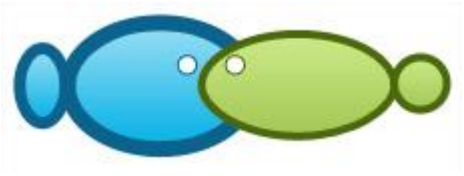

Presence of non-native freshwater fish in Indonesia: A review - Risk and ecological impacts

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Abstract. The introduction of non-native species in various parts of the world negatively impacts biodiversity and the existence of native and endemic species through competition for resources, predation, hybridization, habitat modification, and disease transmission. This article aimed to describe the types of non-native fish that are currently spread in Indonesia. Fish data collection was based on literature studies that have been conducted in Indonesia. The impact of the presence of non-native fish on wild fish and their environment is presented. The bibliographic search was performed in all available databases using the following combinations of key words: non-native freshwater fishes in Indonesia and ecological impact of invasives freshwater fishes all over the world. Scientific articles were collected which were published online from three comprehensive databases of scientific publications, namely PubMed, Google Scholar and Scopus between January to August 2022. All the articles were assessed thoroughly to the existing information regarding the presence of invasive fish in Indonesia and information regarding the ecological impact of the presence of invasive fish in a habitat. Around 92 relevant research reports have been reviewed. From the collected references, the diversity of non-native fish species that spread across Indonesia were classified and the results were summarized. Moreover, further details on the non native species have been found: around 54 introduced freshwater fish species in Indonesia, 14 of which were invasive species and 4 potentially invasive, which could dominate an ecosystem and replace the diversity of the native species in nature and change the structure of freshwater ecosystems, especially the native species.

Key Words: alien fishes, endemic, freshwater fishes, invasive fishes, introduction, native species.

Introduction. The diversity of freshwater fish in Indonesia is very large (Allen 2000; Kottelat et al 1993; Muchlisin & Azizah 2009; Nurjirana et al 2020), currently there are 1,266 species of freshwater fish in Indonesian waters, the second largest after Brazil with 3,547 species (Fishbase 2022). However, the diversity of freshwater species is currently starting to be seriously threatened due to habitat and environmental damage caused by land conversion, pollution, and climate change (Kottelat & Whitten 1996; Thushari & Senevirathna 2020). In addition, the presence of non-native fish is also a threat to the existence of native fish (Wood et al 2017; Spikmans et al 2020).

Non-native fish are species living outside their natural habitat (encompassing exotic, non-indigenous, and alien) (Gozlan et al 2010). The introduction of non-native species is considered as a serious threat to biodiversity (Manchester 2000; Mooney & Cleland 2001; Dudgeon et al 2006; Pulkkinen 2013; Jeschke et al 2014; Guerin et al 2017; Dueñas 2018). Non-native species do not previously occur naturally in an area, but they spread (possibly introduced by humans) into that area (Sagoff 2005; Rahel 2007; Strayer & Dudgeon 2010; Guo et al 2020). The direct impacts of the presence of non-native species on native species occur through competition for resources, predation, hybridization, habitat modification, transmission of diseases (infection or parasitism) and

genetic effects (Brown & Moyle 1991; Correia 2001; Gozlan et al 2005; King et al 2006; Maguire & Gray 2006; McDowall 2006; Bampfylde & Lewis 2007; Blanchet et al 2007; Wagner and Van Driesche 2010; Ribeiro 2012; Insani et al 2020; Serdiati et al 2021). Usually, non-native species are tolerant to environmental changes, such as temperature fluctuations and low oxygen content, being able to invade an environment (Serdiati et al 2020; Hasan & Widodo 2021; Ihwan et al 2021). In addition, non-native fish are able to rapidly breed, reaching a large population (Hasan et al 2020a). This can lead to the extinction of local fish due to massive predation and competition for food and territory (Barriyah et al 2021). Besides, the presence of foreign fish can act as carriers of the disease to native species (Chinchio et al 2020).

Most of the non-native freshwater fish in Indonesia are introduced by humans to increase fishery production and meet world food needs, such as: tilapia, tilapia, pomfret, and others (Gozlan et al 2010; Dewantoro & Rachmatika 2016; Andriyono & Fitrani 2021). In addition, there are also those who are brought in by hobbyists as ornamental fish. These fish have been introduced a long time ago; some people consider them as native to Indonesia. An example is the Nile tilapia, which originates from Africa, but is often released into public waters for the conservation of aquatic biota, even if the presence of non-native fish or invasive species is very dangerous for the native fish. Among the introduced species there are predatory, such as alligators and piranhas, and some competitors. The research aimed to assess the types of non-native fish that exist in Indonesia, including invasive species, in order to better understand their impact on the aquatic ecology in Indonesia. A systematic literature review was conducted following the guidelines of Haddaway et al (2015) by collecting scientific reports that were published online through searches of three comprehensive databases of scientific publications, namely Pubmed, Google Scholar and Scopus between January and August 2022. A preliminary assessment of a subset of articles was conducted and their relevance was evaluated to avoid papers unrelated to the paper's focus. 92 relevant study papers were reviewed and became the reference in writing the current review articles.

Non-native freshwater fishes. Non-native fish are species living outside their natural habitat, while invasive fish are introduced non-native fish that have a negative impact on aquatic communities (Dewantoro & Rachmatika 2016; Andriyono & Fitrani 2021). The introduction of a species into the environment will go through several stages, becoming an invasive species (Kiruba-Sankar et al 2018; Andriyono & Fitrani 2021) (Figure 1).

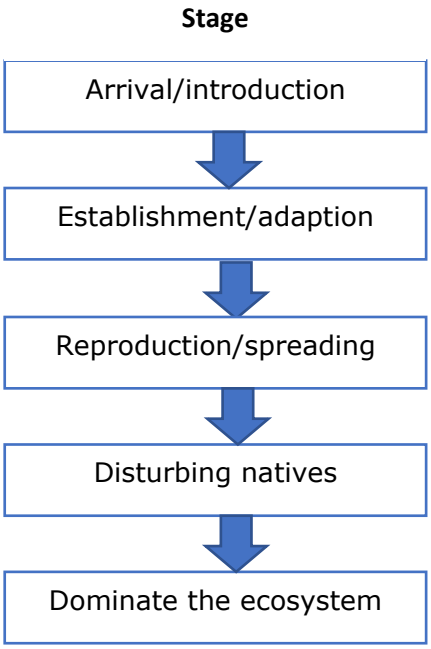


Figure 1. Stage of biological invasion (Kiruba-Sankar et al 2018).

