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A dozen fish: some exotic invasive species found in Brazilian waters and their impacts

Uma dúzia de peixes: algumas espécies exóticas invasoras encontradas em águas brasileiras e seus impactos

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Abstract
The introduction of invasive alien species (IAS) is among the leading causes of biodiversity loss in the world. The arrival of these species causes several imbalances in the natural environment. The establishment of these species depends on their transport, entry, adaptive success, and interactions in the environment. This work aims to present 12 species of exotic invasive fish that occur in natural environments in Brazil in the form of a booklet and to discuss some aspects inherent to legislation changes related to the cultivation of these species. The target audience of this study is mainly fish farmers, fishermen, riverside dwellers, assistance technicians, schools, environmental departments, and rural communities. The list had as a criterion the selection of species that are raised in fish farming stations and that already have records of occurrence in natural ecosystems in the country. These are exotic species introduced (from other countries) and with high invasive potential in Brazilian continental waters. To compose the list of these species, national and international studies that discuss the subject were sought, the following species being selected: *Ctenopharyngodon idella, Hypophthalmichthys molitrix, Hypophthalmichthys nobilis, Cyprinus carpio, Oreochromis niloticus, Coptodon Rendalli, Oreochromis mossambicus, Oreochromis macrochir, Clarias gariepinus, Ictalurus punctatus, Oncorhynchus mykiss, Micropterus salmoides*. In addition to presenting the impacts of invasive alien species on native ichthyofauna, this material will help disseminate technical information and may also be an aid to guide public policy decision making and awareness.
Keywords: aquaculture, biodiversity, distribution, establishment, invasion, legislation

Resumo
A introdução de espécies exóticas invasoras (EEI) está entre as principais causas de perda da biodiversidade no mundo. A chegada dessas espécies provoca vários desequilíbrios no meio natural. O estabelecimento destas espécies depende do transporte, entrada, sucesso adaptativo e interações no ambiente. Este trabalho tem como propósito apresentar 12 espécies de peixes exóticos invasores que ocorrem em ambientes naturais no Brasil na forma de cartilha e discorrer sobre alguns aspectos inerentes as mudanças na legislação em relação ao cultivo destas espécies. O público-alvo desta cartilha são principalmente piscicultores, pescadores, ribeirinhos, técnicos assistencialistas, escolas, secretarias de meio ambiente e a comunidade rural. A lista de teve como critério a seleção de espécies que são criadas em estações de piscicultura e que já possuem registros de ocorrência em ecossistemas naturais do país. Sendo estas, espécies exóticas introduzidas (vindas de outros países) e com alto potencial invasor em águas continentais brasileiras. Para compor a relação destas, foram buscados trabalhos nacionais e internacionais que discorre sobre o tema, sendo selecionadas as seguintes espécies: *Ctenopharyngodon idella, Hypophthalmichthys molitrix*, *Hypophthalmichthys nobilis*, *Cyprinus carpio*, *Oreochromis niloticus*, *Coptodon rendalli*, *Oreochromis mossambicus*, *Oreochromis macrochir*, *Clarias gariepinus*, *Ictalurus punctatus*, *Oncorhynchus mykiss*, *Micropterus salmoides*. Além disso, são apresentados os impactos das espécies exóticas invasoras sobre a ictiofauna nativa, o que ajudará na divulgação de informações técnicas e poderá ser também um auxiliar para nortear tomadas de decisões de políticas públicas e conscientização.
Palavras-chave: aquicultura; biodiversidade; distribuição; estabelecimento; invasão; legislação

1. Introduction

Introducing invasive alien species (IAS) in environments causes several impacts and ecological disequilibrium in both intra- and interspecific interactions of native species since both biodiversity and ecosystems are affected[1,2]. The escaping and development of invasive species harm local populations, resulting in competition and fertile hybridization that affect the natural genetic variability and result in the extinction of these populations[3,4]. Besides, it increases the pathogen incidence, alters biological interactions in trophic webs, and decreases the protection of native populations, decreasing their shelters and safe environments for oviposition, etc.[5,6,7,8,2].

Generally speaking, the occurrence and establishment of IAS of fish in a new environment are subject to four main factors: I – the displacement from their habitats (transport); II – entry into the new environment; III – adaptive success (as a viable reproducing population),

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affected by biotic, abiotic, and geographic environmental pressures; and IV – interactions within the community (after integrating into the introduced environment, the IAS tends to alter the behavior patterns and the ecological niche of the native species)[9]. Still, impacts on native communities may occur before all stages are complete, even after entering an IAS in a new environment.

The invasion of IAS of fish in Brazil occurs in streams and streamlets with different monitoring and oversight levels, including in protected units (PUs), for several reasons (e.g., releases and escape from breeders). Therefore, species with high reproduction and dispersion capacity are more likely to colonize new environments[10]. Pisciculture bears the greatest responsibility for the introduction of IAS within natural environments due to escape events to residual waters (effluent streams and streamlets), rupture or overflow of the cultivation tanks, or even the escape of fertile eggs and fingerlings through the mesh of net tanks in hydroelectric reservoirs[11,12,13,14,15,1]. Although there are dispersal barriers (natural or anthropic), these barriers do not prevent these species from reaching places protected by law, such as PUs (regulated by Law no. 9.985/2000) in Brazil[16]. The occurrence of these species in these areas is evidence of the trespassing of these barriers, resulting in severe environmental issues and the direct introduction into these areas protected by law. Currently, around 90 IAS of fish have been observed in continental waters in Brazil[17].

Identifying the potential introduction vectors of IAS of fish and as well as determining the biological features of the species and their behaviors in environments are effective strategies for managing IAS of fish. Besides, it is fundamental to comprehend the impact of these animals on biogeochemical cycles, tropic chains, interspecific relationships, and nutrient availability in new habitats[18].

Therefore, this study aimed to present a dozen IAS of fish found in Brazil, highlighting the basic biological features of each species with a didactic character aiming to reach the non-academic public, providing them with information about these species and their environmental and socioeconomic impacts[17]. The choice of these species is because these IAS are already cultivated in Brazil. After all, they are IAS to South America and have been found in several Brazilian natural environments, representing a significant threat to local species and the entire biotic environment.

2. Some regulatory aspects regarding the introduction of the IAS of fish in Brazil

2.1 The culture of the IAS of fish in Brazil

In Brazil, the introduction of any animal species without a technical and licensed opinion by the competent environmental agency is prohibited and subjected to the prescribed penalty of detention and a fine, as provided in the Environmental Crimes Law (no. 9.605, of February 12th, 1998) in its 31st article[19]. The 61st law article provides for "*disseminating diseases or plagues or species that may cause damage to agriculture, livestock, fauna, flora, or ecosystems,*" resulting in imprisonment and fines. This environmental crimes law was regulated by Federal Decree 6.514/08[20]. Law 5.179/67 (the Fauna Protection Law) regards the introduction of IAS in the country. Its fourth article defines that "no species may be introduced in the country without a favorable official technical opinion and license issued according to the law"[21].

Several zootechnical performance protocols and studies are available for IAS. Still, such information is not abundant for native species, with some exceptions, such as tambaqui, pirarucu, and some other species. Investing, encouraging, and making protocols for the culture of native species are ways to prevent the arrival of IAS that cause ecological imbalances in ecosystems. The demand for food and fish is growing worldwide, stimulating the aquaculture sector. The aquaculture sector worldwide in 2020 produced 54.4 million tons of freshwater fish[22]. In Brazil, it was estimated that 860.355 t of fish were produced in 2022, an increase of 2.3% in Brazilian aquaculture compared to a year before, in which 841.005 t were produced. tilapia species represented 63.93% of the total fish produced in Brazil in 2022, considering a grand production of 550,060 t, a 3% increase compared to the 534,005 t produced in 2021. The state of Paraná was the leading producing state of this species (187,800 t), followed by São Paulo (77,300 t), Minas Gerais (51,700 t), Santa Catarina (42,500 t), and Mato Grosso do Sul (32,200 t)[23].

