shape and is almost the same as tilapia fish; the difference is its hard and rough scales and pointed anal and dorsal fins. Red devils entered public waters in Indonesia through accidental introduction, this happened due to the escape of seeds carried by the current when they were spread in floating net cages (Isroliyah et al. 2021). Its appearance in Indonesia can also be tracked by stocking activities in Jatiluhur Reservoir in 1995, Sermo Reservoir in 1995, Kedung Ombo Reservoir in 2000, and Sentani Reservoir in 2005, combined with several wild release activities from ornamental fish hobbyists (Umar et al. 2015). The presence of a red devil fish in the ecosystems has become the leading threat to the survival of other fish in the habitats due to its predatory nature that preyed on other fish (Sutimin et al. 2018). The invasive characteristics of red devil fish include fast growth, fast reproduction, high survival ability, ability to adapt to a wide range of environments, diverse types of food and the potential to damage habitat and the environment (Umar et al. 2015). The dominance of invasive species such as red devil fish can cause damage to the balance of aquatic ecosystems due to the reduction or disappearance of several endemic fish species (Dadiono 2023). The impact of red devil fish invasion can be seen in Sermo Reservoir, where in 2005, around 5 kg of fish were caught consist 4 kg of several kinds of fish and 1 kg of red devil fish, but in 2009, around 5 kg of fish caught 4 kg it turned to be red devil fish (Umar et al. 2015).

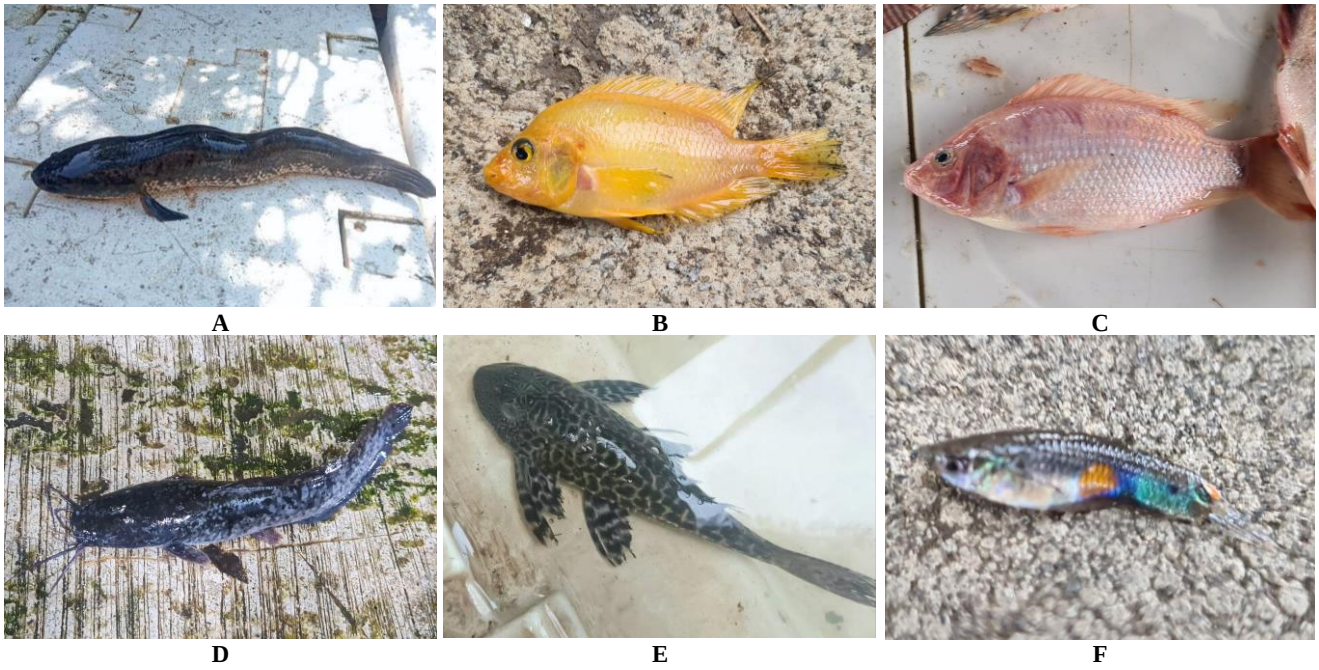

Figure 4. Invasive fish species that are found in the upper Bengawan Solo River, Central Java, Indonesia. A. *Channa striata* (Snakehead fish), B. *Amphilophus citrinellus* (Red devil fish), C. *Oreochromis niloticus* (Tilapia), E. *Clarias gariepinus* (Catfish), F. *Pterygoplichthys pardalis* (Sailfin catfish), G. *Poecilia reticulata* (Guppy)

Oreochromis niloticus (Linnaeus, 1758)

