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Distributional Mapping and Impacts of Invasive Alien Fish in Indonesia: An Alert to Inland Waters Sustainability

(Pemetaan Taburan dan Kesan Ikan Asing Invasif di Indonesia: Amaran terhadap Kelestarian Perairan Darat)

RAHMI DINA[1,*], GEMA WAHYUDEWANTORO[2], SEKAR LARASHATI[1], SITI AISYAH[1], LUKMAN[1], SULASTRI[1], IMROATUSHSHOOLIKHAH[1] & SOPIAN SAURI[3]

[1]Research Center for Limnology and Water Resources, National Research and Innovation Agency (BRIN), Kawasan Sains dan Teknologi Soekarno, Jalan Raya Bogor Km.46, Bogor, West Java, Indonesia 16911
[2]Research Center for Biosystematics and Evolution, National Research and Innovation Agency (BRIN), Kawasan Sains dan Teknologi Soekarno, Jalan Raya Bogor Km.46, Bogor, West Java, Indonesia 16911
[3]Directorate of Scientific Collection Management, National Research and Innovation Agency (BRIN), Kawasan Sains dan Teknologi Soekarno, Jalan Raya Bogor Km. 46, Bogor, West Java, Indonesia 16911

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ABSTRACT

Inland water ecosystems in Indonesia face an increasing threat of alien and invasive alien fish species. Their existence have been found in Indonesian waters since before 1900, and their introduction is rapid and ongoing. In this review, we mapped the distribution of alien and invasive alien fish in different inland waters ecosystem types and islands in Indonesia, based on available literature indexed by Google Scholar. Impacts of invasive alien fish and how to control them are also discussed. This data mining exercise resulted in the successful mapping of alien and invasive alien fish in 72 lakes and 57 river systems, covering 28 provinces. A total of 50 species have spread with different compositions in each type of ecosystem and island. *Oreochromis niloticus* is the most commonly encountered alien species. Moreover, invasive cichlid fish are most frequently found in lakes, while *Pterygoplichthys* spp. are more frequently found in rivers although they can also inhabit many lakes. Java Island is a hotspot of alien and invasive alien fish distribution, with 39 species reported. Invasive alien fish harm native and endemic fish in Indonesia through competition for food, space and direct predation. The gradual reduction of established populations of invasive alien species is necessary to protect Indonesia's freshwater ecosystems.

Keywords: Distribution; exotic; fish; harmful; Indonesia

ABSTRAK

Ekosistem perairan darat di Indonesia menghadapi ancaman yang semakin meningkat daripada spesies ikan asing dan ikan asing invasif. Kewujudan mereka telah ditemui di perairan Indonesia sebelum tahun 1900 dan pengenalan mereka adalah pantas dan masih lagi berterusan. Dalam kertas ini, kami memetakan taburan ikan asing dan ikan asing invasif dalam beberapa jenis ekosistem perairan darat yang berbeza di Indonesia, berdasarkan kesusasteraan tersedia yang telah diindeks oleh Google Scholar. Kesan ikan asing invasif dan cara mengawalnya juga dibincangkan. Latihan perlombongan data ini berjaya menghasilkan pemetaan ikan asing dan ikan asing invasif di 72 tasik dan 57 sistem sungai, meliputi 28 wilayah. Sebanyak 50 spesies telah tersebar dengan komposisi yang berbeza dalam setiap jenis ekosistem dan pulau. *Oreochromis niloticus* ialah spesies asing yang paling biasa ditemui. Selain itu, ikan cichlid invasif paling kerap ditemui di tasik, manakala *Pterygoplichthys* spp. lebih kerap ditemui di sungai walaupun ia juga boleh mendiami kebanyakan tasik. Pulau Jawa ialah kawasan tumpuan pengedaran ikan asing dan ikan asing invasif, dengan 39 spesies yang telah dilaporkan. Ikan asing invasif membahayakan ikan asli dan ikan endemik di Indonesia melalui persaingan untuk makanan, ruang dan pemangsaan secara langsung. Pengurangan populasi spesies asing invasif secara beransur-ansur adalah perlu untuk melindungi ekosistem air tawar Indonesia.

Kata kunci: Berbahaya; eksotik; ikan; Indonesia; pengedaran

INTRODUCTION

Alien or exotic species are non-indigenous species found outside their native range due to human activity, whether introduced intentionally or accidentally. Invasive species are alien species that have become established in a new habitat and negatively impact the economy, ecology, or human health (Atkinson & Domske 2015; IUCN

2017; Lodge et al. 2006). The rate of translocation of aquatic biota continues to increase globally. Freshwater ecosystems are at greatest risk of the negative impacts of invasive alien species, and are particularly prone to biodiversity loss (Gherardi 2010; Havel et al. 2015; Thomaz et al. 2015).

The species-rich freshwater ecosystems of Indonesia are not spared from this threat where of the 1,248 fish species recorded, approximately 400 are endemic (Hubert et al. 2015; Widjaja et al. 2014). *Cyprinus carpio*, an alien fish originating from China, for example, was first recorded in Indonesia prior to 1900 (Eidman 1989) and 16 species were intentionally introduced (Kottelat et al. 1993). Currently there are approximately 247 alien fish species in Indonesia, found both in ornamental fish shops and in open waters (Nuringtyas et al. 2018; Said & Hidayat 2005; Wahyudewantoro & Haryono 2016; Widjaja et al. 2014). The negative impacts of invasive alien fish on inland waters in Indonesia are evident. For instance, Lake Matano, an ancient lake with high biota endemicity, has been invaded by a hybrid cichlid (Luohan) and other invasive alien fish. Luohan has invaded through direct predation on endemic species as well as resources competition (Glaubrecht & von Rintelen 2008; Hedianto & Sentosa 2019; Hedianto et al. 2018; Herder et al. 2012; Sulastri et al. 2020).

Previously, alien and invasive alien fish in Indonesia in general and the negative impacts of certain species have been reviewed by some authors. The threat of invasive alien fish to native fish biodiversity, the status of invasive alien species in Indonesia - including ornamental fish traded in aquaria fish shops - have been generally discussed (Syafei & Sudinno 2018; Umar & Sulaiman 2013; Wargasasmita 2005). The impact of red devil fish (*Amphilophus citrinellus*) and *Pterygoplichthys* spp. have also been reviewed (Umar et al. 2015; Wahyudewantoro 2018). Recently, the global distribution of *Pterygoplichthys* spp. and habitat suitability of *Pterygoplichthys pardalis* and *Pterygoplichthys disjuntivus* in Indonesia have been modelled and mapped (Orfinger & Goodding 2018; Patoka et al. 2020).