Over 70 tilapia species are known worldwide, among which 22 have commercial importance[24]. Among them, the tilapia species covered in this booklet (e.g., the Nile tilapia (*Oreochromis niloticus*), the redbreast tilapia (*Coptodon rendalli)*, the Mozambique tilapia (*Oreochromis mossambicus*), and the longfin tilapia (*Oreochromis macrochir*)] are widely cultivated in Brazil. Besides tilapias, common and grass carps (*Cyprinus carpio* and *Ctenopharyngodon idella*, mainly) and rainbow trout (*Oncorhynchus mykiss*) farming is highlighted in the country. The Southern Brazilian region, comprising the states of Rio Grande do Sul, Santa Catarina, and Paraná, concentrates most of the carp production, with 2.9 t produced in 2021[25]. At the same time, trout production reached 1,993,660 Kg in the country, with Minas Gerais (in the Southeastern region) being the leading producing state[26].

However, most fish production is still carried out inappropriately because of a lack of technical orientation or environmental regulation[14]. Improvements in legislation are also necessary[27] because the current laws may make aquaculture potentially harmful if the introduction of IAS of fish in natural environments is considered[5]. Legislation changes throughout the years facilitated the breeding of exotic freshwater fish[27]. This is because, in general, the

legislation is created by laypeople unaware of the dangers the IAS of fish may represent if they reach natural environments.

2.2 Changes in regulatory laws on the introduction of IAS of fish

Among the laws regulating the introduction of IAS in environments, a landmark was Law no. 5989/09[28], which altered provisions of Law no. 11.959 of June 29th, 2009 (which provides for the National Policy for the Sustainable Development of Aquaculture and Fisheries -PNDSAP). In Article 22, the law covers the responsibility of aquaculture farmers to keep the species safe at their breeding sites and prevent their arrival in Brazilian watersheds[29]. The Bill suffered modifications in the Environment and Sustainable Development Commission, in which the names of IAS that could be cultivated in net cages were excluded from the original proposal. In addition, according to this law, the Brazilian Ministry of Fishing would be in charge of listing the species, and each Brazilian state would be responsible for defining the permit relationship through a normative act of the executive branch.

According to Lima Junior *et al.*[27], the changes in *PNDSAP* through Law no. 5989/09 represent a setback once the changes in the law would not treat the release of IAS of fish and would omit questions related to their previous establishment. Therefore, such easing of legislation is associated with creating IAS, decreasing the restrictions of aquaculture in net cages, and analogous structures utilizing reservoirs to allow such activity.

Another factor that harms native species populations regards the repopulation (storage) made by owners or concessionaries as an environmental reward, which defines the use of autochthonous species in watersheds. Even though they are local species, the release of exotic individuals in the environment, without any scientific criteria, may affect several populations of native species existing in natural environments[30,5]. Therefore, inherent aspects related to changes in environmental law that favor the creation of IAS in reservoirs must be considered. When releases occur (repopulation), such places often provide establishment conditions to species with invasive potentials, harming native species even more[27].

In 2020, the Brazilian Federal Government published Decree no. 10.576/2020, which provides for the assignment of the use of physical spaces in water bodies under the domain of the Union for the practice of aquaculture[31]. Such a decree significantly facilitated the cultivation of IAS of fish in net tanks in Brazilian reservoirs[32]. Another aggravating factor in this decree was the removal of prerogatives from the Brazilian Ministry of Environment in the process of issuing licenses for fish farming in reservoirs, leaving the Aquaculture and Fisheries Secretariat (SAP) in charge of regulating the cultivation of native species and IAS in these locations. The decree allows SAP to release a grant for using the water from reservoirs by the National Water and Basic Sanitation Agency (ANA). Before that, the interested party registered their plans requesting the use of these waters in the ANA. The inspection fragility may directly affect the introduction of IAS into freshwater environments, threatening significant Brazilian fish biodiversity. Considering the limits of the hydrographic basins, this decree may have effects in neighboring countries that converge basins with Brazil (e.g., Uruguay, Paraguay, Bolivia, Argentina, Peru, Ecuador, Colombia, Venezuela, Guiana, etc.), where IAS may be able to overcome existing barriers (e.g., physiographic barriers[33] or dispersion barriers), and establish themselves beyond national borders, reaching ecoregions with high fish species richness and endemism[13].

A legislative change that may be considered an incentive for the introduction of IAS was approved by Law 2510/2019[34] (which refers to the preservation strip in the banks of water bodies in urban areas). This law changes Law no. 12.651 of May 25th, 2012, to provide for permanent protection areas in the urban perimeter and metropolitan regions, which was approved in a virtual plenary session on August 26th, 2021[35]. Another more concerning bill is 614/2018[36] (the protection of non-native species) in the Brazilian state of São Paulo. The law proposal seeks to allow the commercialization of Tucunarés, an invasive species in the state. The bill text has already been passed by parliamentarians in the Legislative Assembly of the State of São Paulo (ALESP).

Finally, another legislative change that could further affect the situation, and is currently in progress, is the environmental licensing relaxation by Law 3.729/04, approved by the Chamber of Deputies on May 13th, 2021[37]. According to this law, fish farming may be regulated through a single environmental license (the law modifies the licensing structure and changes the environmental studies and projects necessary for aquaculture, among other activities). The law matter is awaiting consideration by the Federal Senate under Law 2.159/2021[38]. Regarding this, it is necessary to wait to see whether the legislature will keep the proposal forwarded, which presents itself as a facilitator for regulating potentially impactful activities.

2.3 Possible impacts due to changes in legislation on aquaculture and the incentive for native species cultivation

The easing of legislation and the consequent increase in fish farming in net cages may increase the pressure of IAS on native species, leading to the transmission of genetic variation in local populations[3,27]. Such an easing may lead to the spread of pathogens, competition for resources, increased predation rate, reduced fitness, extirpation, and extinction, among others. Additionally, this measure may change the physical–chemical features of water (e.g., dissolved oxygen, turbidity, pH, and ammonia concentration, among others. If there is an accumulation of sediments, eutrophication of the water may occur, caused by

a surplus feed, increased excreta, etc., inducing the growth of toxic algae[12].

In this way, IASs dominate the places where they are introduced because they compete for food resources, prey on eggs and young forms of native fish, may be carriers of unknown pathogens for the immune system of the natural fauna, and are more efficient in reproduction, with parental care in invaded environments[39,5]. Adding to that, the escape of IAS from net cages, often due to the incompatibility of the physical structure concerning the animals raised (which does not prevent the escape of small fish), for example, may lead to changes in the fishing resources of native species, impacting local economic activity[27].

Cultivating IAS in excavated tanks or nurseries also poses a risk to ecosystems when failures occur in the structure or management of the production system, allowing the animals to escape[14]. However, rearing IASs in excavated tanks may provide better environmental safety. This will occur if these tanks are built far from the water course margins, with a mechanism that prevents leaks in the event of an overflow in the rainy season, and with protection at the exit of wastewater, among other measures compared to net cages[11,12].