Tilapia or *O. niloticus* is a type of freshwater fish that can be found in tropical and subtropical regions that belongs to the Cichlidae family and spread globally (Dailami et al. 2021). Tilapia originated from the Nile River valley in Africa (Arifin 2016). Tilapia is very popular in aquaculture because it is easy to cultivate due to its fast growth, high resistance to diseases and various environmental conditions (Nugroho et al. 2013). Tilapia can be found in several freshwater and brackish water habitats, such as rivers, lakes, swamps, rice fields, and ponds (Arfiati et al. 2022). Generally, tilapia is characterized by the lean and elongated body with several varieties that have the color of gray, blackish, and reddish. Linea lateralis is located in the central lateral of the body and has 34 scales. The eyes are large, protruding, and the edges are white. There are five fins, namely the dorsal fin, ventral fin, pectoral fin, anal fin, and caudal fin, which some of them have hard and sharp fingers-like spines (Amri and Khairuman 2003). It was first introduced in Indonesia from Taiwan, Thailand, and the Philippines in 1969, 1990, and 1994 (Arifin 2016). Currently, the distribution of tilapia is widespread in Indonesia because it is cultivated as a fish for consumption. Besides its benefits, tilapia is considered a threat to aquatic ecosystems because their existence can suppress endemic fish populations, although the risk impact may vary according to the region and the type of native species (Sentosa et al. 2022). Tilapia is seen as an invasive species due to its degree of environmental tolerance, flexible habitat requirements, diverse diet, fast growth, early maturation, low fecundity, extended spawning season, and multiple spawning within a year (Ishikawa et al. 2013). The dominance of a fish species can cause declining the quality of the natural environment, disrupt the balance of fish communities, decrease original genetic traits, and cause infiltration of diseases and parasites in fish (Sentosa et al. 2013). The impact of tilapia domination can be seen in the study of Kurnia et al. (2021), from fishermen of Soedirman Reservoir, Banjarnegara, as many as 51% of fish captured was tilapia, while local fish only 6% of the total fish captured. From the observation, tilapia is relatively easy to find in the Upper Bengawan Solo River. Local residents mentioned that in the last few years, the spreading of tilapia juveniles has been conducted purposely to increase the fish population. Tilapia farming can be found in the Gajah Mungkur reservoir upstream of the Bengawan Solo River, which can also explain its large amount of population.

Clarias gariepinus (Burchell, 1822)

Catfish or *C. gariepinus* are species of freshwater fish that belong to the Clariidae family and are characterized by their ability to use atmospheric air and remain on the land for several hundred meters with the help of their pectoral spines (Teugels 1982). Catfish is one of the famous consumption fish, that firstly introduced to Indonesia from Taiwan in 1986, and at this time is widely cultivated in Indonesia (Samadi 2023). Catfish can be found in rivers with slow currents, swamps, lakes, reservoirs, flooded rice fields, and even in polluted waterways (Ratnasari 2019). Catfish is predominantly a carnivorous fish that mostly feeds on fish, land invertebrates, water insects, gastropods, and zooplankton (Khan et al. 2021). Catfish are easy to acknowledge because of their slick bodies and long barbels

around their mouths (Tabaika 2022). The body of catfish is generally cylindrical and elongated with large and flat head. Catfish skin has no scales but is usually covered by a layer of mucus that helps protect the body from infection and facilitates movement in water. The skin color has whitish to brownish-gray spots. Catfish have good resistance to various environmental conditions and have a relatively fast growth time (Ratnasari et al. 2020). Besides being known for having good adaptability, catfish is also known as a voracious feeder made, it has a fast growth rate (Darseno 2010). Catfish are emerging invaders, and their introduction to aquatic ecosystems can cause direct predation of native fish and shifts in invertebrate community structures (Ellender et al. 2015). The impact of *C. gariepinus* invasion can be seen in Khan et al. (2021), which showed that *C. gariepinus* has high trophic level and low eco-trophic efficiency in Karapuzha Reservoir, India, which means *C. gariepinus* low predation mortality and strong presence in those ecosystems caused all other fish and crustacean populations are heavily predated by it, so it can be interpreted that *C. gariepinus* invasion has considerable impact on the ecosystem food web. According to a local resident found in the study area, the existence of catfish in Bengawan Solo River mostly occurred in the rainy season when the pool from catfish farmers around the river overflowed, then the catfish jumped and got onto the river.

Pteryqoplichthys pardalis (Castelnau, 1855)