However, these articles have not addressed the detailed distribution of all alien and invasive alien fish species inhabiting inland waters. Therefore, in this review, we focus on identifying the extent of alien and invasive alien fish distribution in Indonesia's inland waters based on the inland waters ecosystem type (lentic or lotic) and geographical boundaries. The empirical impacts of these fish in the invaded ecosystem are reviewed, and control measures are suggested. This review focuses solely on alien and invasive alien species that originated outside Indonesia. Local translocations of Indonesian species also occur and have negative impacts on freshwater ecosystems; however, these species are beyond the scope of this manuscript. The results of this study are expected to provide information about the current situation of invasive alien fish in Indonesian inland waters and contribute to the relevant stakeholders for preventing and reducing invasive alien fish.

Materials and Methods

Research articles indexed by Google Scholar from 1998 until mid of 2021 were reviewed to obtain relevant geographical information and to map the distribution of alien and invasive alien fish in Indonesia. A free access software, Harzing's Publish or Perish (Harzing 2007), was used to explore related papers. We have used Indonesian and English keywords that were expected to cover alien and invasive alien fish in two types of ecosystems (standing and running waters) in Indonesia. Data mining was carried out in several stages. In the first stage, the search terms with Indonesian were '*ikan asing, ikan introduksi, ikan invasif, Indonesia'*, '*jenis ikan, danau, waduk*', and '*jenis ikan, sungai, Indonesia'*, while keywords in English were 'alien fish, non-native fish, introduced fish, Indonesia, river, lake, reservoir'. The initial screening showed that the 15 priority lakes or the provinces on the main islands were not included yet. Further, the search was supplemented with keywords in Indonesian that included certain lakes or provinces. A total of 12 searches were performed and can be referred in Supplementary Figure 1.

The reviewed research articles consisted of peer-reviewed published papers, proceedings, and unpublished work such as student theses (full theses or abstracts) and technical reports from the Ministry of Marine Affairs and Fisheries (http://bp3upalembang.kkp.go.id/laporan_teknis). A total of 174 pieces of literature reported the occurrence of alien or invasive alien fish in 72 standing water ecosystems (lakes, reservoirs, and swamp) and 57 running water ecosystems distributed in 28 of 34 provinces (see Supplementary Table 1 materials for details).

Next, the fish species reported from each location were categorised as alien or native species according to Froese and Pauly (2021), Kottelat et al. (1993), and Wahyudewantoro and Rachmatika (2016). Furthermore, the invasive categorisation of alien fish referred to the Regulation of the Ministry of Marine Affairs and Fisheries of the Republic of Indonesia Number 19/Permen-Kp/2020

concerning the Prohibition of Importation, Culture, Distribution, and Release of Dangerous or Harm Fish Species to and from the Fishery Management Territory of the Republic of Indonesia (KKP 2020).

Results

Distribution of alien and invasive alien fish in Indonesia

Analysis of the 174 research articles suggested that a total of 50 species of alien and 18 of them are invasive fish. These fish are belonging to eight orders and ten families, inhabit Indonesia's freshwater ecosystems with a large proportion of these species found in lakes (see Supplementary Table 2 for details).

Alien and invasive alien fish compositions were different in each province and can be referred to Figure 1. In total by island, the highest number of alien and invasive alien fish was reported on Java Island of 39 species, followed by Sumatra (23 species), Sulawesi (15 species), Bali (11 species), Lombok, West Nusa Tenggara (10 species), Papua (8 species), Kalimantan (7 species), Sumbawa, West Nusa Tenggara and Sumba, East Nusa Tenggara (3 species). Alien fish species, particularly those that were introduced for the purpose of consumption, such as *Cyprinus carpio*, *Oreochromis mossambicus*, *Oreochromis niloticus,* and *Trichopodus pectoralis*, have spread throughout Indonesia and can be refer from Figure 1.

Likewise, invasive alien fish species have been detected on most islands. Notable exceptions include a lack of invasive alien cichlid species in Kalimantan and a lack of sailfin catfish in Papua.