Brazilian fish stocks decrease annually. Therefore, investing in creating native species of Brazilian basins may be an alternative for developing more sustainable fishing farming, reducing the negative impacts of IASs in Brazilian waters, and increasing the supply of these fish in the market. In 2022, native species represented 31.04% of national production, with 267,060 t produced (262,370 t in 2021)[40]. A highlight of the period was tambaqui (*Colossoma macropomum*), Brazil's second most cultivated species, reaching 94,593,371 produced tons in 2021[41]. The northern region is the leading producer of native fish (53.7%), totaling 143,500 t in 2022. The northeastern region totaled 56,580 t, while the eastern region produced 49,100 t, which decreased compared to 2021. The states with the most significant production of native fish in 2022 were: Rondônia (57,200 t), followed by Maranhão (39,100 t), Mato Grosso (38,000 t), Pará (24,200 t), and Amazonas (21,300 t)[40]. Despite the significant potential, the development of technologies involving native species is hindered by a lack of incentives. The implementation of appropriate public policies at the federal, state, and municipal levels is crucial in ensuring compliance with regional considerations for each species, particularly those species that are widely consumed.

3. List of the 12 IASs evaluated in this booklet

The species were selected according to their origin (introduced from other countries), occurrence in Brazilian watersheds, and economic importance (in fish farming), and based on studies by Sampaio and Schmidt (2013)[42] and Latini *et al.* (2016)[17] regarding IASs found in Brazil and by Lowe *et al.* (2000)[43], who cataloged the 100 worst IASs. Therefore, 12 IASs were chosen: grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), bigheaded carp (*Hypophthalmichthys nobilis*), common carp (*Cyprinus carpio*), Nile tilapia (*Oreochromis niloticus*), redbreast tilapia (*Coptodon rendalli*), Mozambique tilapia (*Oreochromis mossambicus*), longfin tilapia (*Oreochromis macrochir*), African catfish (*Clarias gariepinus*), channel catfish (*Ictalurus punctatus*), rainbow trout (*Oncorhynchus mykiss*), and black bass (*Micropterus salmoides*).

This booklet, which addresses these species, presents information on their taxonomic classification, etymology, native distribution, morphology, first occurrences in Brazil, history of introduction in Brazil, reproduction, feeding habitat, behavior, and potential environmental effects. Lucas R. F. Santos made all the illustrations. In addition to this, a pamphlet was prepared with the most relevant information present in this booklet.

1. *Ctenopharyngodon idella* (Valenciennes, 1844)/ Common Name: grass carp

Taxonomic classification
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Cypriniformes
Family: Xenocyprididae
Subfamily: Squaliobarbinae
Genus: *Ctenopharyngodon*
Species: *C. idella* (Valenciennes, 1844).

Figure 1. Drawing of *Ctenopharyngodon idella* (Valenciennes, 1844) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

The etymology of *Ctenopharyngodon* comes from the Greek *kteis*, *ktenos* + the Greek *pharynx* = pharynx + odous (Greek) = teeth. The name is related to the pharyngeal teeth of the species[44].

Native distribution

The grass carp (*C. idella*) is native to China, Russia, and West Siberia (Amur River basin), where it typically inhabits water bodies characterized by low currents[45,44].

Morphology

The species exhibits an elongated and cylindrical body shape, with a standard length that is 3.6-4.3 cm greater than its height. The abdomen is grayish in color, while the back displays a brown-black hue. It is characterized by large cycloid scales, with a lateral line consisting of 39-46 scales. The species possesses a terminal mouth without barbels and features two lines of laterally compressed pharyngeal teeth. It possesses a caudal, dorsal, and anal fin, along with one pair of ventral or pelvic fins and one pair of pectoral fins. The caudal fin

is composed of approximately 24 rays, the dorsal fin has 7-8 rays, the anal fin consists of 7-11 rays, the pelvic fin displays eight rays, and the pectoral fin exhibits 16-17 rays [46,17]. The largest recorded individual of this species weighed 45 kg [47].

First occurrences, introduction history, and distribution in Brazil

The first record of the grass carp in Brazil was made in 1971, when the National Department of Constructions Against Droughts (DNOCS) introduced 20 individuals of the species for aquaculture farming. The arrival of the species in natural environments may have been intentional (active release) or unintentional or accidental (throughout escapes) in aquaculture enterprises, although no data are available. Since then, this species has been available in natural environments in Rio de Janeiro, Paraná, Rio Grande do Sul, Pernambuco, and São Paulo[17].

Reproduction

The reproduction of this species in nature occurs between the end of winter and the beginning of spring. The reproducing individuals look for rivers with current and rocky bottoms. In aquaculture tanks, the reproduction of the species is made through artificial induction (hormone application) from the third year of life, when the reproducing individuals reach sexual maturity[48].

Feeding behavior

Individuals of the species feed from phytoplankton and plants available in the environment, such as leaves and seeds[49]. The species is herbivorous. During the initial life stages, the diet of the species includes crustaceans and other invertebrates[50].

Behavior

Individuals of this species live peacefully in groups, control the populations of plants in aquatic environments, and may be cultivated in polycultures in intensive, semi-intensive, or extensive systems. This species has significant growth potential in captivity. It is a species with hardy features for farming[51].

Environmental potential effects

Because of its herbivorous feeding behavior, the grass carp (*C. idella*) may unbalance the primary production of aquatic ecosystems, and their excreta may contribute to the increase of organic matter in the environment[50]. This species has resistant features against pathogens and parasites, which may help to propagate these harmful species to native fish in natural environments[52].

2. *Hypophthalmichthys molitrix* (Valenciennes, 1844)/ Common name: silver carp

Taxonomic classification
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Cypriniformes
Family: Xenocyprididae
Genus: *Hypophthalmichthys*
Species: *H. molitrix* (Valenciennes, 1844).

Figure 2. Drawing of *Hypophthalmichthys molitrix* (Valenciennes, 1844) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

Hypophthalmichthys: Greek, *hypo* = under + Greek, *oftalmos* = eye + Greek, *ichthys* = fish; *molitrix*: *molitrix*, approximately grinder (referring to the pharyngeal grinding apparatus of the species)[53].

Native distribution

The silver carp (*H. molitrix*) has an Asian origin (China and Russia). It has similar features to other carp species, including the common carp[48].

Morphology

The superior portion of the body of the specimens of this species is grayish, greenish, or dark brown, being darker in their head. Their ventral region is whitish or yellowish. The species does not have marked bands or spots on the side of the body of adult individuals with 83–125 scales. The body is laterally compressed with lateral eyes. The fins vary in color, ranging from hyaline to the most pigmented hues. The caudal fin has a darker base than the ends. The anal fin has 13–15 rays. The total dorsal spines are 1–3. The dorsal rays are 6–7. The total number of anal spines is 1–3. The total anal rays are 10–14[54,46,53]. Silver carp may reach 50 kg throughout its lifetime[55].

First occurrences, introduction history, and distribution in Brazil

The first attempts to introduce the species in Brazil took place in 1968 with specimens from China, Japan, and Hungary. However, this species was only effectively introduced in consortium with other species in 1983[56].

The species is distributed in over 65 countries and occurs in several Brazilian states. Its presence is associated with fish farming, sport fishing, and the ornamentation of spaces[57]. This species has already been recorded in natural and artificial areas (reservoirs and dams). The silver carp occurs in the DNOCS reservoirs, São Francisco River, Paranoá Lake in the Federal District, Lagoa dos Patos, and Lagoa Mirim in Rio Grande do Sul[17].

Reproduction

Males of this species reach sexual age around 2 years old and females at 3 years old. In their natural habitats, reproduction occurs between the end of winter and the beginning of spring. Eggs can be incubated in environments

with high ionic concentrations[57,17]. In farms, hormonal induction is necessary through synthetic hormones or by the pituitary gland of carp- hypophysis[17,44,53].

Feeding behavior

This species has a phytoplanktophagous feeding behavior[58]. It feeds on small algae and has a filtering apparatus in the gill arches[54]. In aquaculture enterprises, the feeding of this species relies on artificial food sources due to the characteristics of its filtering apparatus. Specifically, powdered formula feeds are commonly employed[58].

