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Ecological and Genetic Implications Aquaculture Activities

Edited by
Theresa M. Bert

Aquaculture is a rapidly growing industry and aquaculture practices can directly interact with and depend upon the surrounding environment. Therefore, the effects of all types of aquaculture on living natural resources and ecosystems are of significant and increasing national and international interest. In Ecological and Genetic Implications of Aquaculture Activities, numerous nationally and internationally prominent aquaculture researchers contribute 27 chapters that comprise overviews of aquaculture effects on the environment, discussions of genetic considerations, thorough documentation of aquaculture effects and their solutions specific to countries, and approaches toward environmentally sustainable aquaculture. Together, these chapters comprise a comprehensive synthesis of many ecological and genetic problems implicated in the practice of aquaculture and of many proven, attempted, or postulated solutions to those problems. Many chapters can serve as benchmark documentations of specific aquaculture effects on biodiversity at different levels. The authorship is broadly international; the authors represent 18 different countries or international agencies and all continents except Antarctica. The aquaculture effects and their solutions range from local to global and simple to highly technical. Effects common to many levels and types of aquaculture emerge, as well as common solutions.
Aquaculturists, aquaculture researchers, aquaculture industry developers, conservation biologists, environmental scientists, resource managers, and policy makers should find this book interesting and informative.

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Theresa M. Bert (Ed.)

Reviews: Methods and Technologies in Fish Biology and Fisheries

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Salmon farming cages in the Reloncavi Estuary in Southern Chile, photograph by Fernando Jara.

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CHAPTER 16

IMPACTS OF NON-NATIVE FISH SPECIES IN MINAS GERAIS, BRAZIL: PRESENT SITUATION AND PROSPECTS

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Abstract: For some time, the rate of non-native fish introductions has been increasing in South America. There are many reasons for introductions: reservoir stocking programs, aquaculture, sport fishing, control of disease vectors, and the pet trade. Accidental escapes also contribute significantly. In Brazil, despite federal and state regulations, there are misunderstandings about such concepts as native, exotic, allochthonous, or autochthonous fishes and introductions, translocations, reintroductions, and transfers of fishes. Known impacts of exotic fishes include native species extinction, changes in competition and predation rates, limnological perturbations, introduction of diseases and parasites, hybridization with native species, and changes in fisheries composition. The few recorded benefits of non-native species introductions are restricted to the improvement of fish production and sport fisheries. In Minas Gerais, Brazil, records of exotic species have increased over the past seven years. In some of the most important river basins of that state, alien fish species might represent up to 40% of the fish fauna. Congeneric species, such as *Hyphessobrycon bifasciatus* and the exotic *H. eques*, can be captured from the same water body and the non-native species can be much more abundant than the native species. The recent introduction of *Leporinus macrocephalus* from the Pantanal may cause the same impact to the native *L. copelandii*. The widespread introduction of the peacock bass and other piscivorous species is the cause of local extinctions in the central lake of Lagoa Santa and in the

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Rio Doce valley lakes. Genetic problems can also be foreseen with the release of hybrids of *Pseudoplatystoma corruscans* and *P. fasciatum* in areas where only the first species naturally occurs. Tilapine species, the most widely distributed exotics within the state, have had negative impacts on fisheries and on fish species compositions in reservoirs. Solution to these problems must involve the following: (1) better enforcement of legislation governing the sale and transport of live organisms, (2) development of native-species aquaculture, and (3) public awareness programs on the adverse impacts of exotic species to the native fish fauna.

Key words: aquaculture, Brazil, environment, exotic species, fish introduction, fishery, Minas Gerais, ornamental fishes, stocking

1. INTRODUCTION

Although the introduction of non-native freshwater fish species is an ancient practice, it has become frequent on a global scale since the end of the 1800s. There are many reasons for introductions. Purposeful introductions can be for stocking reservoirs, improving aquaculture, controlling undesirable disease vectors, enhancing sport fishing, stocking ornamental fish, or increasing angler catches (Welcomme, 1984; Crivelli, 1995; Lever, 1998). In addition, fish confined for various reasons often escape. After habitat alterations, the introduction of alien species is the second main cause of fish species extinctions (Miller et al., 1989; Moyle and Leidy, 1992). Crivelli (1995) showed that, in the Mediterranean Sea, more than 80% of endemic freshwater fishes coexist with one or more exotic or transferred species, and many examples can be found in Cowx (1998).