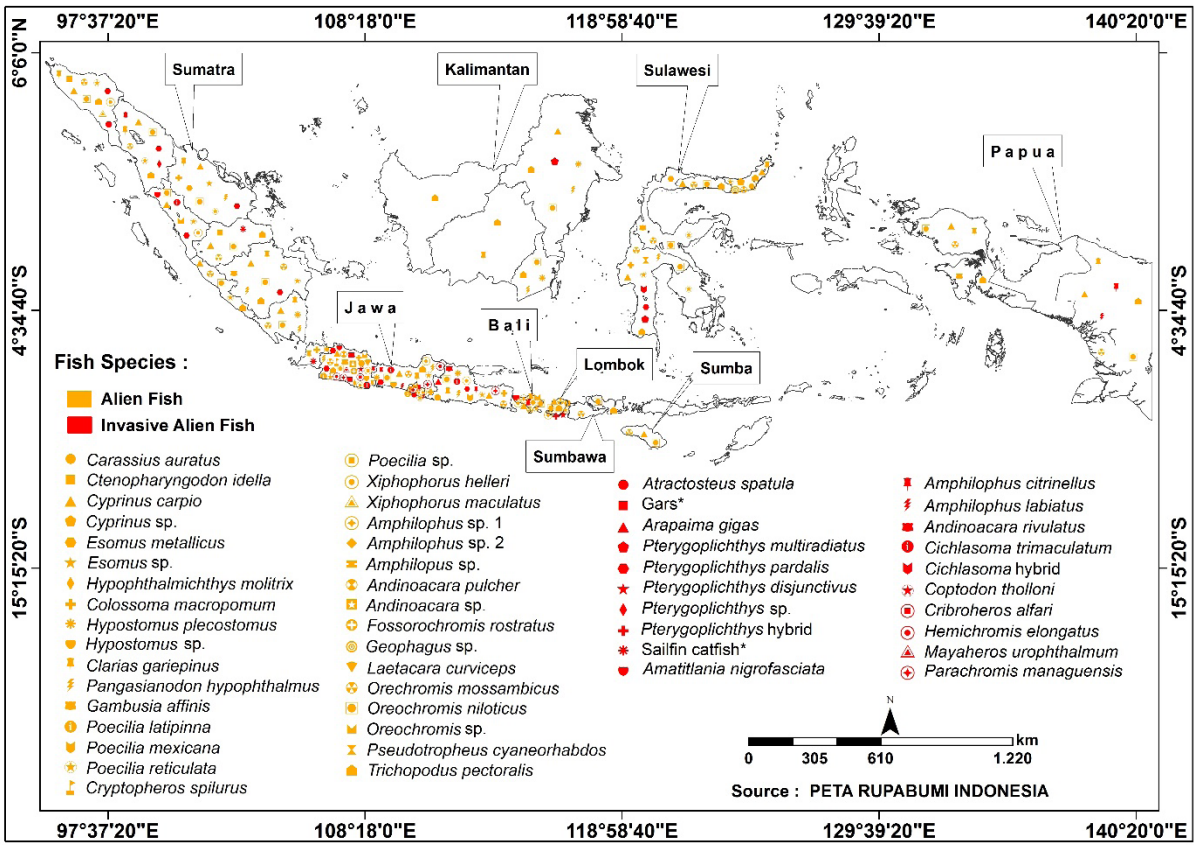

FIGURE 1. Map of alien and invasive alien fish distribution in Indonesia

Discussion

Distribution of alien and invasive alien fish in Indonesia

This study identified larger number of alien and invasive alien fish found in inland water ecosystems compared to reports by Wargasasmita (2005) (19 species) and Syafei and Sudinno (2018) (13 species), although it is smaller than Wahyudewantoro and Rachmatika (2016) (55 species) and Nuringtyas et al. (2018) (247 species), who included ornamental species traded in the aquaria industry.

The alien species most commonly found in lakes and rivers were *Oreochromis niloticus*, *O. mossambicus*, *Cyprinus carpio, Trichopodus pectoralis, Clarias gariepinus, Pangasianodon hypophthalmus, Poecilia reticulata,* and *Xiphophorus helleri*. For example, *O. niloticus* was found in 73% of lakes that were sampled and in 68% of rivers.

Some species were initially introduced for commercial purposes, namely *Oreochromis niloticus, O. mossambicus, Cyprinus carpio, Trichopodus pectoralis, Clarias gariepinus*, and *Pangasianodon hypophthalmus*, whilst the remainder were released as ornamental fish. These alien species have long existed in Indonesia; *Cyprinus carpio* from China has been present in the freshwater ecosystems of Indonesia since before 1900 and continues to be introduced (Eidman 1989). The guppy, *Poecilia reticulata*, is one of the world's most popular aquarium fish and has escaped or been introduced into rivers and lakes all over the tropics. By 1929 it was present in the majority of the ponds and ditches in West Java. *Oreochromis mossambicus* was first discovered in the Serang River, Java Island in 1939 (Costa-Pierce et al. 1988), *O. niloticus* was first introduced in 1969 (Kottelat et al. 1993), *Pangasianodon hypophthalmus* in 1972 (Darmawan et al. 2016), and *Clarias gariepinus* in 1985 (Iswanto et al. 2015). *Oreochromis niloticus, O. mossambicus,* and *Cyprinus carpio* are three of the ten most frequently introduced fish species globally and have negatively impacted ecosystems in 75 to 86% of the countries where they are deemed invasive (Gherardi 2010).

Other species, including the grass carp *Ctenopharyngodon idella* and the silver carp *Hypophthalmichthys molitrix,* were deliberately introduced for experimental purposes in the 1940s and 1960s, respectively. The aquaculture potential of *C. idella* and the performance of *H. molitrix* to utilise plankton more efficiently were studied (Eidman 1989). Later, grass carp were introduced into Lake Kerinci, Sumatra in 1995 to eradicate a water hyacinth (*Eichornia crassipes*) explosion (Umar & Sulaiman 2013). The silver carp grew rapidly in ponds in West Java, but the fish farmers experienced marketing challenges and did not continue farming this species (Emmawati et al. 2005).

Notably, the dominant invasive alien fish at the two different ecosystems are markedly dissimilar. The most common invasive alien fish in lentic ecosystems are cichlids, while in rivers sailfin catfish dominate. Invasive cichlids occur in 31% of lakes and sailfin catfish in 35% of rivers. Sailfin catfish appear highly adaptable and also inhabit 20% of lakes, whereas invasive cichlids are only found in 14% of rivers. Cichlidae is a large family comprising between 1,300 and 1,900 species (Froese & Pauly 2021). Originating from South and Central America, Africa, Asia Minor, India, and Sri Lanka, many species are farmed for the aquarium market and for fish production (Britannica 2017; Froese & Pauly 2021; Kottelat et al. 1993). Generally, cichlids prefer a lentic ecosystem or slow-moving area of rivers, although some species are found in flowing waters (Joanna 2021).

The sailfin catfish is a tropical fish originated from the Amazon River basin, South America (Froese & Pauly 2021; Kottelat et al. 1993) where it inhabits a variety of lotic and lentic habitats (Hoover 2004). This fish, popular with aquarists, is now also found extensively beyond its natural habitat. Kottelat et al. (1993) reported aquaria or breeding ponds, particularly around Jakarta, to be the primary sources of sailfin catfish, a species that has now spread to almost all regions of Indonesia. The habitat suitability model shows that most of Indonesia's waters are suitable for the establishment of *Pterygoplichthys pardalis*, while more limited habitat for *Pterygoplichthys disjuntivus* (Patoka et al. 2020). The spread of invasive cichlids is equally concerning; cichlids have been detected in lakes containing high numbers of endemic species, including Lake Matano in South Sulawesi and Lake Sentani in Papua (Herder et al. 2012; Ohee et al. 2018). The widespread distribution of these invasive fish is highly concerning due to the harm they inflict. For instance, the main negative impacts of *Pterygoplichthys* spp. on the environment are the destruction of ecosystems and resources competition with native species. Furthermore, the major socioeconomic impact is the decline of other commercial fisheries resources catch (Orfinger & Goodding 2018).

In this review, we assessed the distribution of 18 invasive alien fish species in Indonesia's inland waters, from a total of 50 alien fish species identified from research articles. It is possible that the number of alien and invasive alien fish species is higher than recorded in

this review, and their distribution in Indonesia's inland waters more widespread. This could arise if publications were not indexed by Google Scholar or have not yet been published. The continued monitoring of Indonesian inland waters is essential for tracking the number and distribution of alien and invasive alien species in these important habitats. More, the presence of alien fish species – species which have not yet been determined invasive in government regulation – should be regularly monitored to determine any impacts. Those species, such as *H. plecostomus* and *O. niloticus*, have negatively affected the native fish and habitat at invaded ecosystems. In Malaysian waters, *H. plecostomus* and *O. niloticus* have dominated the ecosystem and could effectively reduce the native species. Further, the burrowing behaviour of *H. plecostomus* could worsen the bank erosion (Ahmad et al. 2020; Hoover 2004).