Behavior

This species is suitable for polyculture in fish farming. It grows from 1.0 to 1.5 kg/year in good conditions. The species controls phytoplankton as it consumes it as food. The species uses a special filtering apparatus present in its gill arches. Silver carp removes excess plants from the environment. The species can help improve water quality in aquaculture crops[48]. Still, it may compete with other species when in overpopulation. The species can also treat the waste of water, domestic effluents, and pig farming[17,27]. Studies on the behavior of this species in the wild are still needed. The use of biological controls for this species should be rational. Therefore, monitoring the species and its place of creation is necessary.

Potential environmental effects

Through its diet based on green microalgae (phytoplankton), silver carp can help to control the excesses of plants available in water[59]. Eutrophication decreases oxygenation at night and can cause asphyxiation, leading to the death of fish in aquacultures[60]. In natural environments, this characteristic can be harmful by reducing dissolved oxygen and altering the links at the base of the food chain[59].

3. *Hypophthalmichthys nobilis* (Richardson, 1845)/ Common name: bighead carp

Taxonomic classification
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Cypriniformes
Family: Xenocyprididae
Genus: *Hypophthalmichthys*
Species: *H. nobilis* (Richardson, 1845).

Figure 3. Drawing of *Hypophthalmichthys nobilis* (Richardson, 1845) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

The origin of the name of the species comes from the Greek *hipo* = under, *ophthalmos* = eyes, *ichthus* = fish, and *nobilis*: noble[61].

Native distribution

The bighead carp (*H. nobilis)* has an Asian origin, mainly from the Amur River basin, between the Chinese and Russian borders[62].

Morphology

Small scales cover the body of this species, and there are black skin spots all over its skin, with its superior body portion grayish, greenish, or dark brown, with a darker color over its head. The ventral region has a whitish or yellowish coloration. The mouth of the species has no barbels, and the species has a sizable head, which is the greatest related to congener carp species. Its scales are tiny, and 96–120 are in its lateral line. The posterior margin of the last dorsal fin is sawed[17,46,61]. There are registered specimens over a meter in standard length and a maximum weight of 40 kg[63].

First occurrences, introduction history, and distribution in Brazil

The species arrived in Brazil between 1975 and 1983 after encouragement for its cultivation by the Federal Government[56]. The Superintendence of Fisheries Development (SUDEPE) introduced the species in southern Brazilian regions with specimens from China[64].

The Bighead Carp is one of the most cultivated species in Brazil. Its introduction was to cater to fish farming, especially polyculture systems. The species has already been found from Rio Grande do Sul to Pernambuco[17].

Reproduction

Naturally, individuals of this species breed before the end of winter or the beginning of spring. It reaches sexual maturity in the first year of life, obtaining the best reproductive rates between two and five years. A female weighing 1–2 kg can produce up to 100,000 eggs and spawn three times a year. In commercial farms, reproduction is induced by synthetic hormones or the removal of the pituitary for the production of fingerlings[17,61].

Feeding behavior

The bighead carp belongs to the group of filter feeders, feeding on zooplankton, preferably[58], and depending on availability, it may feed on phytoplankton and detritus[65].

Behavior

This species is eurythermic, tolerating significant temperature variations. Its specimens live in the upper water column and regions with high organic content. Reproduction in a natural environment occurs in rapids waters, 1–2 meters deep, and with vegetation on the banks[61]. In regions with sudden drops in water temperature, juveniles and adults gather in large shoals and migrate to deep regions, where specimens cease their activities[17].

Potential environmental effects

This species is very efficient in filtering due to its highly specialized gill rakers[66], which filter particles up to 4 µm. On fish farms, adults survive in waters with brackish characteristics, which allow its occurence in several places in Brazil. In a natural environment, the species is highly competitive in the trophic chain, altering food availability and hybridizing with native species[17].

4. *Cyprinus carpio* (Linnaeus, 1758)/Common name: common carp

Taxonomic classification
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Cypriniformes
Family: Cyprinidae
Genus: *Cyprinus*
Species: *C. carpio* (Linnaeus, 1758).

Figure 4. Drawing of *Cyprinus carpio* (Linnaeus, 1758) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

The name of this species comes from the Latin word *Cyprinus, cyprinus* = carp. *Carpio*.

Native distribution

The common carp (*Cyprinus carpio*), also known as Hungarian carp, is an Asian species that has been cultivated for more than 2000 years. Distribution records indicate that the species has also been established in Europe and Africa for over 600 years [67,17].

Morphology

Scale, mirror, line, and leather carp varieties are cultivated in Brazil. Specimens of the common carp have an elongated and slightly depressed body. Their color is variable, and the upper part of the body may be grayish or greenish-brown (back). Ventral region whitish, yellowish, or golden. There are no apparent bands or spots on the side of the body, which have 32–38 scales under the lateral line. The mouth of the specimens of the species is slightly subterminal, with a pair of maxillary barbels (shorter on the upper lip). Pharyngeal teeth 5:5, long dorsal fin with 17–22 rays, and a strong spine in the front. Anal fin with 6–7 rays[68,46]. The heaviest individual recorded weighed 40.1 kg[69].

First occurrences, introduction history, and distribution in Brazil

The first record of the species in Brazil is from 1982, when it was introduced into the country from the United States[70]. Still, the species was recorded in São Paulo as far as 1904, with specimens brought from Germany to the municipality of Piracicaba[71]. The species has already been found in the natural environments of at least 15 states of the Brazilian federation (in biomes such as the Pantanal, Amazon, Cerrado, Caatinga, Atlantic Forest, and Coastal regions)[17].

Reproduction

This species reproduces from May to June. Spawning occurs in shallow waters with good plant availability so that the eggs can adhere and the embryo can develop. In each spawning event, the number of eggs a female weighing 1.0 kg releases is estimated at more than 100,000[72,73]. One to three spawning events occur during the reproduction period.

Feeding behavior

The common carp is omnivorous and feeds on detritus, vegetables, insects, crustaceans, small mollusks, earthworms, etc.[74]. Nevertheless, specimens of this species prefer benthonic invertebrates when possible. The mouth of this species is protractile and terminal, and two pairs of barbels have a sensory function[46,73]. On the Iguaçu River, their food consists of superior plants[75].

Behavior

The common carp is a benthic species greatly influenced by water temperature, which affects its spawning and feeding behavior[76]. The species preferentially lives in lentic environments composed of thin substrates, vegetation, and water availability at high temperatures [17]. During the winter, specimens of the species are sheltered at the bottom of the watercourse. The specimens can sometimes bury themselves in the available substrate, decreasing their activities while awaiting the spring[68].

Potential environmental effects

This species is widely cultivated due to its hardiness, disease resistance, and high fertility. It supports certain variations in temperature and water quality[77]. It is tolerant to the low availability of dissolved oxygen resulting from these variations and its simple management compared to other species. All these cultivation characteristics make it very present in fish farming stations, and its introduction harms natural environments. Other impacts of this species in the natural environment are mainly related to changes in water quality and increasing turbidity in the water column due to its feeding behavior (removing the bottom water)[17]. This species is a strong competitor of native species in natural environments. It preys upon fish eggs, fish larvae, and invertebrates[52].

5. *Oreochromis niloticus* (Linnaeus, 1758)/Common name: Nile tilapia

Taxonomic classification
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Cichliformes
Family: Cichlidae
Subfamily: Pseudocrenilabrinae
Genus: *Oreochromis*
Species: *O. niloticus* (Linnaeus, 1758).

Figure 5. Drawing of *Oreochromis niloticus* (Linnaeus, 1758) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

The name of the species comes from *Oreochromis* (Latin), *aurum* = gold + *chromis* (Greek) = fish. *Niloticus* = Amharic (Ethiopian) word meaning "warm spring"[78].