The first stage is the introduction, intentional or unintentional, which is the process of the arrival of a species in a new habitat whose characteristics might be similar under certain aspects. The second stage is the adaptation process for non-native species to be able to live normally in a new environment, without showing symptoms of stress or disease, supporting the colonization of the new environment. After the adaptation process, the species is able to reproduce in a new habitat, allowing non-native species to replace native species, modifying the diversity of the habitat. And, at the last stage in this process, non-native species can shift the abundance of native species because they have dominated an ecosystem (McMahon 2002; Kinnison et al 2008, Phillips et al 2006; Keller et al 2011; Minchin et al 2013; Kiruba-Sankar et al 2018; Andriyono & Fitrani 2021).

Fish introduction in Indonesia. Introduced species are species extracted from outside their natural range (Macdonald et al 2007), which colonize the reference habitat. Artificial introduction could be due to hobbyists or cultivators, in order to increase fishery production (e.g. tilapia and carp). Based on the reviewed literature, it is estimated that a total of 54 introduced species have been recorded in Indonesia (Dewantoro & Rachmatika 2016). Those species are dominated by the Cichlidae family, representing as much as 30% of the estimated species currently circulating (Table 1). Cichlids are considered exotic and interesting fish, being preferred by hobbyists. Cyprinidae family represent the second most abundant introduced fish, for instance the Koi fish.

Table 1

Introduced freshwater fish in Indonesia

Species	*Popular name*	*Family*	*Origin*
Cohlasoma urophthalmum	Mexican mojarra	Cichlidae	Central America
Cichla temensis	Speckled pavon	Cichlidae	South America
Cyphotilapia frontosa	Humphead cichlid	Cichlidae	East Africa
Gymnogeophagus balzanii	Argentine humphead	Cichlidae	South America
Heros severus	Banded cichlid	Cichlidae	South America
Microgeophagus ramirezi	Ram cichlid	Cichlidae	South America
Neolamprologus brichardi	Fairy cichlid	Cichlidae	Africa
Parachromis dovii	Guapote	Cichlidae	Central America
Pelvicahcromis pulcher	Rainbow krib	Cichlidae	Africa
Pterophylum scalare	Freshwater angelfish	Cichlidae	South America
Pseudotropheus zebra	Zebra mbuna	Cichlidae	Africa
Symphysodon discus	Discus	Cichlidae	South America
Uaru amphiacanthoides	Uaru	Cichlidae	South America
Andinocara rivulatus	Green terror	Cichlidae	South America
Esomus metallicus	Flying barb	Cyprinidae	Thailand
Carasius auratus	Goldfish	Cyprinidae	Asia
Cyprinus carpio	Koi	Cyprinidae	Western Europe
Epalzeorhynchos frenatum	Rainbow Shakminnow	Cyprinidae	Asia
Myxocyprinus asiaticus	Chinnese sucker	Cyprinidae	China
Protopterus aethiopicus	Marbled lungfish	Protopteridae	Africa
Prototerus annectens	West African lungfish	Protopteridae	Africa
Polypterus palmas	Shortfin bichir	Protopteridae	Africa
Polyodon spatula	Mississipi paddlefish	Protopteridae	South America
Pharactochepalus hemioliopterus	Retail catfish	Pimelodidae	South America
Pseudoplatystoma corrucans	Spotted sorubim	Pimelodidae	South America
Pseudoplatystoma fasciatum	Barred sorubim	Pimelodidae	South America
Osteoglossum biccirbosum	Arwana	Osteoglossidae	South America
Scleropages leihardti	Spotted Australian Arwana	Osteoglossidae	Australia
Chalceus erythrurus	Tucan fish	Characidae	South America

Species	*Popular name*	*Family*	*Origin*
Paracheirodon axelrodi	Cardinal terra	Characidae	South America
Synodontis angelicus	Angel squeaker	Mochokidae	Africa
Synodontis ocellifer	Ocellated synodontis	Mochokidae	Africa
Oxydoras sifontensi	Black talking catfish	doradidae	South America
Pterodoras granulosusi	Granulated catfish	doradidae	South America
Melanotaenia maccullochi	Macculoch's rainbowfish	Melanotaeniidae	Osenia
Melanotaenia splendida	Eastern rainbowfish	Melanotaniidae	OSenania
Botia lobacbata	Reticulate loach	Cobitidae	Pakistan, India
Chilodus punctatusi)	Spotted Headstander	Chilodontidae	South America
Schizodon fassciatus	Aracu comum	Anostomidae	South America
Ctenolucius hujeta	Gar charancin	Ctenoluciidae	South America
Pangasianodon hypophthalmus	Striped catfish	Pangasiidae	Asia
Clarias gariepinus	North African catfish	Claridae	Africa/Asia
Corydoras aeneus	Bronze corydoras	Callichthyidae	South America
Sternopygus macrurus	Longtail knifefish	Sternopygidae	South America
Apteronotus albifrons	Black ghost	Apteronotidae	South America
Poecilia sphenops	Molly	Poecillidae	Central America
Monodactylus sebae	African moony	Monodactylus	Africa
Potamotrygon motoro	South America freshwater stingray	Dasyatidae	South America
Gymnarchus niloticus	Aba	Gymnarchidae	Africa
Monocirrhus polyacanthus	Amazon leaf fish	Polycentridae	South America
Betta spendens	Simese fighting fish	Osphronemidae	Thailand
Trichogaster pectroralis	Snakeskin gourami	Belontiidae	Asia
Colisa lalia	Dwarf gourami	Osphronemidae	Asia
Pogoneleotris heterolepis	Greek	Eleotridae	Malaysia

Source: Dewantoro & Rachmatika (2016); Hasan et al (2020b); Serdiati et al (2020); Valen et al (2022).

Invasive freshwater fishes in Indonesia. Invasive fish are introduced as non-native fish that have a negative impact on aquatic communities (Cucherousset & Olden 2011). Currently, the invasive fish that dominate Indonesian waters come from the Cichlidae family (Table 2), such as *Aequidens pulcher*, *Amphilophus alfari*, *Astronotus ocellatus, Hermichromis elongatus*, *Parachromis managuensis*, *Oreochromis niloticus*, *Amphilophus labiatus*. Especially *A. labiatus* are dominant in some lakes and rivers. This species is native to Central America: Atlantic slope of Nicaragua, in Nicaragua and Managua Lakes, coming from tropical waters and lives in water temperature 21-26°C with a pH of 7.0, although adaptable to pH 6.0–8.0. *A. labiatus* dominates the catches of in several reservoirs and lakes in Indonesia, reaching 40-60%. In Jatiluhur Reservoir in 2003 and 2004, the catches proportion was around 40%, and in 2011 it was around 30%. In Kedung Ombo about 60% and Lake Sentani around 45% and even higher (Kartamihardja & Umar 2006; Umar et al 2015). Other invasive fish species found in Indonesia are from the Lepisostidae, Charcadidae, and Poeciliidae families (Dewantoro & Rachmatika 2016).