IMPACTS OF INVASIVE ALIEN FISH IN INDONESIA'S FRESHWATER ECOSYSTEMS

The potential of an alien fish species to become an invasive species depends on its biological characteristics (Geiger et al. 2005). Characteristics associated with invasive species are: high dispersal capability through seeds, eggs, or highly mobile larval stages; an ability to reproduce both sexually and asexually; high fecundity; short generation and juvenile development times; rapid adaptation to environmental stress; high tolerance to environmental heterogeneity; desirability to, and association with, humans (edibility, game species); omnivorous; and demonstrate brood care. Species exhibiting more of these characteristics have the greatest potential to become invasive. Subsequently, the success of invasive species is further influenced by characteristics of the habitat (Gherardi 2010). Attributes that make a habitat vulnerable to invasive species are climate suitability, extent of disturbance of the habitat, low biodiversity, absence of predators, the presence of empty niches, and low food web connectivity.

The entry of alien fish species into aquatic ecosystems can directly affect native fish through predation, competition for food resources, and competition for habitat in both nursery and spawning grounds. Indirectly, invasive species affect the processes in aquatic ecosystems (Erarto & Getahun 2020). The latter impacts of invasive species include biodiversity loss following the extinction of endemic and native fish species, decreased water quality, and degradation of ecosystem services (Krantzberg 2019). These negative impacts have been observed in Indonesia's freshwater ecosystems and can be referred from Table 1.

Luohan, a hybrid cichlid where the parental are composed of '*Cichlasoma'*, *Amphilophus,* and *Paraneetroplus* (*Vieja*) (Herder et al. 2012) - the most dominant invasive alien species in Lake Matano, an ancient lake with high endemicity - has spread rapidly (Herder et al. 2012) and become dominant, constituting 42-52% of the total catch from the lake (Hedianto & Sentosa 2019; Nasution & Dina 2019). The reproductive attributes of Luohan including their parental care habits, ability to reproduce in various substrate types, partial spawning, and year-round spawning (Hedianto et al. 2018) facilitated their rapid increase in abundance. Luohan in Lake Matano inhabit all substrate types and depths (Hedianto et al. 2018; Sulastri et al. 2020) and overlap with the habitats of endemic biota such as *Telmatherina* spp. and *Glossogobius matanensis*. Furthermore, a study of the trophic interactions of the Lake Matano fish community indicated that Luohan had similar feeding habits and competed with these endemic fish species for prey. Luohan also preyed directly on *Telmatherina* spp. and preyed on the eggs of *Glossogobius matanensis* (Hedianto & Sentosa 2019; Herder et al. 2012). In addition to threatening endemic fish species, Glaubrecht and von Rintelen (2008) found that Luohan also threaten the existence of endemic gastropods (*Tylomelania* sp.). Moreover, *Cichlasoma trimaculatum* in Sempor Reservoir grow isometrically, as they do in their natural habitat, suggesting they have adapted well to the new environment. Moreover, monthly recruitment accelerates the population increase in the reservoir (Hedianto et al. 2014).

The reproduction of *Amphilophus citrinellus* in the Djuanda Reservoir, West Java has been studied, and it is known that the fish spawn throughout the year under varying water conditions. Stomach content study showed that they feed on plankton, aquatic plant, fish, mollusc, insects, worms, fish pellets, and detritus that similar to feeding habit of native fish *Barbonymus balleroides*. Further, *A. citrinellus* abundance has also reduced the commercial catch (Tampubolon et al. 2015, 2014). A laboratory experiment of feeding habits showed that *A. citrinellus* are carnivorous and consumed all fish species offered (namely, *O. mossambicus*, *O. niloticus, Trichopodus pectoralis, Macrobrachium rosenberghii, Poecilia reticulata, Cyprinus carpio,* and *Clarias batrachus*). Their active and aggressive behaviour will exarcerbate the vulnerability of native fish populations if *A. citrinellus* are released into new wild habitat (Baskoro et al. 2009). Another species, *A. labiatus*, also spread rapidly in Lake Sentani, Papua (Ohee et al. 2018).

TABLE 1. Reported impacts of invasive alien fish in Indonesia's freshwater ecosystems

Species	Impacts	References
Luohan	- Direct predation on native, endemic species - Food and habitat competition with native, endemic species due to high abundance	Glaubrecht & von Rintelen (2008); Hedianto et al. (2018); Hedianto & Sentosa (2019); Herder et al. (2012); Sulastri et al. (2020)
Amphilophus citrinellus	- Food and habitat competition with native, endemic species due to high abundance - Reduce commercial catch	Tampubolon et al. (2015, 2014)
Pterygoplichthys spp.	- Food and habitat competition with native, endemic species due to high abundance - Damaging fishing gears	Hadiaty (2011); Hasrianti et al. (2020)
Other Cichlids (*Amatitlania nigrofasciata; Hemichromis elongatus*; *Parachromis managuensis*)	- Established population, high abundance, good performance (growth)	Hedianto & Purnamaningtyas (2011); Hedianto et al. (2013); Jayanti et al (2020); Kresnasari (2020); Rahman et al. (2012); Sentosa & Wijaya (2013)

Jayanti et al. (2020), Rahman et al. (2012), and Sentosa and Wijaya (2013) have reported the invasive cichlid *Amatitlania nigrofasciata* being dominant in Lake Beratan and Buyan, Bali. In Lake Beratan, it grows isometrically and rapidly achieving gonad maturity. *Amatitlania nigrofasciata* adapt well to variability in food availability, switching from a primary food source of insects to phytoplankton if required. This adaptability endangers native fish, particularly *Rasbora lateristriata* in Buyan and *Rasbora baliensis* in Lake Beratan, where catches of economically valuable fish have declined. The abundance of another species, *Hemichromis elongatus*, also increased rapidly and significantly in Ir. H. Djuanda reservoir, West Java (Hedianto & Purnamaningtyas 2011). *Parachromis managuensis*, which dominated the catch in Penjalin Reservoir, Central Java, is another carnivorous invasive alien species that grows isometrically (Hedianto et al. 2013; Kresnasari 2020). An explosion of *Pterygoplichthys* spp. occurred in Lake Sidenreng, South Sulawesi and resulted in the species comprising 54% of the total catch there (Hasrianti et al. 2020). As well as negatively impacting the environment, sailfin catfish also cause damage to fishing gear, such as cast net and gillnet used in the Ciliwung River (Hadiaty 2011).