Native distribution

The Nile tilapia (*O. niloticus*) is native to rivers of the Israeli coast (the junction of the African continent) and African rivers, including the Nile[79,80].

Morphology

The species has a compressed body with dark and regular vertical stripes on its caudal fin. It has a silver-green coloration on the side of its body. There are 27–33 tracks on its first branchial arch. Its dorsal fin has 16–17 spines and 11–15 flexible rays; the anal fin has three spines and 10–11 flexible rays and the caudal fin is truncated[17,78]. Males may appear bluish-pink and have dark throats, bellies, and anal and pelvic fins. Conversely, females may be brownish, silvery, or white and have thin vertical bars. The maximum recorded weight for the species was 4.3 kg[81].

First occurrences, introduction history, and distribution in Brazil

This species has been cultivated in several countries. In Brazil, its farming began in the 1970s[82,17,80]. Through DNOCS, the Brazilian government imported the species mainly for cultivation in reservoirs in the Northeast to replace *C. rendalli*, the first tilapia species introduced in the country, which exhibited low weight gain[83].

Nile tilapia occurs in all the main river basins in the country[84]. It occurs in artificial and natural environments of the Atlantic Forest, Cerrado, Pantanal, Caatinga, and Amazon biomes, although its presence is more noticeable in the northeast and southeast regions[17,52,83].

Reproduction

Reproduction in tilapia occurs from three to six months of age, depending on the species. Spawning can occur more than four times a year. During reproduction, the male becomes more aggressive, defends its territory from the presence of other individuals, courts the female, and digs the nest[78]. During this period, males also display and typically have a reddish belly. Once the nest is ready, any attracted female will enter and release the eggs. Afterward, the male releases the semen. After fertilization, the female incubates the eggs in her mouth and leaves the nest (she is the one who protects the offspring), while the male arranges the nest and searches for new females to reproduce[17,46,78]. Reproduction is split and early (in captivity), lasting 4–5 months[85], when the specimens reach 30 g[86].

Feeding behavior

This species is omnivorous and feeds on zooplankton and phytoplankton. However, its diet may vary according to ontogeny and environmental and seasonal changes. Therefore, this is an opportunistic species[87].

Behavior

Individuals of the species perform parental care efficiently, protecting their offspring from predators[88,89]. In addition to being easy to adapt to climatic variations, this species supports temperature variations from 8 to 42 ºC. It survives in brackish waters with low levels of dissolved oxygen, high concentrations of ammonia and salinity, and significant pH variation (between 6 and 8.5). This species is diurnal and has excellent reproductive capacity. It is resistant to diseases and infections[80,79,78,17].

Potential environmental effects

Nile tilapia accounts for more than 90% of aquaculture production in Brazil[46,80]. Specifically, the states of Paraná, São Paulo, and Santa Catarina are the main producing centers of these species[90]. This species has a significant invasive capacity, as it is resistant to pathogens and parasites, posing a threat to native fish populations once it establishes itself easily in new environments[17]. Due to releases or escapes, the arrival of this species in natural ecosystems can cause a decrease in the population density of native species, making the species dominant in these places[52]. Nile tilapia can affect zooplankton biomass through predation or indirectly by consuming its food resources such as phytoplankton and suspended debris[91,92,93]. Additionally, the presence of the species has been associated with changes in water quality[17].

6. *Coptodon rendalli* (Boulenger, 1897)/Common name: redbreast tilapia

Taxonomic classification
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Cichliformes
Family: Cichlidae
Genus: *Coptodon*
Species: *C. rendalli* (Boulenger, 1897).

Figure 6. Drawing of *Coptodon rendalli* (Boulenger, 1897) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

Tilapia is a name that originates from the African dialect Bechuana, which means fish[46].

Native distribution

The redbreast tilapia (*C. rendalli*, Boulenger, 1897) is native to the Congo River basin, Tanganyika Lake, Malawi Lake, Zambeze River, and coastal zones from the Zambeze River delta[94].

Morphology

This species has an olive-green color, dark spots across its body, and a yellow or red belly. Its dorsal fin is olive green, with a red and white to dark gray margin and oblique spots. The caudal fin is punctuated on the dorsal portion and red or yellow on the ventral portion of its body. They have 15–17 spines and 10–13 dorsal-fin rays, three spines, and 9–10 anal-fin rays[46,94]. The heaviest individual recorded was 2.5 kg[95].

First occurrences, introduction history, and distribution in Brazil

Redbreast tilapia was the first tilapia species introduced in Brazil, arriving in the country in 1950 through the São Paulo hydroelectric concessionaire (Light) and in 1952 by the Secretary of Agriculture of the State of São Paulo. These introductions occurred to repopulate the dams and as an alternative to the proliferation of aquatic macrophyte algae that clogged hydroelectric turbines[96]. Although it is commonly found in the country, its cultivation is discouraged due to its low weight gain and early reproduction performance. This species is widespread throughout the country, being found in natural environments in the states of Rio Grande do Sul, Santa Catarina, Paraná, São Paulo, Minas Gerais, Rio de Janeiro, Mato Grosso do Sul, Federal District, Pernambuco, and Amapá[17].

Reproduction

Males nest in clean, shallow, and well-oxygenated water. The male protects the nest and seeks to attract the female for mating. After spawning, the male fertilizes the eggs, the female keeps them in her mouth, where they remain until a week before birth, and the male leaves the territory. The female's care for the eggs is essential, as they need to be maintained well-oxygenated and protected from exposure to pathogens and predator attacks. Parental care toward the offspring lasts two to three weeks after birth[12,17,94]. This species has a sexual dimorphism, in which males are larger than females. Males have a thorn in their dorsal fins, and the tips of the dorsal and anal fins are pointed and elongated. In females, these structures are rounded[46,94].

Feeding behavior

This species is generalist and omnivorous, having multiple feeding sources[97,98,99,83] that vary depending on the life stage and season.

Behavior

This species supports a specific variation in water temperature and salinity. During reproduction, it searches for vegetated areas with shallow waters to build its nest and spawn. This species features biparental care[94]. Under favorable temperature conditions for the species, spawning can occur within 50–60 days. It survives in an environment with high salinity. The species is a benthopelagic freshwater species capable of doubling its population in 4.5 years[17].

Potential environmental effects

Like other tilapia species, redbreast tilapia is harmful to native populations when introduced in environments outside of cultivation. Therefore, this species alters the diversity of local species and reproduces quickly. Their offspring have a high survival rate and a significant resistance to environmental adversities. The species supports a certain degree of eutrophication, is tolerant to parasites, propagates them to native species, and has low food selectivity[17,100].

7. *Oreochromis mossambicus* (Peters, 1852)/Common name: Mozambique tilapia

Taxonomic classification
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Cichliformes
Family: Cichlidae
Genus: *Oreochromis*
Species: *O. mossambicus* (Peters, 1852).

Figure 7. Drawing of *Oreochromis mossambicus* (Peters, 1852) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

The etymology of the species comes from the

Latin *Oreochromis:* aurum = gold + the Greek chromis = a fish; *mossambicus* comes from the Greek words *oreos* = from the mountains and *chroma* = color; *mossambicus* describes a geographic area, Mozambique, from which the species is native[78].

Native distribution

The Mozambique tilapia (*O. mossambicus*, Peters, 1852) is native to southeastern Africa, specifically the Bushman River basin in the Eastern Cape to the Zambezi River delta[101,102].

Morphology

The dorsal fin of this species has 15–16 spines and 10–13 rays, while the anal fin has three spines and 7–12 soft rays. Its head has considerably large scales, starting with two scales between the eyes and then nine scales up to the dorsal fin. Males have an elongated and pointed mouth due to enlarged mandibles, often causing the upper profile to become concave[78]. The heaviest recorded individual weighed 1.1 kg[103].