Freshwater fish that are potentially invasive. Invasive fish have high adaptability, are able to reproduce quickly, and are able to live with the types of food that are available around them; sometimes there is no competition so they become top predators. Some of the most ecologically disastrous introductions have involved the transfer of predatory fishes (Gozlan et al 2010). There are several types of introduced fish in Indonesia, which are potentially invasive and become top predators in the wild, including *Arapaima gigas*. In 2018, this species has been found in the Brantas River (Syafei &

Sudinno 2018; Fadjar et al 2019). *A. gigas* has been introduced for a long time in Indonesia and is very likely to become invasive and a top predator if it is released into a natural habitat (Table 3).

Table 2

List of the occurrence of the invasive freshwater fish species introduced into Indonesia

Species	*Popular name*	*Family*	*Origin*
Aequidens pulcher	Blue acara cichlid	Cichlidae	Central America
Amphilophus alfari	Pastel cichlid	Cichlidae	Central America
Amphilophus labiatus	Red devil	Cichlidae	Central America
Astronotus ocellatus	Oscar	Cichlidae	South America
Hermichromis elongatus	Banded jewel cichlid	Cichlidae	Africa
Parachromis managuensis	Jaguar guapote	Cichlidae	Central America
Oreochromis niloticus	Nile tilapia	Cichlidae	Africa
Mozambique tilapia	Mozambique tilapia	Cichlidae	Africa
Atractosteus spatula	Aligator gar	Lepisostidae	North America
Lepisosteus osseus	Longnose gar	Lepisostidae	North America
Lepisosteus oculatus	Spotted gar	Lepisostidae	North America
Pterygoplichthys pardalis	Amazon sailfin catfish	Loricariidae	South America
Pygocentrus nattereri	Red piranha	Characidae	South America
Ganbusia affinis	Mosquitofish	Poeciliidae	North America

Source: Sentosa et al (2013); Umar et al (2015); Dewantoro & Rachmatika (2016); Hasan et al (2020a); Insani et al (2021); Hasan et al (2019); Mangitung et al (2021); Faqih et al (2020); Serdiati et al (2021); Hasan & Widodo (2022).

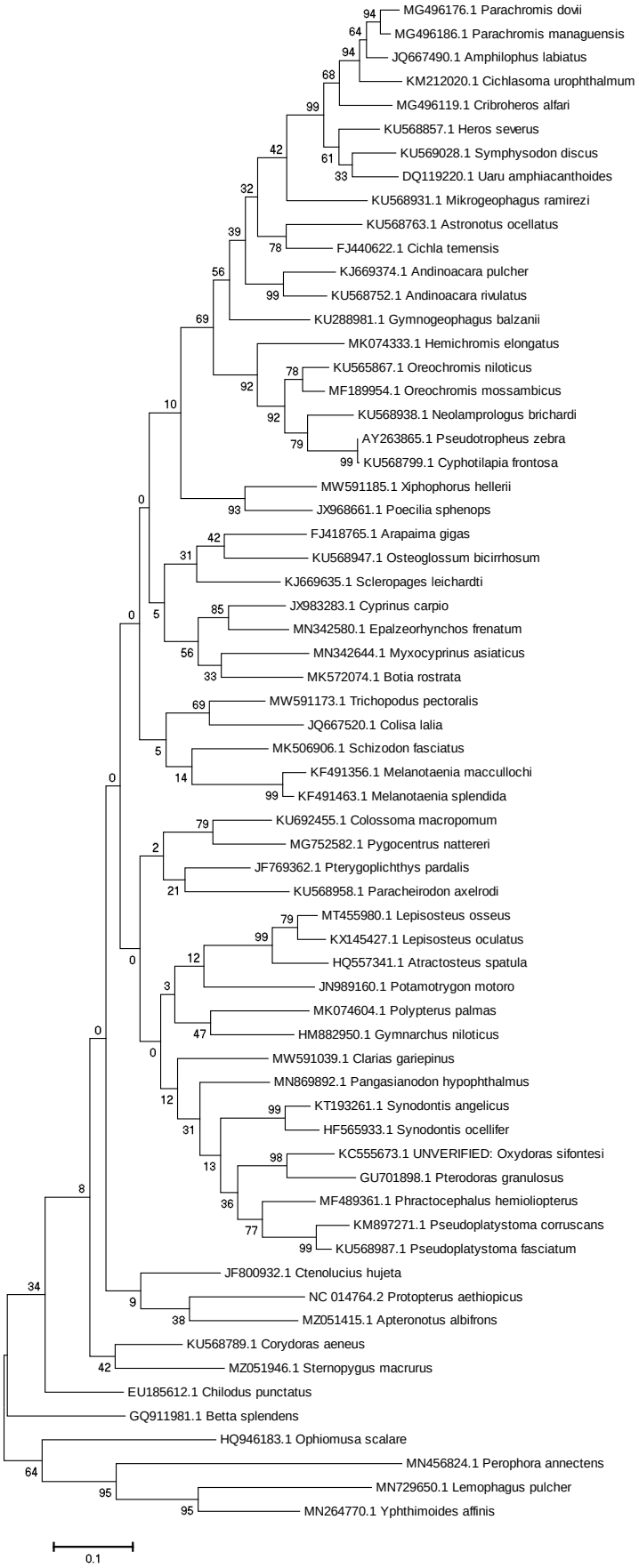
Table 3

Species that are potentially invasive

Species	*Popular name*	*Family*	*Origin*
Arapaima gigas	Arapaima	Osteolossidae	South America
Colossoma macropomum	Chacama	Characidae	South America
Poecillia reticulata	Guppy	Poecillidae	Venezuela
Xiphophorus hellerii	Platy	Poecillidae	North America

Source: Dewantoro & Rachmatika (2016); Fadjar et al (2019); Syafei & Sudinno (2018).