The *P. pardalis* is one of the sailfin catfish groups that originated from the Amazon River in South America, but now their presence has spread worldwide (Wahyudewantoro 2018). Sailfin catfish belongs to order Siluriformes, suborder Loricarioidei, family Loricariidae mainly characterized for its several unique morphological characteristics such as ventrally oriented sucker mouths, bony plates covering their bodies, a bi-lobed swim bladder, and fenestrae in the skull (McAdams and Michael 2023). Sailfin catfish are able to maintain their life because it has additional respiratory organs in the form of labyrinths, they can be found in various waters such as rivers, streams, lakes, ponds, ditches, rice fields, swamps, brackish waters, and even in waters polluted by heavy metals (Wahyudewantoro 2018). Sailfin catfish was determined by discrete dark spots on the lateral and caudal peduncle with a pattern of uncoalesced dark spots on a light background, stout pectoral fins with rough surfaces and inferior disc-like protrusible mouth. Body coloration, particularly on the abdomen, consists of dark spots. The head exhibits linear patterns forming geometric shapes. The body behind the head is completely plated dorsally and laterally. Naked belly with plates occurring on the ventral side of the caudal peduncle region. Ventral surface of the pectoral girdle covered in skin mesial to the coracoid strut. Caudal peduncle round in cross-section. And adipose fin present in the peduncle region (Mogalekar 2017). Sailfin catfish is often used as ornamental fish because it is popular for its habits of eating algae, macrophytes, detritus, sand, mud, and small organisms, which can help aquarium tanks clean (Parvez et al. 2023). When it becomes larger, this fish consumes more things, including other fish's eggs that are placed in the same pond. This caused some keepers to release it to several open waters (Elfidasari 2020). Behind its potential and beautiful color, it turns out that sailfin catfish are a threat to existing populations of native fish species due to their high population and adaptability, so it is possible that they can become pests for aquaculture activities (Wahyudewantoro 2018). Population explosions of sailfin catfish were studied by Hasrianti et al. (2020) in Lake Sidenreng, Sidenreng Rappang District, South Sulawesi. This study found that the invasion of sailfin catfish caused a decrease in local fishermen's target fish catch, where 53.81% of the fish caught by the nets were sailfin catfish. The dominance of the sailfin catfish in these locations is due to competition and eating habits of sailfin catfish that prey on fish eggs. According to local residents, the existence of sailfin catfish presumably came from the release of pet fish that reproduced and distributed through the Upper Bengawan Solo River and its tributaries.

Poecilia reticulata (Peters, 1859)

The *P. reticulata*, or guppy, is a fish that originated from Central and South America and belongs to the Poeciliidae family (Sasami et al. 2021). Poeciliidae is a family of freshwater fish that is relatively small-sized, able to survive in various water conditions, tolerant of changes in pH and temperature, have rapid reproduction, and have diverse colors such as red, blue, green, and yellow (Islamy et al. 2023). Guppy is often used as an ornamental fish because of its attractiveness and various color patterns (Soelistyowati et al. 2007). It is also popular for its unique characteristic, where its body has a slight, small, and diverse color line that is fascinating on its several fins. Guppy is usually bred to produce unique offspring, making it one of the ornamental fish that has economic value (Akbar 2022). The body shape looks elongated and cylindrical; it has 1 dorsal fin, 1 caudal fin, 2 ventral fins, and 2 pectoral fins. The males have bright and varied body colors or patterns, have wide or long tails, and have a gonopodium as a reproductive instrument (Hardaningsih and Yulanda 2023). Guppy usually lives in groups and prefer shallow over deeper microhabitats, but may depend on rearing conditions and the presence of predators and other guppies (Houde 1997). Guppy is opportunistic benthopelagic omnivores whose diet depends on local abundance and availability of prey. Its food consists of algae, protozoans, diatoms, small crustaceans, mosquito larvae, and other organic detritus (Lawal et al. 2012). The introduction of guppy started in 1920 by Dutch colonial in Indonesia to control mosquito larvae. However, as it adapted, guppy began to multiply and spread widely until it was categorized as an invasive species (Nurmalita 2015). Guppy is known as an invasive species due to their rapid reproduction and their habits as predators of the eggs and larvae of other fish, so they can eat the offspring of other fish around them. Guppy is also known for its adaptability to aquatic habitats such as ponds with murky water, water channels, and ditches in lowland areas to mountain rivers (Humaira 2023). The impact of Guppy invasion was studied by Deacon (2010), who reported that Guppy

invasion in several regions, such as Madagascar, Japan, Thailand, Australia, Mexico, and Peru, caused declining of certain native species through the spread of disease and competition for resources, implicating ecosystem level, and interfering aquaculture processes.

In conclusion, the diversity of fish in Upper Bengawan Solo River, Central Java, is composed of 20 species from 12 families, where the most dominant family was Cyprinidae, followed by Bagridae and Cichlidae. The most captured fish was tilapia (*O. niloticus*) from the Cichlidae family, which was obtained from all the sampling stations. In the study area, a species with high conservation status was also found, namely *R. lateristriata*, which is listed as vulnerable (VU) according to the IUCN Red List. Invasive fish species found in Bengawan Solo River, Central Java, consist of 6 species, namely snakehead fish (*C. striata*), red devil fish (*A. citrinellus*), tilapia (*O. niloticus*), catfish (*C. gariepinus*), sailfin catfish (*P. pardalis*), and guppy (*P. reticulata*). Tilapia also being the most dominant invasive species along Bengawan Solo River in Central Java, which can be found in all stations. The introduction of invasive fish in the Bengawan Solo River was caused by several reasons, such as intentional release for stocking population, escaping fish from nearby farms, and wild releases from fish keepers.

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