First occurrences, introduction history, and distribution in Brazil

The species was introduced in 1981 for genetic crosses to be performed with another tilapia species for cultivation in fish farming[104,105]. There are hybrid individuals in Brazil produced from *O. urolepis hornorum* and *O. mossambicus* called redbreast tilapia or Florida tilapia[100].

Overall, tilapia are among the 100 worst-introduced species. They occur in over 90 countries, spread across five continents[106,107]. There are 77 species of tilapia described and divided into four genera: *Sarotherodon*, *Oreochromis*, *Petrotilapia*, and *Tilapia*. Although the disclosure of records of the species *O. mossambicus* in Brazilian waters is still not very restricted, there are data on its occurrence in the wild; an example is in the Tietê River, in the municipality of Buritama[108]. There is also an occurrence of *O. mossambicus* in the wild in Paraíba[52].

Reproduction

Spawning in lakes typically occurs on the edges, with sandy or muddy bottoms. The male makes the nest and defends the territory in search of a partner to mate. The nest is excavated by making a basin-shaped hole in the center of its territory, where the female lays 100–1700 eggs, and the male fertilizes them. After fertilization, the female incubates the eggs alone. The fries hatch in the female's mouth after 3–5 days, depending on temperature[109,78]. The hatchlings are released from the mouth between 10–14 days but remain close to the female and enter her mouth, if threatened, until about three weeks old. In the initial phase, the hatchlings and schools of juveniles look for shallow waters, where they feed during the day, and look for deep waters at night. Females rear several litters during a season, beginning sexual activity from four months of age. The same female spawns more than four times a year. However, in cultivation in warm regions, spawning occurs throughout the year[100,78].

Feeding behavior

This species is omnivorous. Its diet includes various food types, such as algae, insects, crustaceans, fish, etc. It is also a generalist tilapia species, but its habits may vary according to the life stage[56].

Behavior

This species has diurnal habits[53] and can withstand temperature variations, living well in brackish waters with high salinity[110]. It performs parental care for the offspring. The female incubates the eggs, being able to form schools of fish[111]. It is considered one of the most successful freshwater invasive exotic fish worldwide[112,113]. It tolerates variations in salinity[114,115].

Potential environmental effects

As with other tilapia species, their introduction into natural environments can drastically affect fresh and brackish water biota since they compete for food, niches, and other resources. It alters the physical-chemical patterns of water and is a vector for pathogens that cause diseases. In general, tilapias tolerate temperature and water variations with little dissolved oxygen. They have a significant reproductive capacity and parental care that contribute to the increase in population in invaded ecosystems[116, 117,118].

8. *Oreochromis macrochir* (Boulenger, 1912)/Common name: longfin tilapia

Taxonomic classification
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Cichliformes
Family: Cichlidae
Genus: *Oreochromis*
Species: *O. macrochir* (Boulenger, 1912).

Figure 8. Drawing of *Oreochromis macrochir* (Boulenger, 1912) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

The name of the species *Oreochromis* comes from the Latin word aurum = gold + the Greek word chromis = a fish, maybe a perch *macrochir and from the Greek word* macros = big and the Greek "cheir" = hand or pectoral fin in fish, referring to the sizable pectoral fin[119].

Native distribution

This species is natural to the African continent, occurring on the upper reaches of the Zambezi and Congo Rivers[120].

Morphology

This species has very long pectoral fins that can reach the caudal fin. The dorsal fin has 15–17 spines and 11–14 rays. The body has greenish, silvery, or light yellowish colors. The belly is whitish or yellowish, and has brown or black spots in the temporal region, in the operculum below the eyes. Usually, the head is large in males. It has 7–8 rows of transverse spots present on the caudal fin[17,78] The maximum recorded length was 43.3 cm. There is no information on the maximum weight of the species[121].

First occurrences, introduction history, and distribution in Brazil

The first record of the species in the wild occurred in the municipality of Porto Seguro (Bahia) in the Buranhém River[17]. The species was also recorded in 10 reservoirs in Paraíba, with fish farming related to its introduction, where escapes took place[17,52]. It is still little cultivated in the country, although farming in net cages is practiced in the Grande River in Barra, Bahia. The species was introduced into the country for fish farming.

Reproduction

The reproductive period runs from September to March in the southern regions of the original distribution of the species. Males build nests in shallow water and defend them. The nest is a volcano-shaped central mound with a flat or slightly concave top. The male protects his territory and searches for partners. He courts several females in succession, and these can mate with more than one male in the same summer, forming large populations of young individuals. Several nests were built. When the male attracts a female to his den, both fish swim toward the center of the nest. Then, the female lays her eggs—500 to 2,000 per clutch—and the male (with a genital papilla approximately 25-mm long) swims over them. The female performs parental care. A female can carry up to 1,300 eggs in her mouth. The eggs have a diameter of 3 mm and are greenish-brown in color; a female can reproduce for several seasons at intervals of about five weeks. They seek shelter in places with vegetation during the reproductive period[122,78].

Feeding behavior

Young fish consume invertebrates and zooplankton to feed themselves. Nevertheless, this habit is lost with advancing age, as the fish start to feed preferentially on plants, algae, insects, crustaceans, seeds, fruits, and roots[17,52].

Behavior

This species has an excellent reproduction capacity and parental care for its offspring. The female incubates the eggs and protects the young in her mouth, ensuring their survival and contributing to the establishment of their populations. In breeding territory, individuals make a nest with an accumulation of sediments with a concave upper part. Individuals of this species can withstand temperature variations from 18 to 35°C[17].

Potential environmental effects

Although information on the impacts of introducing this species into continental waters in Brazil is scarce (compared to other tilapia species), it is known to be similar to those already reported for other congener species. This species is a strong competitor with native species, preying on fish and zooplankton[52]. This species habitually turns over the bottom of aquatic environments to make nests. This process leads to alterations in the physical–chemical patterns of the water. Additionally, *O. macrochir* represents a danger to the population growth of native species since its population increases quickly.

9. *Clarias gariepinus* (Burchell, 1822)/Common name: African catfish

Taxonomic classification
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Siluriformes
Family: Clariidae
Genus: *Clarias*
Species: *C. gariepinus* (Burchell, 1822).

Figure 9. Drawing of *Clarias gariepinus* (Burchell, 1822) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

The name *Clarias* comes from the Greek word *chlaros* = vivid, in reference to the ability of fish to live a long time out of water. *Gariepinus* was named after the river in which it was found, the Gariep River in South Africa.

Native distribution

The African catfish (*C. gariepinus*), Clariidae family, has Asian origins. It is naturally distributed in southern and northern Africa, the Middle East, Israel, Syria, and southern Turkey[123,124]. It is a species introduced in other locations in Africa, Asia, and Europe[125].

Morphology

The African catfish has an anguilliform body with long dorsal and anal fins. Its bony head is large and

flattened (depressed), its eyes are small, and its mouth is wide and terminal, with four pairs of barbels (external mandibular barbel longer than the inner pair). The teeth in the premaxilla and lower jaw are small, thin, and arranged in several rows[126,127,125]. The dorsal fin has a translucent base without spines. The anal fin is long without spines, with a red body and base and white anterior and black posterior borders. Other fins with translucent bases and red body. This species does not have an adipose fin[125]. There are occurrences of individuals with an average length of up to 1.5 m and reaching up to 60 kg in their native distribution[128].