Phylogenetic of non-native. 64 coding sequences of introduced fish that invaded Indonesia were retrieved from the genbank with registered access codes and then formed an evolutionary tree using MEGA6 (Tamura et al 2013). The purpose of making this phylogenetic tree is to classify species based on their kinship and show the relatives of invasive fish that dominate in Indonesia. There are several clades formed by the phylogenetic tree; the largest and dominating clade comes from the family Cichlidae, with as many as 20 species; *Cohlasoma urophthalmum* (Gunther 1862), *Cichla temensis* (Humboldt 1821), *Cyphotilapia frontosa* (Boulenger 1906), *Gymnogeophagus balzanii* (Perugia 1891), *Heros severus* (Heckel 1840), *Microgeophagus ramirezi* (Myers & Hary 1948), *Neolamprologus brichardi* (Pol 1974), *Parachromis dovii* (Gunhter 1864), *Pelvicahcromis pulcher* (Boulenger 1901) *Pterophylum scalare* (Schultz 1823), *Pseudotropheus zebra* (Boulenger 1899), *Symphysodon discus* (Heckel 1840), *Uaru amphiacanthoides* (Heckel 1840), *Andinocara rivulatus* (Gunther 1860), *Aequidens pulcher* (Gill 1858), *Amphilophus alfari* (Meek 1907), *Amphilophus labiatus* (Günther 1864), *Astronotus ocellatus* (Agassiz 1831), *Hermichromis elongatus* (Guichenot 1861), *Parachromis managuensis* (Günther 1867), *Oreochromis niloticus* (Linnaeus 1758), Mozambique tilapia (Peters 1852). The Cichlidae family is a monophyletic group of the Perciformes order (Kaufman & Liem 1982). Most of Cichlidae originate from America and Africa, and are currently also distributed to other continents (Ribbink 1991). The morphology of cichlid species has been studied for almost 100 years and various classification schemes have been proposed (Trewavas 1973, Greenwood 1987).



Cichlidae

Figure 2. Phylogenetic tree of the non-native freshwater fishes introduced to Indonesia, by the Maximum Likelihood method (sequences from the genbank).

Risk and ecological impacts. Freshwater fish invasions had an impact on operating at various levels of biological organization of the ecosystems. Case studies based on literature are provided to demonstrate the ecological impact of the presence of invasive fish. In general, the impacts of non-native species on the native species occur through competition for resources, predation, hybridization, habitat modification, transmission of diseases (infection or parasitism) and genetic effects (Cucherousset & Olden 2011). Some types of non-native freshwater species' ecological impacts on various levels of biological organizations are presented in Figure 3.

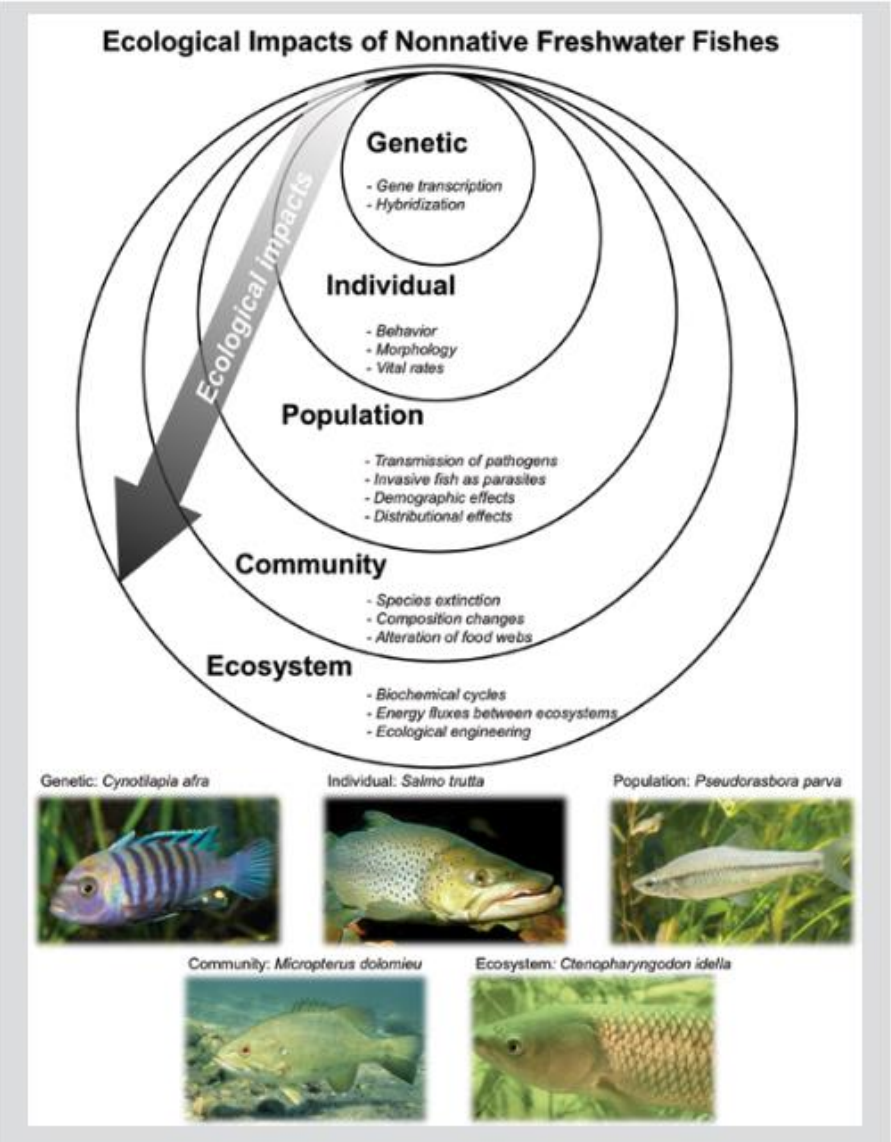


Figure 3. A schematic representation of the ecological impact of non-native freshwater fishes of the biological organization (Cucherousset & Olden 2011).

Genetic level. The ecological impact of non-native freshwater fish on genetics is at the level of gene transcription patterns and hybridization. It was reported that the inhibition between non-native fish and native fish increases the risk of extinction (Allendorf et al 2001). Hybridization between native and non-native species can reduce reproductive efficiency due to the wasted gametes of native species, especially if the population of native species is vulnerable (Cucherousset & Olden 2011). Furthermore, hybridization can replace native brood populations due to hybrid vigor. This occurs in hybrids of the native Pecos pupfish (*Cyprinodon pecosensis*) and the invasive sheepshead minnow (*Cyprinodon variegatus*) in North America, found to be superior in terms of growth and swimming endurance (Rosenfield et al 2004). Lastly, hybridization can reduce genetic

integrity in native populations such as non-native rainbow trout in Montana to native west slope trout (*Oncorhynchus clarki lewisi*), which reduces the native species' fitness (Muhlfeld et al 2009).

Individual level. At the individual level, non-native fish will affect the behavior, morphology, and vital rate of native fish. An example of an influence on behavior is that non-native fish can change the behavior of native species when they are numerically dominant and/or more aggressive than native species. Behavioral changes due to interspecific competition, such as changes in territory and feeding habits, can also inhibit the growth of native fish (Cucherousset & Olden 2011). For example, native Atlantic salmon fry has been more active during the day since rainbow trout were introduced, due to the interference competition for feeding areas (Blanchet et al 2008). When non-native species are introduced to a new environment, there will be new selection pressures on native fish, that require adaptation in order to be sustainable (Strauss et al 2006). This will change the morphology of native fish in order to compete with non-native species (Bourke et al 1999; Mooney & Cleland 2001; Fisk et al 2007; Latta et al 2007). Non-native fish can also affect the vital traits of local fish (i.e., growth and reproduction). through physical injury or reduced foraging activities, due to a predatory behavior of non-native fish. Predation on the embryos of native fish prevents their reproductive success, because native fish breeders will maintain the embryo until it depletes energy reserves for further reproduction (Segev et al 2009; Corkum et al 2004; Steinhart et al 2004; Steinhart et al 2005).