The rate of introductions is still increasing in South America. This trend have been noticed in late 1980s (Welcomme, 1988). In Brazil, introductions did not begin until the early 20th century, coincident along with the growth of aquaculture activities. At that time, the federal government promoted the use of fish as an animal protein source for human consumption in the poor and arid Northeastern region of the country. Several Brazilian fishes, as well as species from other countries, were placed in reservoirs, and many became established. Escapes from fish-culture farms and from reservoir stocking programs in the Northeastern region were the initial sources of fish introductions in Brazil. Some purposeful introductions were also carried out in rivers during this time. Carps, tilapias, and Brazilian species such as the pirarucu (*Arapaima gigas*), peacock basses (*Cichla* spp.), croakers (*Plagioscion* spp. and *Pachyurus* spp.), curimbatá (*Prochilodus argenteus* = *P. marggravii*), and piaus (*Leporinus* spp.) are believed to be the first exotics released outside of their natural ranges (Menezes, 1953a, b).

A second period of introductions occurred in the middle 20th century, when hydroelectric power companies built hatcheries to mitigate the impacts negative of large dams on the reproductive migrations of native fish species. To minimize the impacts of their dams to migratory species, these energy companies invested in the development of fish production technology for those species. Although they made mistakes (e.g., the production and release of non-native species), they contributed significantly to native fish production technology, particularly of migratory species.

A third period of introductions is now in progress, fueled by an increased demand for fish production, the aquarium trade, and ''pay-to-fish'' (fee-fishing) farms. These activities have stimulated the transfer of Brazilian species among basins, as well as the introduction of additional non-Brazilian fish species, such as the very aggressive walking catfish *Clarias gariepinus* (Alves et al., 1999) and the rainbow trout, *Oncorhynchus mykiss* (Magalhães et al., 2002a).

Few studies report the impacts of alien fish species on the Brazilian native fish fauna, but such concerns are increasing. Here, we describe the fish species introductions in the state of Minas Gerais, southeastern Brazil (Figure 1). We outline the history of legislation involving introductions, describe the pathways for introductions and the actual or possible impacts of introductions, and provide recommendations for minimizing further introductions in the future. We use English common names, and scientific names from the Fishbase Project (www.fishbase.org; Froese and Pauly, 2003). For unlisted species, the Brazilian or translated names are used.

2. LEGAL ASPECTS OF INTRODUCTIONS IN BRAZIL

In Brazil, there are conflicts in interpreting the laws that deal with non-native species. The misunderstandings began with confusion over concepts and terms. Even with specific federal and state laws, there are misunderstandings about concepts such as native, exotic, allochthonous, or autochthonous species and introduction, translocation, reintroduction, or transfer of species.

In a Federal Decree (#145/98-1998), these categories of aquatic species are defined as follows:

1. native: species with origin and natural occurrence in Brazil;
2. exotic: species of foreign origin and natural occurrence only in other countries, even if already introduced to Brazil;
3. autochthonous: species of origin and natural occurrence within the Brazilian watershed in question;
4. allochthonous: native species of origin and natural occurrence in Brazil but outside the Brazilian watershed in question.