In addition to fish species known to be invasive, there are many more alien species that have not yet been proven to negatively impact the economy, ecology, or human health but which possess the biological attributes that characterise invasive species. One such example, *Xiphophorus helleri,* has an isometric growth pattern, is omnivorous (Jayanti et al. 2020; Parawangsa et al. 2019), and is currently the second most abundant species in Lake Buyan. Elsewhere, *X. helleri* in Lake Tamblingan matures rapidly (Parawangsa et al. 2020). In another example, the catch of *Oreochromis niloticus* in the upper Kumbe River, which is the original habitat of Arowana fish in Papua, is now higher than of native fish species. *Oreochromis niloticus* has similar food habits to the native fish species (Sentosa & Satria 2015).

A further concern regarding the arrival of alien species in the freshwater ecosystems of Indonesia is that

alien species may host pathogens and spread disease to the populations of native fish species. In the 1980s, common carp in the Bogor region of Indonesia were affected by a disease outbreak caused by the pathogenic bacteria *Aeromonas salmonicida* and *A. hydrophilia* and a virus. The outbreak, the first of its kind, also infected the native fish species *Osphronemus goramy* and *Clarias batrachus*. Although the pathogens' origin could not be ascertained, this event raised the government's awareness of the negative impacts of the introduction of fish (Eidman 1989). The Koi Herpes Virus (KHV) outbreak, which first appeared in the UK in 1996, also reached Indonesia in 2002 via the international fish trade (Wasito et al. 2013). The arrival of KHV caused a deadly outbreak of disease with 80-95% mortality in common carp and Koi fish culture within two weeks (Sumiati & Sunarto 2012).

Alien fish species also reduce aquatic ecosystem services. For example, Kodiran et al. (2020) conducted an economic analysis of the impact of alien freshwater crayfish (*Cherax quadricarinatus* and *Procambarus clarkii*) in Lake Lido, West Java. *Cherax quadricarinatus* were predicted to compete with the native species *M. sintangense* for food resources, whilst *P. clarkii* were predicted to compete with the native species *M. rosenbergii.* As such, the economic cost of the loss of the native species resulting from the introduction of these two alien species was estimated to be between IDR785 and IDR1,417 per individual.

CONTROL OF INVASIVE ALIEN FISH IN INLAND WATERS ECOSYSTEM

Gherardi (2010) outlined three steps for handling alien species in accordance with the biodiversity convention. Firstly, efforts must be made to prevent introductions and translocations. Secondly, efforts must be made to immediately eradicate any established populations of invasive species. Lastly, where the available resources are limited and immediate eradication is not feasible, efforts should be made to gradually reduce the population of invasive species.

The Indonesian government, through the relevant ministries, has issued several regulations to help prevent the introduction of invasive fish species to inland waters. The first regulation, through the Decree of the Minister of Agriculture 179/Kpts/Um/3/1982, prohibits the entry of seven dangerous fish species from abroad into the territory of the Republic of Indonesia (Hadiaty 2007). Regulations are continuously updated through the Regulation of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia Number PER.17/MEN/2009 (KKP 2009), refined to Number 41/PERMEN-KP/2014 (KKP 2014), and, most recently, Number 19/PERMEN-KP/2020 (KKP 2020). A total of 71 species of invasive fish are prohibited by the latest Ministerial regulation. The import, culture, distribution, and export of these species are all restricted. Furthermore, imported fisheries commodities must meet the requirements of the current regulations including having a health certificate issued by a competent authority in the country of origin and an entry permit from the Directorate General of Aquaculture, Ministry of Marine Affairs and Fisheries. Import is further limited to particular designated points and contact must be made with a designated officer immediately upon arrival to fulfil quarantine measures (KKP 2021).

The negative impacts of invasive species have been proven for a long time, both globally and within Indonesia. Despite the preventative measures stipulated by current regulations, the release of alien species into inland waters still occurs. A thorough and long-term campaign to raise public awareness of the dangers of releasing alien species into public waters is urgently required. A study of public awareness in northern Wisconsin, USA showed that people involved in lake-based recreation, members of a lake association, and people who were college-educated were the most aware of the invasive species that threaten freshwater ecosystems (Eiswerth et al. 2011). People outside these groups need to be educated about invasive alien species. In addition, promoting native fish instead of alien as ornamental fish needs to be encouraged, given that all invasive fish currently observed are exotic ornamental fish.

At present, many species of invasive alien fish have established populations in Indonesia's freshwater ecosystems and should be eradicated or controlled. The best documented account of eradication is the removal of *P. parva* from five lakes in England and Wales. The procedure used was extremely expensive despite the small areas of water being treated and this approach is unlikely to be extended to wider water basins (Gherardi 2010). The geographical conditions of Indonesia, the widespread distribution of invasive alien fish species, and the limited availability of infrastructure and human resources, all present considerable challenges to the 'rapid eradication' approach. Instead, the gradual reduction and control of invasive alien species appears more feasible.

One possible approach to this objective is to apply intensive fishing effort using selective fishing gear. For Luohan in Lake Matano, for example, it is recommended to catch fish before they attain length at first maturity which is about 10 and 13.3 cm for red devil in Ir. H.

Djuanda reservoir (Hedianto et al. 2018; Tampubolon et al. 2015). Awareness to carry out intensive fishing should be built at the government to the community level. For instance, the need for an action plan from the relevant ministries in the priority locations, particularly. Equally important, it is necessary to inform fishers or anglers to kill the caught invasive alien fish. The socio-economic impact such as the decline catch of high economic value fisheries resources needs to be intensively warned. Hopefully, such efforts will trigger the fishers to catch the invasive alien fish voluntarily.

Some invasive alien fishes such as sailfin catfish have been utilized, for consumption or livestock feed due to the good nutritional content (Hadiaty 2011; Hasnidar 2021; Patoka et al. 2020). Similarly, *Amphilophus labiatus* in Lake Sentani is consumed by the local community (Ohee & Budi 2021). On the other hand, the quality of invasive alien fish must first be assessed. Sailfin catfish meat from the Ciliwung River contained several heavy metals that exceeded the maximum limits for fishery meat products specified by BPOM in 2017 (Ismi et al. 2019).

However, caution is needed in promoting the use of invasive alien fish. It needs to be emphasized that the main aim is to gradually reduce invasive alien fish population. In the future, maintaining efforts of those considered beneficial populations must be avoided.

Conclusion

The threat of biodiversity loss from Indonesian freshwater ecosystems is increasing due to the rising number of alien fish species in lakes and rivers. The most successful invasive alien species are ornamental cichlids, which frequently inhabit lakes, and sailfin catfish, which inhabit both lakes and rivers. Whilst Java Island is a notable hotspot, invasive alien species have been recorded throughout Indonesia. The negative effects of invasive alien fish on the biodiversity of Indonesia's inland waters have been observed and, in the future, the release rate of ornamental fish into public waters must be reduced. One way to achieve this is to increase public awareness of the threat posed by alien species to the native and endemic species of Indonesia's freshwater ecosystems.