Population level. Invasive fish can affect the distribution of native species by reducing their abundance through predation and by displacing them from optimal habitats, through competitive exclusion (Cucherousset & Olden 2011; Hasan et al 2021). For example, the presence of red devil fish, released either intentionally or unintentionally, has dominated several reservoirs in Indonesia (Umar et al 2005), so it is reported that the catch of red devil fish reaches 40-60% in some reservoirs. In Jatiluhur Reservoir, the catch of red devil fish is generally higher than other catches, such as milkfish (*Channos channos*), congo (*Parachromis managuensis*), tilapia (*Oreochromis niloticus*), goldfish (*Cyprinus carpio*), bougainvillea (*Mystus nigriceps*), jambal (*Pangasionodon hypopthalmus*) (Kartamihardja & Umar 2006). The high number of catches of red devil fish in some public waters indicates that this invasive species became a dominant species and has shifted the presence of native fish.

Community level

Species extinction. The presence of invasive fish in the waters caused damage and decreased the biodiversity, consequently it changed the structure of freshwater ecosystems, especially the pre-existing local ones (Strayer 2010; Rahim et al 2013; Havel et al 2015). It was reported that invasive fish caused the extinction of 39% of the world's fish species in 400 years (Kiruba-Sankar et al 2018). Conservative estimates suggest that 150–200 (or 60%) of the endemic fish species (most of which are not fully described) are already extinct (Witte et al 1992). Invasive fish will affect the struggle for territory and the food competition. In addition, predatory invasive fish will affect the number and diversity of native fish (Parker et al 1999; Dudgeon 2006; Bohn et al 2008). It was estimated that 50% of 1205 fish introductions recorded for aquaculture have been established in the wild (Casal 2006). Extinctions and decline in fish diversity in Indonesia continue to arrive, for instance in the waters of Lake Towuti, which is recorded as the seventh deepest lake in the world. In 1993 there were still 52 endemic fish species (Kottelat et al 1993) and they almost halved 10 years later; in 2003, there were fewer than 28 remaining endemic fish species (Wirjoatmojo et al 2003). In Lake Poso, several endemic fish are declared extinct, one of which is *Adrianichthys kruyti*. In Jambi Province, three species are almost threatened with extinction, namely: lais kaca fish (*Kryptoperus minor*), crooked machete fish (*Macrochirichtys marcrochirus*), and pearl sepat fish (*Trichopodus leerii*) (Sukmono et al 2013). The IUCN Red List reported seven freshwater fish species in Bangka Island which are endangered, including *Parosphromenus deissneri*,

wild *Betta schalleri*, *Encheloclarias tapeinopterus* (vulnerable), wild *Betta chloroparynx* (critically endangered), *Sundadanio gargula* (vulnerable), and *Parosphromenus julinae*.

Composition change. In addition to causing species extinction, the presence of foreign fish can also change the composition of the waters or the composition of the main watershed (Leprieur et al 2008; Cucherousset & Olden 2011). For example, in Bali's Beratan Lake, several non-native fish species were introduced intentionally or unintentionally. Studies showed that in Lake Beratan there are 17 species of fish, 70% of which are introduced species (Sentosa et al 2013). Some of these introduced fish species have the characteristics of invasive foreign fish. In addition, Jatiluhur Reservoir, Senani Lake and Kedung Ombo Reservoir are dominated by invasive red devil fish as much as 40-60% of the total catch (Umar et al 2015).

Alteration of food webs. Introduced fish have often been able to disrupt the trophic relationships of native predatory fish and to shift their trophic niches, thereby profoundly altering the structure of food webs in lake ecosystems (Cucherousset & Olden 2011). For example, Smallmouth bass which has been widely introduced to parts of North America, acts as a top predator having a major impact on the diversity, abundance, and community structure of prey fish. It has disrupted the trophic relationship of native predatory fish, encouraging the lake trout to shift its trophic niche towards the, thus changing the structure of the food web in the lake ecosystem (Rahel 2000; MacRae & Jackson 2001).

Ecosystem level. At the ecosystem level, introduced fish can modify biochemical cycles such as the nutrient cycle (nitrogen and phosphorus), for example, the introduction of tilapia can increase nitrogen and phosphorus availability and promote algae growth (Figueredo & Giani 2005; Eby et al 2006). In addition, introduced fish can modify the energy fluxes between ecosystems, through the exchange of nutrients, energy and organisms, and they can also change the habitats (as ecosystem engineers). A number of case studies have reported that non-native fish species can act as ecosystem engineers, severely affecting the environment, once withdrawn from their native habitat (Cucherousset & Olden 2011).

Conclusions. Most of the non-native freshwater fishes were introduced to Indonesia by hobbyists or cultivators to increase fishery production. A total of 54 introduced freshwater fish species have been recorded in Indonesia, dominated by the Cichlidae family (an estimated 30% of the species currently circulating). As many as 14 of the non-native species are invasive and 4 species are potentially invasive, including *Arapaima gigaz*. Impacts of the presence of non-native species on native species have occurred through competition for resources, predation, hybridization, habitat modification, transmission of diseases and genetic effects. Invasive fish can affect the distribution of native species by reducing their abundance through predation and by displacing them from optimal habitats through competitive exclusion. The presence of invasive fish also causes damage and decline in biodiversity and changes the structure of freshwater ecosystems, especially the local pre-existing ones. Invasive fish caused the extinction of 39% of the world's fish species in 400 years. The International Union for Conservation of Nature (IUCN) recorded 87 Indonesian endangered fish species, 57 of which being threatened with extinction due to various factors such as habitat change, loss, pollution, overexploitation of resources and introduction of invasive fish into a habitat. In addition to causing species extinction, the presence of foreign fish can also change the composition of the waters or the composition of the main watershed. For example, in Bali's Beratan Lake, where several non-native fish species were introduced, about 70% of population is currently composed of introduced species. In addition, Jatiluhur Reservoir, Senani Lake and Kedung Ombo Reservoir are dominated by the invasive red devil fish, at a level of 40-60% of the total catch.