However, these definitions may create inappropriate loopholes in the laws or in the interpretations of the law. Here, we do not distinguish biological differences between the introduction of an exotic species or an allochthonous species. If a peacock bass (*Cichla* spp., from Amazonia) or a walking catfish (*Clarias* spp., from Africa) is introduced into a river outside of its natural range, either is a non-native species to the host community. The deleterious effects of both on the native fauna could be the same. Therefore, we assume that the terms exotic, alien, non-indigenous, and non-native have the same meaning and use only the

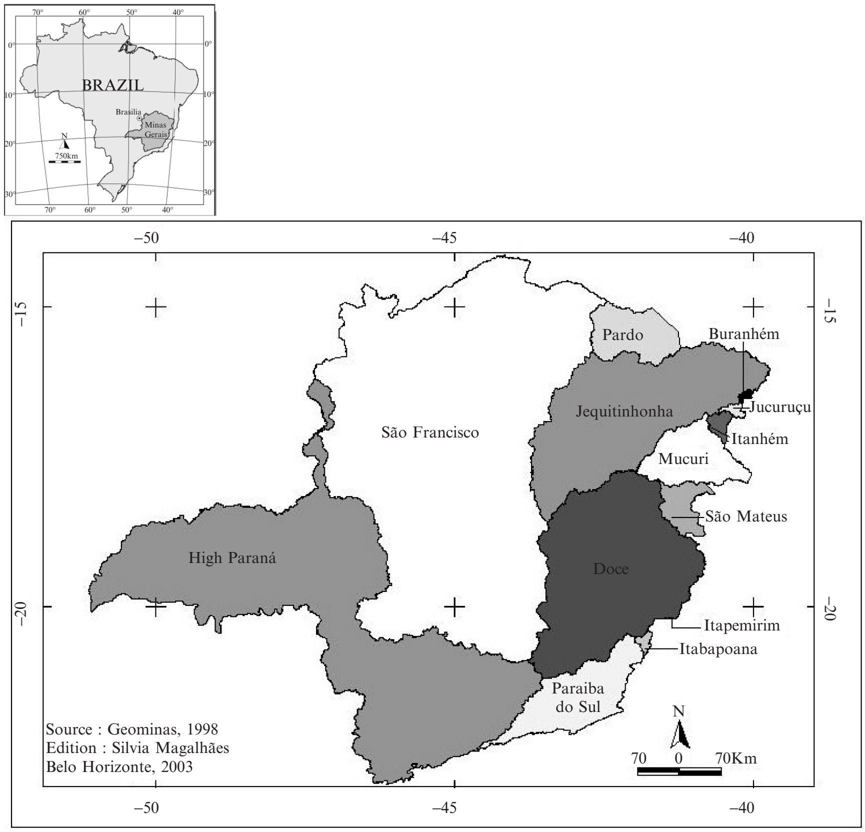

Figure 1. Location and river basins of Minas Gerais, Brazil

term non-native. Legislation should consider all of these terms equally; all imply that the species under consideration is not from the river basin in question.

Activities associated with the movements of these species are also defined by Brazilian law, as follows:

1. introduction: import of a non-native species, or a hybrid, into an area where it did not occur before;
2. translocation: any process of moving a species between river basins, from inside or outside the country;
3. reintroduction: import of a non-native species, or a hybrid, into an area where it occurred before;
4. transfer: translocation of a given species from one river basin to another, where it is considered to be allochthonous.

Especially in a nation with the size and geographic complexity of Brazil, where river basins and states are larger than some other nations, it matters little from an ecological perspective whether a non-native species comes from a different country, continent, or Brazilian river basin, when that species is released into the natural environment. From an ecological perspective, the laws must consider any species as non-native when it is located outside of its natural range of distribution. The historical geographic range of the species is also important when you are questioning whether a species is non-native.

In Brazil, there are good federal and state laws on introducing non-native species. For example, Federal Law # 9.605-1998 states the following:

1. introduction is prohibited and considered a crime;
2. transfer, translocation, and reintroduction must be licensed.

In addition, in Minas Gerais, State Law # 12.265-1996 and Decree-Law # 38.744-1997 state the following:

1. introduction is considered damaging to the native fauna and is prohibited without government permission;
2. the culture and transport of live fishes must be licensed.