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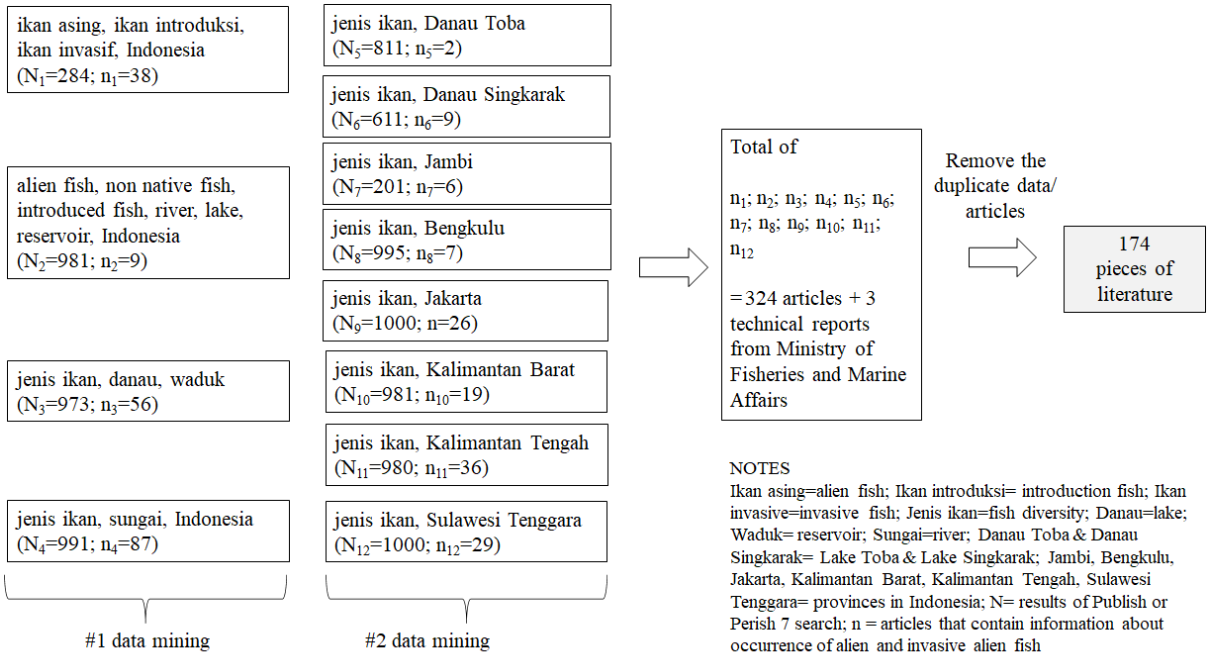
*Corresponding author; email: rahm027@brin.go.id



SUPPLEMENTARY FIGURE 1. Steps of literature search and list and distribution of alien and invasive alien fish detected locations

SUPPLEMENTARY TABLE 1. List of locations

Sumatra

Lake

1. Lake Laut Tawar (Marini & Fahmi 2015, Muchlisin 2012)

2. Lake Ie Sayang (Astuti & Nufus 2019)

3. Lake Toba (Dina et al. 2018; Tjahjo et al. 1998; Wijopriono et al. 2010)

4. Koto Panjang Reservoir (Warsa et al. 2008)

5. Lake Maninjau (Roesma 2013; Samir et al. 2021)

6. Lake Singkarak (Lubis et al. 2013)

7. Lake Kerinci (Samuel & Suryati 2014; Suryati et al. 2013)

8. Lake Tes (Binur 2008)

9. Watervang Reservoir (Harahap et al. 2020)

10. Teluk Gelam Swamp (Samuel et al. 2002)

11. Lake Gegas (Utomo et al. 2020)

12. Lake Ranau (Sumino et al. 2017; Wulandari et al. 2019)

13. Simpang Reservoir (Muchlisin 2012)

River

1. Krueng River System
- Aceh River (Muchlisin 2012)

2. Ligan River System
- Lagean River (Muchlisin 2012)

3. Samalanga River System
- Batee Iliek River (Muchlisin 2012)

4. Kluet River System
- Kluet River (Mardianti et al. 2017)

5. Meurebo River System
- Tujoeh River Buloh River Pucuk Laot River and Meurebo River (Nasir 2014)

6. Peusangan River System
- Wih Pesangan River (Marini & Fahmi 2015)

7. Singkil River System
- Alas River (Maghfiriadi et al. 2018)
- Sopokomil River (Simanjuntak 2012)

8. Percut River System
- Percut River (Safitri 2017)

9. Asahan River System
- Asahan River (Simanjuntak 2013)

10. Batang Gadis River System
- Batang Gadis River (Atifah & Lubis 2017)

11. Siak River System
- Tapung Mati River (Pulungan & Safrina 2014)
- Air Hitam River (Pinem et al. 2014)
- Tenayan River (Pulungan 2012)
- Ukai River (Pulungan 2011)
- Umban Sari River (Pasaribu et al. 2020)

12. Kampar River System
- Kampar Kanan River (Fithra & Siregar 2010)
- Kampar River (Husnah & Aida 2005)

13. Masang Kiri River System
- Batang Durian (Cindy et al. 2017)

14. Batanghari River System
- Batang Bungo River (Syaputra et al. 2017)

- Batanghari River (Paramudita et al. 2020, Purwoko et al. 2020)
- Terap River (Arpiagam et al. 2017)

15. Lais River System
- Lais River (Pariyanto et al. 2021)

16. Manna River System
- Air Manna River (Pariyanto et al. 2021)

17. Musi River System
- Muara Batun River (Makri 2018)
- Musi River (Bahri 2007; Eddy et al. 2012)
- Rawas River (Mutiara & Sahadin 2017, Samuel & Adjie 2008)
- Kelingi River (Samitra & Rozi 2018)
- Lempuing River (Dharmadi et al. 2009)
- Padang River (Mutiara 2017)