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References

Allen G., 2000 Marine fishes: A field guide for angler and diver. Periplus, Singapore, 292 p.
Allendorf F. W., Leary R. F., Spruell P., Wenburg J. K., 2001 The problems with hybrids: Setting conservation guidelines. Trends in Ecology and Evolution 16:613–622.
Andriyono S., Fitrani M., 2021 Non-Native species existence and its potency to be invasive species on freshwater ecosystem in East Java Province, Indonesia. Egyptian Journal of Aquatic Biology and Fisheries 25:1013-1024.
Bampfylde C. J., Lewis M. A., 2007 Biological control through intraguild predation: case studies in pest control, invasive species and range expansion. Bulletin of Mathematical Biology 69:1031–1066.
Bariyyah S. K., Saleh S. M., Insani L., Seridati N., Valen F. S., 2021 Jaguar Cichlid, *Parachromis managuensis* (Günther, 1867) (Perciformes, Cichlidae): An introduced exotic fish in Grati Lake, East Java, Indonesia. Ecology, Environment and Conservation 27:S272-S275
Blanchet S., Loot G., Bernatchez L., Dodson J. J., 2007 The disruption of dominance hierarchies by a non-native species: an individual-based analysis. Oecologia 152:569–581.
Blanchet S., Loot G., Bernatchez L., Dodson J. J., 2008 The interaction of interspecific competition and environmental variability on the diel activity of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 65:1545–1553.
Bohn T., Amundsen P. A., Sparrow A., 2008 Competitive exclusion after invasion? Biological Invasions 10:359–368.
Bourke P., Magnan P., Rodriguez M. A., 1999 Phenotypic responses of lacustrine brook charr in relation to the intensity of interspecific competition. Evolutionary Ecology 13:19–31.
Brown L. R., Moyle P. B., 1991 Changes in habitat and microhabitat partitioning within an assemblage of stream fishes in response to predation by Sacramento squawfish (*Ptychocheilus grandis*). Canadian Journal of Fisheries and Aquatic Sciences 48:849–856.
Casal C. M., 2006 Global documentation of fish introductions: The growing crisis and recommendations for action. Biological Invasions 8:3-11.
Chinchio E., Crotta M., Romeo C., Drewe J. A., Guitian J., Ferrari N., 2020 Invasive alien species and disease risk: An open challenge in public and animal health. PLoS Pathogens 16(10):e1008922.
Corkum L. D., Sapota M. R., Skora K. E., 2004 The round goby, *Neogobius melanostomus*, a fish invader on both sides of the Atlantic Ocean. Biological Invasions 6:173–181.
Correia A. M., 2001 Seasonal and interspecific evaluation of predationby mammals and birds on the introduced red swamp crayfish *Procambarus clarkii* (*Crustacea, Cambaridae*) in a freshwater marsh (Portugal). Journal of Zoology 255:533–541.
Cucherousset J., Olden J. D., 2011 Ecological impacts of non-native freshwater fishes. Fisheries 36:215–230.
Dewantoro G. W., Rachmatika I., 2016 [The introduction and Invasive fishes in Indonesia]. Lipi, Jakarta, pp. 136-158. [In Indonesian].
Dudgeon D., Arthington A. H., Gessner M. O., Kawataba Z., Knowler D. J., Leveque C., Naiman R. J., Richard A. H. P., Soto D., Stiassny M. L. J., Sullivan C. A., 2006 Freshwater biodiversity: Importance, threats, status and conservation challenges. Biological Reviews 81:163-182.
Dueñas M. A., Ruffhead H. J., Wakefield N. H., 2018 The role played by invasive species in interactions with endangered and threatened species in the United States: a systematic review. Biodiversity and Conservation 27:3171–3183.

Eby L. A., Roach W. J., Crowder L. B., Stanford J. A., 2006 Effects of stocking- up freshwater food webs. Trends in Ecology and Evolution 21:576–584.
Fadjar M., Islamy R. A., Herawati Y., 2019 Short communication: First record of *Arapaima gigas* (Schinz, 1822) (Teleostei: Osteoglossomorpha), in the Brantas River, Sidoarjo, East Java, Indonesia. Biodiversitas Journal of Biological Diversity 20:3527-3531.
Faqih A. R., Maftuch M., Hasan V., 2020 Range expansion of *Parachromis managuensis* (Günther, 1867) (Perciformes, Cichlidae) in Java, Indonesia. Biotropia 29(1):90-94.
Figueredo C. C., Giani A., 2005 Ecological interactions between Nile tilapia (*Oreochromis niloticus*) and the phytoplanktonic community of the Furnas Reservoir (Brazil). Freshwater Biology 50:1391–1403.
Fisk D. F., Latta L. C., Knapp R. A., Pfrender M. E., 2007 Rapid evolution in response to introduced predators I: rates and patterns of morphological and life-history trait divergence. BMC Evolutionary Biology 7:22.
Gozlan R. E., St-Hilaire S., Feist S. W., Martin P., Kent M. L., 2005 Biodiversity – disease threat to European fish. Nature 435:1046.
Gozlan R., Britton R., Cowx I., Copp G., 2010 Current knowledge on non-native freshwater introductions. Journal of Fish Biology 76:751-786.
Greenwood P. H., 1987 The genera of pelmatochromine fishes (Teleostei, Cichlidae). A phylogenetic review. Bulletin of the British Museum (Natural History) Zoology 53:139-203.
Guerin G. R., Martín-Forés I., Sparrow B., Lowe A. J., 2017 The biodiversity impacts of non-native species should not be extrapolated from biased single-species studies. Biodiversity and Conservation 27(1):1-11.
Guo Q., Cen X., Song R., Mckinney M., Wang D., 2020 Worldwide effects of non-native species on species-area relationships. Conservation Biology 1-11.
Hasan V., Widodo M. S., 2021 [*Parachromis managunesis* (Günther, 1867): Presence of foreign predatory fish in Lombok, West Nusa Tenggara]. Jurnal Ilmu Perikanan 12(2):180-184. [In Indonesian].
Hasan V., South J., Ktz A., Ottoni F., 2022 First record of the small-eyed loter *Prionobutis microps* (Weber, 1907) (Teleostei: Eleotridae: Butinae) in Java, Indonesia. Cybium: International Journal of Ichthyology 46:49-51.
Hasan V., Widodo M. S., Faqih A. R., Mahasri G., Valen F. S., Tamam M. B., Yonarta D., Pratama F. S., Fitriadi R., 2020b Presence of striped flying barb *Esomus metallicus* (Teleostei, Cyprinidae) from West Sumatra, Indonesia. Ecology, Environment and Conservation 26(August Suppl. Issue): S73-S75.
Hasan V., Pratama F., Malonga W., Annisa C., 2019 First record of the Mozambique tilapia, *Oreochromis mossambicus* Peters, 1852 (Perciformes, Cichlidae), on Kangean Island, Indonesia. Neotropical Biology and Conservation 14:207-211.
Hasan V., Widodo M., Islamy R. A., Angga P., Dewa A., 2020a New records of alligator gar, *Atractosteus spatula* (Actinopterygii: Lepisosteiformes: Lepisosteidae) from Bali and Java, Indonesia. Acta Ichthyologica Et Piscatoria 50:233–236.
Hasan V., Valen F. S., Islami R. A., Widodo M. S., Saptadjaja A. M., Islam I., 2020 Short Communication: Presence of the vulnerable freshwater goby *Sicyopus auxilimentus* (Gobiidae, Sicydiinae) on Sangihe Island, Indonesia. Biodiversitas 22(2):573-581.
Havel J. E., Kovalenko K. E., Thomaz S. M., Amalfitano S., Kats L. B., 2015 Aquatic invasive species: challenges for the future. Hydrobiologia 750:147–170.
Ihwan, Pratama F. S., Yonarta D., Faqih A. R., Widodo M. S., Valen F. S., Tamam M. B., Hasan V., 2020 Presence of Asian catfish *Clarias batrachus* (Siluriformes, Clariidae) in Madura Island, Indonesia. AACL Bioflux 13(2):958-962.
Insani L., Hasan V., Valen F. S., Pratama F. S., Widodo M. S., Faqih A. R., Islamy R. A., Mukti A. T., Isroni W., 2020 Presence of the invasive Nile tilapia *Oreochromis niloticus* Linnaeus, 1758 (Perciformes, Cichlidae) in the Yamdena Island, Indonesia. Ecology, Environment and Conservation 26(3):1115-1118.
Jeschke J., Bacher S., Blackburn T., Dick J., Essl F., Evans T., Gaertner M., Hulme P., Kühn I., Mrugała A., Pergl J., Pyšek P., Rabitsch W., Ricciardi A., Richardson D.,