However, such laws are frequently controlled, repressed, not followed, or, with the assistance of ambiguous terminology, manipulated.

Misunderstanding and misinterpretation of laws can lead to mismanagement of native species or inappropriate mitigation of environmental damage. For example, because regulations for both native and exotic species have restrictions on the sizes of fish that can be legally caught and kept, a fisherman may be prohibited from catching a non-native species at a size smaller than the legal length, but may be allowed to fish for an officially endangered species (e.g., the jaú, *Zungaro jahu* = *Paulicea luetkeni* [Machado et al., 1998]) within the permitted size range. There are many examples in which prosecutors require an environmental aggressor or polluter to stock fishes in order to mitigate damage, often a fish kill. Because as the accused generally have little knowledge of local species or access to fry of appropriate native species, such judgments can lead to the release of non-native species that further harm the native species.

Local environmental or sports-fishing interests may also cause the creation of inappropriate measures. For example, the Itamonte local government, by means of decree number 001-1997, created a sport fishing area at the Rio Aiuruoca headwaters to stimulate a rainbow trout fishery supported by the National Sport Fishing Development Program (PNDPA, 2000).

In summary, although laws governing non-native fish species exist, in practice, fish introductions are of little concern. In fact, any citizen can buy cultured fish from any Brazilian river basin or from another country and release them into privately owned water bodies. The owners and managers of many privately operated hatcheries state in magazine advertisements that their fishes can be delivered to anywhere in Brazil.

3. THE SITUATION IN MINAS GERAIS

3.1. General Overview

Minas Gerais, which is slightly larger than France, is one of the biggest Brazilian states. It has an area of $586{,}528.3\,km^2$ and a growing population, currently of approximately 18 million people (IBGE, 2002). It is drained by 13 different river basins (Figure 1); the São Francisco and High Paraná are among the largest hydrographic basins in Brazil. A total of around 400 fish species, including 63 non-natives, have been recorded in the state. These numbers could be underestimates because some river systems have not yet been thoroughly investigated.

For each basin, the total number of known species, number of known non-native species, and change in the number of non-native species in the past six years are shown in Figure 2A. To obtain a perspective on the proportions of non-native species to the total number of species in each river basin, we used an index of contamination, as calculated by the following equation:

$$\mathrm{CI} = \frac{\mathrm{E}}{\mathrm{N} + \mathrm{E}}$$

where CI = contamination Index, E = number of exotic species, and N = number of native species. The CI varies from 0 in pure assemblages, with no non-natives, to 1 in totally contaminated communities, with only non-native species.

In Figure 2B, we illustrate the relationship between the total number of species and the proportional level of non-native species contamination in each of these river basins. Fortunately, the two largest river basins in Minas Gerais, the High Paraná and São Francisco, contain relatively low proportions of non-native species (Figure 2B). In contrast, most of the less diverse, smaller river basins contain relatively high numbers and proportions of non-native species, particularly the Paraíba do Sul and Doce (Figure 2). (We acknowledge that the number of species may not be a good indicator of the total number of non-native individuals in a river basin and that the thoroughness of sampling is not equal among river basins.)

The Neotropical biogeographic area is the world's richest in fish species (around 8000 species [Schaefer, 1998]), but is also one of the least known (Menezes, 1996). In Minas Gerais, non-native species records have increased over the past seven years, compared with available data through 1996 (Alves and Vieira, 1996). Relatively large numbers of new records have been documented for some areas. Those are areas where few past studies were conducted or where field research is currently occurring. Nevertheless, the number of non-native species introductions into Minas Gerais may be underestimated.