First occurrences, introduction history, and distribution in Brazil

It was introduced and dispersed irregularly in Brazil. Its arrival is related to aquaculture activity. The introduction began in 1986 when there were illegal escapes that allowed the establishment of the species in the inland waters of the country[129,130,56]. Currently, its occurrence has been observed in several basins in Brazil[131]. The first occurrence of the species was recorded in a natural environment in the Itajaí-Açu River in Santa Catarina in 1989[132]. The species has already been recorded in eight Brazilian states, namely: Minas Gerais, Santa Catarina, São Paulo, Espírito Santo, Rio de Janeiro, Rio Grande do Sul, Paraná, and Goiás[133,134].

Reproduction

The breeding season of the species occurs during the flood period, between July and December in its native distribution and from November to March in Brazil[17].

Feeding behavior

This species is omnivorous, with a diet consisting of several food items such as small fish, crustaceans, insects, small amphibians, aquatic plants, seeds, and fruits[135]. Its diet varies according to environmental food availability[126].

Behavior

Individuals of this species are nocturnal, predatory, and opportunistic. In the natural environment, they move over moist soil during long periods of drought [124]. In fish farming, they can migrate from one tank to another by "crawling" under the ground, thanks to the production of mucus associated with their very resistant pectoral fins. These structures allow individuals to move easily[136,127]. Individuals of this species easily adapt to new environments.

Potential environmental effects

The African catfish is characterized by being extremely tolerant to environmental pressures[136]. This species has an accessory respiratory organ, pseudolungs (arborescent organs), which allow it to breathe air, ensuring advantages in degraded places with low environmental quality[123]. This species has a wide diet[137] and is an efficient predator and strong competitor for the resources consumed by native species. This is one of the most threatening IASs for native fish.

10. *Ictalurus punctatus* (Rafinesque, 1818)/Common name: channel catfish

Taxonomic classification
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Siluriformes
Family: Ictaluridae
Genus: *Ictalurus*
Species: *Ictalurus punctatus* (Rafinesque, 1818).

Figure 10. Drawing of *Ictalurus punctatus* (Rafinesque, 1818) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

Ictalurus comes from the Greek *ichthys* = fish + *ailouros* = cat. The species *punctatus* means *Ictalurus* (Greek) = catfish, and *punctatus* comes from the Latin = stained (referring to the black spots in the body of individuals from this species)[138,139].

Native distribution

The American catfish (*I. punctatus*) is a species native to North America that is present in the central channels of the United States, southern Canada, and northeastern Mexico[140], with a wide distribution in the Mississippi basin.

Morphology

The body of individuals of this species is olive or black in the upper portion, and the belly is white. They may have dark lateral spots, and old males may be slightly blacker. They have a large head and barbels around the mouth[141,142]. The anal fin has 24–30 rays with a rounded shape, the caudal fin is bifurcated, and the species has an adipose fin. These fin shapes help to identify the species compared to other catfish. On the other hand, the longitudinal lateral line begins at the operculum and ends at the beginning of the caudal fin and has a sensory function[143,144,145]. The maximum recorded weight for this species was 26.3 kg[146].

First occurrences, introduction history, and distribution in Brazil

The first introduction record of this species in the country was in 1971. This introduction occurred intentionally for fish farming activity[17]. Between 1972 and 1973, SUDEPE and DNOCS introduced the species. Pentecostes, in Ceará, was the pioneer region in studies of the cultivation of the species. The species was cultivated in Irati in Paraná in 1980. This region was identified as the introductory origin for the species in the state[147]. Occurrence records are found in Lagoa dos Patos (Rio Grande do Sul), in two dams in Ceará, and in the Guaragaçu River, in Paraná[17,148].

Although the species has been introduced into

natural environments in Brazil, its dispersion still seems restricted in some locations, as reported by Cruz-Spindler *et al.*[149]. In this study, an individual (female) was captured, and the authors suggested that the introduction occurred by escape from a fish farming station.

Reproduction

Sexual maturity in the species is reached around 2–3 years. The females lay the eggs in holes where they are incubated, and the male protects the place. The temperature of the water determines the period of incubation and development of the eggs[139].

Feeding behavior

This species is omnivorous, preferably carnivorous. Its diet comprises fish, mollusks, benthic crustaceans, gastropods, small amphibians, and, secondarily, aquatic vegetation[150,145].

Behavior

This species has a nocturnal habit[139] and has taste buds along the external surface of its body, with a high presence near the four pairs of barbels around the mouth and inside the oropharyngeal cavity[151]. It has large numbers of highly specialized olfactory receptors (inside the pits of its nostrils) that can smell amino acids (taste of L-alanine and L-arginine; L-amino acids) in amounts equivalent to one part per 100 million of water.

Potential environmental effects

In addition to having a range of foods that make up its diet, the American catfish has a very well-developed sense of smell and taste, which ensures its ease in searching for food in waters with high turbidity[142, 17]. These characteristics indicate that the American catfish, when present in a natural environment, is an excellent competitor, taking significant advantage of native species [152,141,148].

11. *Oncorhynchus mykiss* (Walbaum, 1792)/Common name: rainbow trout

Taxonomic classification
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Salmoniformes
Family: Salmonidae
Genus: *Oncorhynchus*
Species: *O. mykiss* (Walbaun, 1792).

Figure 11. Drawing of *Oncorhynchus mykiss* (Walbaum, 1792) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

The word *Oncorhynchus* comes from the Greek onyx, *-ychos* = nail + *rhyngchos* = snout. *Oncorhynchus* means hooked snout. The word *mykiss* is a vernacular name for the species in Kamchatka, Russia[138,139].

Native distribution

This species is native to North America (United States and Canada), in waters that drain into the Pacific Ocean[139].

Morphology

The color of this species varies according to the age, environment, and sexual condition of the individuals (during the reproductive period, the male has a more attractive color). Specimens from rivers are darker compared to lakes[153]. The dorsal fins have 10–12 rays and 3–4 spines, while in the anal fin, the number of rays varies between eight to 12 and three to four spines, and the caudal fin has 19 rays without spines[154,68,111]. The maximum recorded weight for this species was 25.4 kg[155].

First occurrences, introduction history, and distribution in Brazil

The first report of introduction of this species in the country is from 1913, in Serra da Mantiqueira, in Minas Gerais. There are also reports of its introduction by business people in Rio de Janeiro, who acquired embryonated eggs from Europe, resulting in 150 fingerlings released into the rivers of Alto da Boa Vista[156,17]. In 1949, fingerlings escaped the Jacu Pintado and Bonito rivers in São Paulo, in the Serra da Bocaina region, through the Division of the Institute of Hunting and Fishing of the Ministry of Agriculture. This introduction explored its reasonable market value (gastronomic) and promoted sport fishing. In 1950, this species released many fingerlings in the rivers of Serra da Bocaina. In 1951, the ability of the species to survive and reproduce in high-altitude rivers in the country was verified. Since then, the species has been introduced into several rivers in national territory. In the 1970s, the species was implanted in Campos do Jordão, the first commercial trout farm in Brazil[157].

Trout was initially introduced into rivers with the justification of being a fish that performs well in the fish market and because it is a species that would attract sport fishing. Today, it is farmed both in natural and artificial environments. Regarding its presence in nature, there are records of occurrence in the Serra Gaúchas, Serra da Mantiqueira, Serra do Itatiaia, Serra da Bocaina, and Serra dos Órgãos. Its presence is related to first-order watercourses, with good oxygenation, low temperature, and flowing water[17,156,157].

Reproduction

Sexual maturation in males occurs at two years of age and in females at three years. The reproduction of rainbow trout takes place preferably in winter, with the highest concentration being from May to August. This period is marked by short days and lower water temperatures (on average 10ºC), providing ideal reproductive conditions[138,139].

Feeding behavior

This species is carnivorous and consumes various types of aquatic and terrestrial invertebrates (e.g., insects, mollusks, crustaceans) and small fish, among others[156].