Java

Lake	River
14. Sempor Reservoir (Purnomo et al. 2013)	18. Cimadur River System - Cimadur River (Rachmatika et al. 2004)
15. Rawa Pening (Weri & Sucahyo 2017)	19. Ciujung River System - Ciujung River Ciberang River (Rachmatika et al. 2004)
16. Rawadanau (Gunawan & Jamadi 2016)	- Cidanau River (Abdurahim et al. 2004)
17. Kedung Ombo Reservoir (Aisyah & Widihastuti 2016; Adjie & Fatah 2015)	20. Cibanten River System - Cibanten River (Indaryanto et al. 2020)
18. Ir. H. Djuanda Reservoir (Hendrawan et al. 2021)	21. Cisadane River System - Cisadane River (Hadiaty 2011)
19. Cirata Reservoir (Firda 2015; Herawati et al. 2017; Tjahjo & Purnamaningtyas 2008)	22. Ciliwung River System - Ciliwung (Hadiaty 2011; Rosnaeni. et al. 2017)
20. Telaga Sari (Rahayu et al. 2019)	23. Cimandiri River System - Cipelang River (Robin & Supendi 2016)
21. Karangkates Reservoir (Amin et al. 2019; Hasan et al. 2020; Mingka 2013)	24. Ciletuh River System - River Ciletuh (Bunga 2015)
22. Lahor Reservoir (Amin et al. 2019; Mingka 2013)	25. Cisadea River System - Cisadea River (Paujiah et al. 2013)
23. Galunggung Cauldron (Haryono & Wahyudewantoro 2020)	26. Citarum River System - Citarum River (Sugianti & Astuti 2018)
24. Penjalin Reservoir (Hedianto et al. 2013; Setyaningrum et al. 2021)	27. Cimanuk River System - Cimanuk River (Amirullah et al. 2012; Herawati et al. 2020; Sjafei et al. 2001) - Cibaranangsiang River (Rachmatika & Wahyudewantoro 2006)
25. Situ Panjalu (Warsa & Purnomo 2012)	
26. Ranu Klindungan Grati (Munawaroh 2021)	
27. Situ Bagendit (Nurfiarini & Purnomo 2017)	

28. Situ Cilala (Pratiwi et al. 2015)

29. Telaga Warna (Sulistiono et al. 2010)

30. Cacaban Reservoir (Miftahurrohman et al. 2016)

31. Darma Reservoir (Tjahjo & Purnamaningtyas 2004)

32. Jatigede Reservoir (Nurhayati et al. 2020)

33. Malahayu Reservoir (Purnomo & Warsa 2011)

34. Sermo Reservoir (Djasmani & Djumanto 2014; Suryandari et al. 2021)

35. Sumengko Reservoir (Arviani et al. 2018)

36. Wadaslintang Reservoir (Kurnia et al. 2017)

37. Wonogiri Reservoir (Kartamihardja et al. 2011)

38. Situ Babakan (Wati 2008)

39. Danau Kampus IPB (Hadiaty 2007)

28. Ciwulan River System (Haryono & Wahyudewantoro 2020)
- Cibukur stream (upper)
- Drainage system
- Cibukur stream (lower parts 1)
- Cipongkor stream
- Cikunir stream
- Cibukur stream (lower parts 2)
- Citunggul stream

29. Citanduy River System
- Cikawung River (Nuryanto et al. 2015)
- Rivers in Gunung Sawal area (Haryono 2017)
- Rivers in Galunggung area (Haryono & Wahyudewantoro 2020)
- Cijalu River (Nuryanto et al. 2016)

30. Serayu River System
- Serayu River (Haryono 2012; Haryono et. al 2014; Romdhon et al. 2015)
- Pelus River (Susanto 2019)
- Banjaran (Prayitno & Rukayah 2019)
- Klawing River (Pramono et al. 2018)
- Rivers in Gunung Slamet area (Haryono 2012)

31. Juwana River System
- Juwana River (Purwanto et al. 2014)

32. Luk Ulo River System
- Luk Ulo River (Wahyuni & Zakaria 2018)

33. Progo River System
- Elo River (Darma & Putra 2020)

34. Pening River System
- Damar River (Riharista et al. 2013)

35. Garang River System
- Kreo River (Astuti 2015)
- Kaligarang River (Aprilliyani 2020)

36. Mangkang Barat River System
- Beringin River (Yuliawati 2019)

37. Bengawan Solo River System
- Bengawan Solo (Adjie & Utomo 2017; Utomo et al. 2006)

38. Opak-Oyo River System
- Code River (Trijoko et al. 2016)
- Opak River (Djumanto & Probosunu 2011; Yudha et al. 2020)

39. Brantas River System
- Kali Surabaya (Mahmud 2019)
- Brantas (Fadjar et al. 2019; Hayati et al. 2017; Serdiati et al. 2020; Valiant 2014)

40. Bedadung River System
- Bedadung River (Munandar & Eurika 2016)

Kalimantan (Borneo)

Lake	River
40. Lake Semayang (Suyatna et al. 2017)	41. Kapuas River System - Kapuas River (Adjie & Utomo 2011)
41. Lake Panggang Swamp (Agusliani & Dharmaji 2017)	42. Kumai River System - Sekonyer River (Nurudin et al. 2013)
42. Lake Talan (Burnawi 2009)	43. Seruyan River System - Seruyan River (Pangestu & Siswanto 2020)
43. Lake Bangkau (Rahman et al. 2010)	44. Kahayan River System - Rungan River (Suraya & Haryuni 2013)
44. Upau Swamp (Ulimaz 2020b)	45. Barito River System - Barito (Asyari 2006; Bahri 2009; Prasetyo 2006) - Martapura River (Iriansyah et al. 2021)
45. Lake Jalan Pangen (Decenly et al. 2014)	46. Tabunio River System - River in Sungai Bakar village (Ulimaz 2020a)
46. Lake Purun (Decenly et al. 2014)	47. Sawangan River System - Batang Banyu River (Ermawati et al. 2017)
47. Lake Bulat (Decenly et al. 2014)	48. Mahakam River System - Mahakam River (Kasim et al. 2015) - Lempake Tepian River (Purwati et al. 2021) - Separi River (Sukarti et al. 2013)
48. Lake Panggu Alas (Decenly et al. 2014)	

Sulawesi

Lake	River
49. Lake Matano (Hedianto & Sentosa 2019; Herder et al. 2012; Samuel et al. 2017)	49. Maros River System - Pattunuang River, Bantimurung River, Pucak River, Batubessi River (Nur et al. 2019)
50. Lake Talaga (Herjayanto et al. 2019; Putri et al. 2015)	50. Konaweha River System - Pohara River (Parenti et al. 2014)
51. Lake Bolano (Herjayanto et al. 2019)	
52. Lake Lindu (Herjayanto et al. 2019, Zainal et al. 2017)	
53. Lake Poso (Herjayanto et al. 2019)	
54. Lake Rano (Herjayanto et al. 2019)	
55. Lake Sibili (Herjayanto et al. 2019)	
56. Lake Kalimpa'a (Tambing)(Herjayanto et al. 2019)	
57. Lake Tempe (Dina et al. 2020, 2019; Nasrul 2016)	