Sendek A., Vilà M., Winter M., Kumschick S., 2014 Defining the impact of non-native species. Conservation Biology 28(5):1188-1194.
Kartamihardja E. S., Umar C., 2006 [Structure and feeding habits of fish communities in the limnetic zone of the Ir. Juanda, West Java]. Jurnal Penelitian Perikanan Indonesia 2(3):159-166. [In Indonesian].
Kaufman L., Liem K. F., 1982 Fishes of the suborder Labroidei (Pisces: Perciformes): Phylogeny, ecology and evolutionary significance. Breviora 472:1-19.
Keller R. P., Geist J., Jeschke J. M., Kuhn I., 2011 Invasive species in Europe: ecology, status, and policy. Environmental Sciences Europe 23:1-23.
King R. B., Ray J. M., Stanford K. M., 2006 Gorging on gobies: beneficial effects of alien prey on a threatened vertebrate. Canadian Journal of Zoollogy 84:108–115.
Kinnison M. T., Unwin M. J., Quinn T. P., 2008 Eco-evolutionary vs. habitat contributions to invasion in salmon: experimental evaluation in the wild. Molecular Ecology 17(1):405-414.
Kiruba-Sankar R., Raj J. P., Saravanan K., Kumar K. L., Angel J. R. J., Velmurugan A., Roy S. D., 2018 Invasive species in freshwater ecosystems–Threats to ecosystem services. Biodiversity and Climate Change Adaptation in Tropical Islands, Elsevier Inc, pp. 257-296.
Kottelat M., Whitten A. J., Kartikasari S. N., Wirdjoadmodjo S., 1993 Freshwater fishes of Western Indonesia and Sulawesi. Periplus, Jakarta, 461 p.
Kottelat M., Whitten A., 1996 Freshwater biodiversity in Asia with special reference to fish. World Bank Technical Paper 343(343):1-59.
Latta L. C., Bakelar J. W., Knapp R. A., Pfrender M. E., 2007 Rapid evolution in response to introduced predators II: the contribution of adaptive plasticity. BMC Evolutionary 7:21.
Leprieur F., Beauchard O., Blanchet S., Oberdorff T., Brosse S., 2008 Fish invasions in the world's river systems: when natural processes are blurred by human activities. PLoS Biology 6:404–410.
Macdonald D., King C., Strachan R., 2007 Introduced species and the line between biodiversity conservation and naturalistic eugenics. Key Topics in Conservation Biology 187-205.
MacRae P., Jackson D., 2001 The influence of smallmouth bass (*Micropterus dolomieu*) predation and habitat complexity on the structure of littoral zone fish assemblages. Canadian Journal of Fisheries and Aquatic Sciences 58(2):342–351.
Maguire C., Grey J., 2006 Determination of zooplankton dietary shift following a zebra mussel invasion, as indicated by stable isotope analysis. Freshwater Biology 51(7):1310–1319.
Manchester S. J., Bullock J. M., 2000 The impacts of non-native species on UK biodiversity and the effectiveness of control. Journal of Applied Ecology 37(5):845-864.
Mangitung S. F., Hasan V., Isroni W., Serdiati N., Vale F. S., 2021 Mozambique tilapia *Oreochromis mossambicus* (Peters, 1852) (Perciformes: Cichlidae): New record from Masalembo Island, Indonesia. Ecology, Environment and ConservationEco 27(3):1091-1093.
McDowall R., 2006 Crying wolf, crying foul, or crying shame: alien salmonids and a biodiversity crisis in the southern cool-temperate galaxioid fishes? Reviews in Fish Biology and Fisheries 16(3):233–422.
McMahon R. F., 2002 Evolutionary and physiological adaptations of aquatic invasive animals: r selection versus resistance. Canadian Journal of Fisheries and Aquatic Sciences 59(7):1235–1244.
Minchin D., Cook E. J., Clark P. F., 2013 Alien species in British brackish and marine waters. Aquatic Invasions 8(1):3-19.
Mooney A. A., Cleland E. E., 2001 The evolutionary impact of invasive species. Colloquium 98(10):5446-5451.
Muchlisin Z., Azizah M. N. S., 2009 Diversity of freshwater fish in Aceh waters, Indonesia. International Journal of Zoological Research 5:62-79.