Behavior

The species inhabits rivers with crystalline, cold, pure, and well-oxygenated waters, characteristic of higher altitude regions. For reproduction, the female excavates the nest using body undulations to open it. The nest is made in running water with a gravel bottom or shallow, low-temperature water with good oxygenation. After fertilization (the female releases the oocyte, and the male releases the sperm), the male takes care of the surroundings[68,138,139].

Potential environmental effects

Trout is a carnivorous species at the top of the food chain. Its introduction into natural environments is hazardous to native ichthyofauna. One study demonstrated the impact of introducing trout in high-altitude streams in the south of the country. Its presence caused a decrease in species richness and abundance of native fish in places such as the Silveira River basin in the municipality of São José dos Ausentes, in Rio Grande do Sul. Thus, it is suggested that its occurrence leads to a decrease in habitat and competition for resources on the part of the species[17,156,157]. Other expected impacts of introducing this species in nature are related to the reduction of local genetic variability and medium- and long-term effects in the decrease in immunity of native fauna, among others[154].

12. *Micropterus salmoides* (Lacepède, 1802)/Common name: black bass

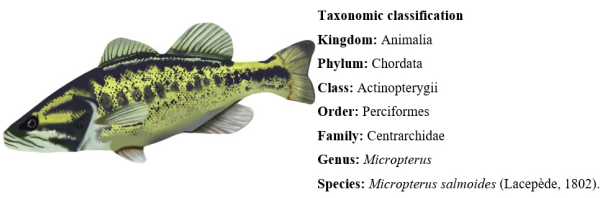

Figure 12. Drawing of *Micropterus salmoides* (Lacepède, 1802) and its taxonomic classification. Illustration by Lucas R. F. Santos.

Etymology

The name *Micropterus* comes from the Greek *micros* = small + *pteron* = wing, fin. The word *salmoides* is a reference to trouts and salmons[139].

Native distribution

This species is native to North America, occurring in southern Canada and the northern United States (in the Hudson Bay and Mississippi River, Atlantic drainages from North Carolina to Florida), as well as northern Mexico[17,158].

Morphology

The color of this species is quite varied, with olive green on the back and a black stripe on the side. This species exhibits tones between very light yellow and white in the lower region. It has a large mouth with a jaw in front of the eyes. It has 10 spines and 12–14 rays on the dorsal fin, three spines and 10 to 12 rays on the anal fin, and 17 rays on the caudal fin[159,139,153]. The highest recorded weight was 10.1 kg[160].

First occurrences, introduction history, and distribution in Brazil

The first introduction record of the species in Brazil dates back to 1922, in the municipality of Belo Horizonte, Minas Gerais[161]. The species was brought to fish farming activity in the country. However, sport fishing is also a significant factor in its dispersion in the sites of occurrence[17].

This species is considered cosmopolitan and is present practically on all continents. Several reports of environmental impacts related to the introduction of this species in natural environments in many countries occurred in at least 78 countries[17,139,153]. In Brazil, records are found in São Paulo, Minas Gerais, Santa Catarina, Paraná, Rio Grande do Sul, and the Federal District[161,162]. Perhaps because it is a species with specific environmental requirements, it has not yet been recorded in other states.

Reproduction

Reproduction in this species occurs in three phases: pre-spawning, spawning, and post-spawning. In the pre-spawning and spawning seasons, capturing the species is easier. However, its capture is more difficult in the post-spawning period. This species is oviparous. The male becomes very aggressive during the breeding season. It builds its nest on muddy bottoms and relatively shallow water[163,139]. The same female can visit several nests and mate with several males. The male takes care of and ventilates the fertilized eggs for about 29 days. The birth of the fry occurs between spring and summer when the water temperature is around 15ºC. In fish farms,

reproduction can occur from one year of age. However, it is more common after two years. In breeding ponds, they reproduce naturally without human intervention. No apparent sexual dimorphism between males and females has been reported[164,161,158,17].

Feeding behavior

This species has carnivorous feeding behavior, preferably on small fish, insects, larvae, frogs, and other beings. The species is considered a voracious predator, agile, and aggressive in capturing food[165,166].

Behavior

This species is very active in food searches and has little selectivity. The male is territorial and protects the nest, eggs, and fry in the first weeks of life, performing parental care[139].

Potential environmental effects

As this species is at the top of the chain, its arrival in natural environments has the potential to cause several impacts, possibly preying on various fish or organisms (with ample options in the diet) that fit in its mouth[17]. The black bass is among the 100 worst invasive species in the world[43,162], usually occurring in lakes, hydroelectric reservoirs, and dams.

4. Concluding Remarks

This material was intended to disseminate information as a booklet for the scientific and non-scientific community, seeking to reach breeders, fishermen, riverside dwellers, schools, and municipal environmental departments. These agents are of fundamental importance for environmental preservation, conservation of native fish species, and maintenance of their diversity, working consciously and stimulating the environmental education of those involved.

One of the main points shown here involves the changes in Law no. 11.959/09, which provides for the National Policy for the Sustainable Development of Aquaculture, made through Bill 5.989/09. This change removes some restrictions on farming exotic fish species and those with invasive attributes. Another point is Decree no. 10.576/2020, which makes the cultivation of IASs more flexible in the waters of the Union reservoirs, which poses a significant risk to the local ichthyofauna. In addition to current decision-making processes, such as the ongoing changes in obtaining environmental licenses, which are perceived as a relaxation of the licensing process, there is a potential setback in the application of criteria for assessing environmental impacts. Consequently, exotic species may exploit the vulnerabilities of this new process.

This informative material aims to bring to light the aspects that cause controversy within ecology and conservation, showing that the introduction of invasive exotic fish species can be directly related to actions such as irresponsible releases and ventures that were poorly planned (which allow the escape of fish), in addition to highlighting regulatory setbacks (laws) in the field[5,27]. Thus, it may serve as an endorsement of good production practices with responsibility and environmental safety.

The impacts of the arrival of invasive exotic species in the environment are felt directly by native species, which may cause a decrease or even the extinction of local species. This is mainly caused by increased competition, proliferation of diseases, and reduction of available resources, among others. Aquaculture is one of the main vectors of these introductions, and the species of international origin presented in this study would not occur in any basin in the country, considering the existing dispersion barriers.

It is concluded that maintaining the balance between food production and the search to reduce the environmental impacts of introducing invasive exotic species can help conserve native species. This challenge goes beyond the terrestrial environment, and due care and proper management in natural aquatic ecosystems are needed. Scientific knowledge and planning of effective public policy actions are necessary, combined with technical guidelines and information dissemination. This disclosure, aimed at the non-academic public, could be an essential tool for preserving native species to raise awareness about the impacts of invasive exotic species on local ecosystems among those responsible for the vectors. Adding management and management, great protection is indicated for fish farms, making them more sustainable (or less impactful) and investing in biosecurity against leaks. For example, the implementation of screens or filters for the effluents generated before releasing them in environments, disinfecting, and sterilizing the tanks (nursery) after the production cycles are measures that will contribute to mitigating cases of leaks and also to controlling the proliferation of diseases in the system[167].

Declaration of conflict of interest

The authors declare that there is no conflict of interest.

Author contributions

Conceptualization: E. A. Moreira. *Data curation:* E. A. Moreira and D. P. Silva. *Methodology*: E. A. Moreira. *Supervision:* D.P Silva. *Writing (original draft, review & editing)*: E. A. Moreira and D. P. Silva.

Supplementary material (only available in the electronic version) - link will be available after publication

Flyer - A dozen fish: Some exotic invasive species found in Brazilian waters (https://revistas.ufg.br/vet/article/view/74647/40077)

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