58. Lake Limboto (Haryono 2004; Hermanto et al. 2013; Krismono & Kartamihardja 2010)

59. Lake Towuti (Samuel et al. 2017)

60. Lake Tondano (Haryono 2004; Jamlean et al. 2018; Makmur et al. 2015)

61. Lake Moat (Haryono 2004)

62. Lake Sidenreng (Andy Omar et al. 2020; Dewi et al. 2020)

63. Lake Buaya (Andy Omar et al. 2020)

64. Bilibili Reservoir (Amir 2006)

Papua

Lake	River
65. Lake Sentani (Ohee et al. 2019; Ohee & Keiluhu 2018)	51. Digoel River System - Digoel River (Buhdy et al. 2018)
66. Lake Paniai (Samuel et al. 2018)	52. Kumbe River System - Kumbe River (Sentosa & Satria 2013; Ulukyanan et al. 2019)
	53. Merauke River System - Wanggo River (Laratmase et al. 2019) - Maro River (Sugianti & Satria 2017)
	54. Prafi River System - Nimbai River (Manangkalangi & Kaliele 2011)
	55. Sorong River System - Mariat River (Hidayah et al. 2020)

Bali

Lake

67. Lake Batur (Sentosa et al. 2016)

68. Lake Beratan (Sentosa et al. 2016)

69. Lake Buyan (Pertami et al. 2019; Sravishta et al. 2017)

70. Lake Tamblingan (Pertami et al. 2019)

Nusa Tenggara

Lake	River
71. Batu Jai Reservoir (Siswanta et al. 2020; Patoka et al. 2020)	56. Belimbing River System - Belimbing River (Sari et al. 2019)
72. Taliwang Reservoir (Tjahjo & Purnomo 1998)	57. Kambaniru River System - Kambaniru River (Siswanta et al. 2020)

SUPPLEMENTARY TABLE 2. List of alien and invasive fish and their frequency of occurrence in lakes and rivers

No	Ordo	Family	Genus	Species	Type	Occurrence Frequency (%)	
						Lake	River
1	Cypriniformes	Cyprinidae	*Carassius*	*Carassius auratus*	Alien	2.8	1.8
2			*Ctenopharyngodon*	*Ctenopharyngodon idella*	Alien	5.6	1.8
3			*Cyprinus*	*Cyprinus carpio*	Alien	46.5	28.1
4				*Cyprinus* sp.	Alien	1.4	
5				*Esomus metallicus*	Alien		1.8
6				*Esomus* sp.	Alien		1.8
7				*Hypophthalmichthys molitrix*	Alien	2.8	
8	Characiformes	Serrasalmidae	*Colossoma*	*Colossoma macropomum*	Alien	7.0	3.5
9	Lepisosteiformes	Lepisosteidae	*Atractosteus*	*Atractosteus spatula*	Invasive		1.8
10	Osteoglossiformes	Osteoglossidae	*Arapaima*	*Arapaima gigas*	Invasive		1.8
11	Siluriformes	Loricariidae	*Hypostomus*	*Hypostomus plecostomus*	Alien	1.4	10.5
12				*Hypostomus* sp.	Alien		3.5
13			*Pterygoplichthys*	*Pterygoplichthys multiradiatus*	Invasive	2.8	
14				*Pterygoplichthys pardalis*	Invasive	12.7	33.3
15				*Pterygoplichthys disjunctivus*	Invasive	1.4	
16				*Pterygoplichthys* sp.	Invasive		1.8
17				*Pterygoplichthys* hybrid	Invasive	1.4	
18		Clariidae	*Clarias*	*Clarias gariepinus*	Alien	14.1	22.8
19		Pangasiidae	*Pangasianodon*	*Pangasianodon hypophthalmus*	Alien	15.5	
20	Cyprinodontiformes	Poeciliidae	*Gambusia*	*Gambusia affinis*	Alien	4.2	1.8
21			*Poecilia*	*Poecilia latipinna*	Alien		5.3
22				*Poecilia mexicana*	Alien	1.4	
23				*Poecilia reticulata*	Alien	21.1	31.6
24				*Poecilia* sp.	Alien		1.8
25			*Xiphophorus*	*Xiphophorus helleri*	Alien	11.3	21.1
26			*Xiphophorus*	*Xiphophorus maculatus*	Alien	1.4	

27	Cichliformes	Cichlidae	*Amatitlania*	*Amatitlania nigrofasciata*	Invasive	4.2	3.5
28			*Amphilophus*	*Amphilophus citrinellus*	Invasive	15.5	1.8
29				*Amphilophus labiatus*	Invasive	5.6	5.3
30				*Amphilophus* sp. 1	Alien	1.4	
31				*Amphilophus* sp. 2	Alien	1.4	
32			*Andinoacara*	*Andinoacara pulcher*	Alien		5.3
33				*Andinoacara rivulatus*	Invasive	1.4	7.0
34				*Andinoacara* sp.	Alien	2.8	
35			*Cichlasoma*	*Cichlasoma trimaculatum*	Invasive	8.5	1.8
36				*Cichlasoma* hybrid	Invasive*	1.4	
37			*Coptodon*	*Coptodon tholloni*	Invasive	1.4	
38			*Cribroheros*	*Cribroheros alfari*	Invasive	1.4	1.8
39			*Cryptopheros*	*Cryptopheros spilurus*	Alien		1.8
40			*Fossorochromis*	*Fossorochromis rostratus*	Alien	1.4	
41			*Geophagus*	*Geophagus* sp.	Alien	1.4	
42			*Hemichromis*	*Hemichromis elongatus*	Invasive	4.2	1.8
43			*Laetacara*	*Laetacara curviceps*	Alien	1.4	
44			*Mayaheros*	*Mayaheros urophthalmum*	Invasive	1.4	1.8
45			*Oreochromis*	*Oreochromis mossambicus*	Alien	45.1	45.6
46				*Oreochromis niloticus*	Alien	73.2	68.4
47				*Oreochromis* sp.	Alien	2.8	3.5
48			*Parachromis*	*Parachromis managuensis*	Invasive	8.5	1.8
49			*Pseudotropheus*	*Pseudotropheus cyaneorhabdos*	Alien	1.4	
50	Anabantiformes	Osphronemidae	*Trichopodus*	*Trichopodus pectoralis*	Alien	40.8	22.8

*Herder et al. (2012)