Muhlfeld C. C., Kalinowski S. T., McMahon T. E., Painter S., Leary R. F., Taper M. L., Allendorf F. W., 2009 Hybridization reduces fitness of cutthroat trout in the wild. Biology Letters 5(3):328–331.
Nurjirana, Afrisal M., Sufardin, Haris A., Burhanuddin A. I., 2020 Diversity and distribution freshwater ichthyofaunal of West Sulawesi. IOP Conference Series: Earth and Environmental Science 486:012079.
Parker I. M., Simberloff D., Lonsdale W. M., Goodell K., Wonham M., Kareiva P. M., Williamson M. H., Van Hole B., Moyle P. B., Byers J. E., Goldwasser L., 1999 Impact toward a framework for understanding the ecological effects of invaders. Biological Invasions 1(1):3–19.
Phillips B., Brown G., Webb J., Shine R., 2006 Runaway toads: an invasive species evolves speed and thus spreads more rapidly through Australia. Nature 439:803
Pulkkinen K., Ruokonen T. J., Mykrä M., Tambe G., Karjalainen J., Hämäläinen H., 2013 Indirect effects of invasive crayfish on native fish parasites. Ecosphere 4(4):1-9.
Rahel F., 2007 Biogeographic barriers, connectivity and homogenization of freshwater faunas: it's a small world after all. Freshwater Biology 52(4):696–710.
Rahel F. J., 2000 Homogenization of fish faunas across the United States. Science 288:854–856.
Rahim K. A. A., Esa Y., Arshad A. B. 2013 The influence of alien fish species on native fish community structure in Malaysian Waters. Kuroshio Science 7(1):81-93.
Ribbink A. J. 1991 Distribution and ecology of the cichlids of the African Great Lakes. In: Cichlid fishes: Behavior, ecology and evolution. Keenleyside M. H. A. (ed), Chapman and Hall, New-York, 86 p.
Ribeiro F. M. V., Leunda P., 2012 Non-native fish impacts on Mediterranean freshwater ecosystems: Current knowledge and research needs. Fisheries Management and Ecology 19:142-156.
Rosenfield J. A., Nolasco S., Lindauer S., Sandoval C., KodricBrown A., 2004 The role of hybrid vigor in the replacement of Pecos pupfish by its hybrids with sheepshead minnow. Conservation Biology 18:1589–1598.
Sagoff M., 2005 Do non-native species threaten the natural environment? Journal of Agricultural and Environmental Ethics 18(3):215-236.
Segev O., Mangel M., Blaustein L., 2009 Deleterious effects by mosquitofish (*Gambusia affinis*) on the endangered fire salamander (*Salamandra infraimmaculata*). Animal Conservation 12:29–37.
Sentosa A., Wijaya D., Tjahjo D. W., 2013 [Risk study of the presence of introduced fish in Lake Beratan, Bali]. Prosiding Forum Nasional Pemulihan dan Konservasi Sumberdaya Ikan IVPurwakarta, 16 p. [In Indonesian].
Serdiati N., Yonarta D., Pratama F. S., Faqih A. R., Valen F. S., Tamam M. B., Hamzah Y. I. G., Hasan V., 2020 *Andinoacara rivulatus* (Perciformes: Cichlidae), an introduced exotic fish in the upstream of Brantas River, Indonesia. AACL Bioflux 13(1):137-141.
Serdiati N., Insani L., Safir M., Rukka A. H., Mangitng S. F., Valen F. S., Tamam M. B., Hasan V., 2021 Range expansion of the invasive Nile tilapia *Oreochromis niloticus* (Perciformes: Cichlidae) in Suawesi sea and first record for Sangihe Island, Tahuna, North Sulawesi, Indonesia. Ecology, Environment and Conservation 27(1):168-171.
Spikmans F., Lemmers P., op den Camp H. J. M., van Haren E., Kappen F., Blaakmeer A., van der Velde G., van Langervelde F., Leuven R. S. E. W., van Alen T., 2020 Impact of the invasive alien topmouth gudgeon (*Pseudorasbora parva*) and its associated parasite *Sphaerothecum destruens* on native fish species. Biological Invasions 22:587–601.
Steinhart G. B., Marschall E. A., Stein R. A., 2004 Round goby predation on smallmouth bass offspring in nests during simulated catch-and-release angling. Transactions of the American Fisheries Society 133:121–131.
Steinhart G. B., Sandrene S., Weaver R. A., Stein E. A., Marschall, 2005 Increased parental care cost for nest-guarding fish in a lake with hyperabundant nest predators. Behavioral Ecology 16:427–434.

Strauss S. Y., Lau J. A., Carroll S. P., 2006 Evolutionary responses of natives to introduced species: what do introductions tell us about natural communities? Ecology Letters 9:357–374.
Strayer D. L., Dudgeon D., 2010 Freshwater biodiversity conservation: recent progress and future challenges. Journal of the North American Benthological Society 29:344–358.
Strayer D. L., 2010 Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future. Freshwater Biology 55:152-174.
Sukmono T., Solihin D. S., Rahardjo M. F., Affandi R., 2013 [Iktiofauna in lowland tropical forest waters, Hutan Harapan Jambi]. Jurnal Iktiologi Indonesia 13(2):161-174. [In Indonesian].
Syafei L. S., Sudinno D., 2018 [Invasive foreign fish, challenges to the sustainability of aquatic biodiversity]. Jurnal Penyuluhan Perikanan dan Kelautan 12(3):145-161. [In Indonesian].
Tamura K., Stecher G., Peterson D., Filipski A., Kumar S., 2013 MEGA6: Molecular evolutionary genetics analysis version 6.0. Molecular Biology and Evolution 2725-2729.
Thushari G. G. N., Senevirathna J. D. M., 2020 Plastic pollution in the marine environment. Heliyon 6(8):e04709.
Trewavas E., 1973 On the cichlid fishes of the genus Pelmatochromis with a proposal of a new genus for *P. congicus*; on the relationship between Pelmatochromis and Tilapia and the recognition of Sarotherodon as a distinct genus. Bulletin of the British Museum (Natural History) Zoology 26:331-419.
Umar C., Kartamihardja E. S., Aisyah, 2015 [Invasive impact of red devil fish (*Amphilophus citrinellus*) to fish diversity in inland water in Indonesia]. Jurnal Kebijakan Perikan Indonesia 7(1):55-61. [In Indonesian].
Valen F. S., Hasan V., Ottoni F. P., Nafisyah A. L., Erwinda M., Annisa A. N., Adis M. A., 2022 First country record of the bearded gudgeon Pogoneleotris heterolepis (Günther, 1869) (Teleostei: Eleotridae) from Indonesia. IOP Conference Series: Earth and Environmental Science 1036:012074.
Wagner D. L., Van Driesche R. G., 2010 Threats posed to rare or endangered insects by invasions of nonnative species. Annual Review of Entomology 55:547–568.
Witte F., Goldschmidt T., Goudswaard P. C., Ligtvoet W., Van Oijen M. J. P., Wanink J. H., 1992 Species extinction and concomitant ecological changes in Lake Victoria. Netherlands Journal of Zoology 42:214–232.
Wood K. A., Hayes R. B., England J., Grey J., 2017 Invasive crayfish impacts on native fish diet and growth vary with fish life stage. Aquatic Science 79:113–125.
*** Fishbase, 2022 List of freshwater fishes reported from Indonesia. https://www.fishbase.se/country/CountryChecklist.php?resultPage=4&what=list&trpp=50&c_code=360&sortby=alpha2&ext_CL=on&ext_pic=on&vhabitat=fresh

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