Tilapine species (i.e., *Oreochromis* spp. and *Tilapia* spp.) are the most widespread non-native species in Minas Gerais, and they are present in almost all river basins. In reservoirs, aspects of their biology (omnivorous feeding habit, reproductive strategy with parental care, resistance to pollution, adaptations

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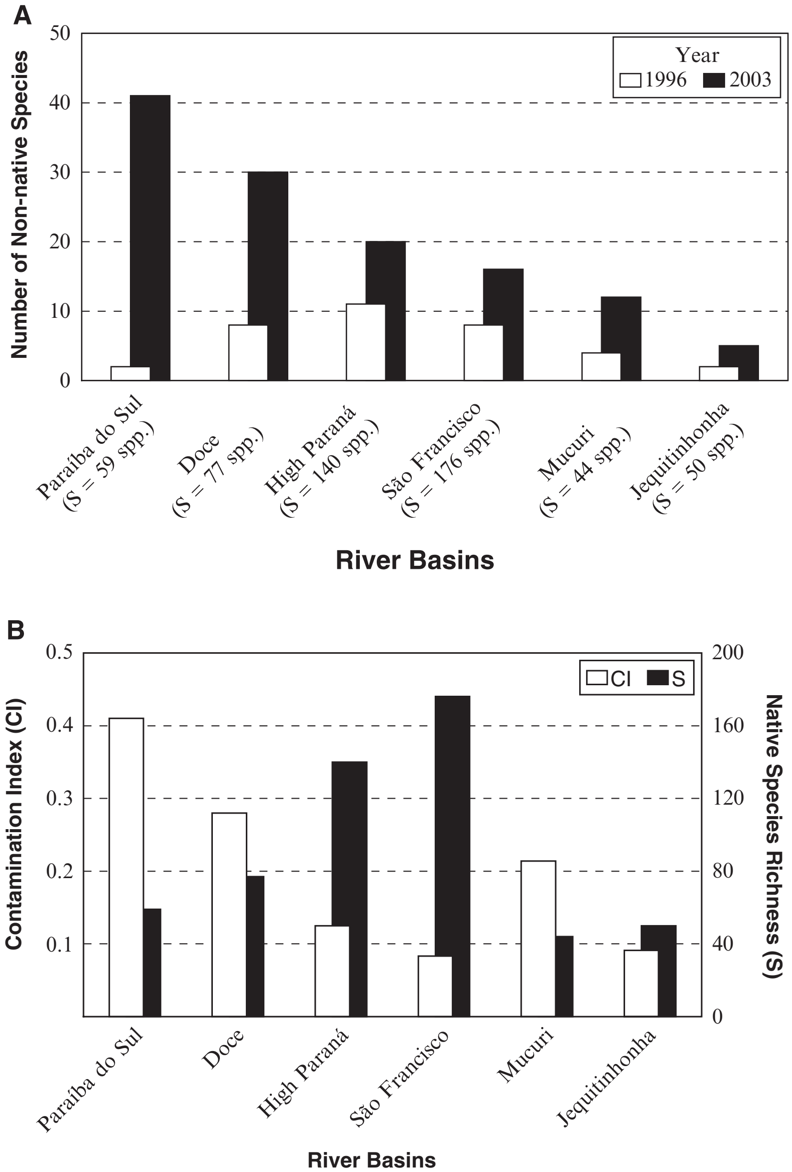

Figure 2. Characterization of fish species in Minas Gerais, Brazil main river basins. Values are based on estimates from Alves et al. (1998), Costa et al. (1998), and V. Vono, Universidade Federal de Minas Gerais (personal communication). A. Number of exotic fish species, 1996 and 2003. In brackets: the total species richness (S) in each river basin. B. Total number of species (black bars; includes both native and non-native fishes; and level of contamination with non-native fish species (white bars). Index used to calculate level of contamination is presented and defined in the text (Section 3.1)

to still waters, fast growth) are advantages in competition with native species. In most reservoirs, they have large populations and are commercially fished. In other regions of the country, the negative impacts of these species have changed not only fisheries but also fish species compositions in reservoirs (Menescal and Attayde, 2001).

3.2. Purposes and Known Impacts of Introductions

The purposes of fish introductions in Minas Gerais are well known, as they are in the rest of the world. Some factors that contribute to the number of introductions are proximity of hatcheries to rivers, river alterations (dams, canals, and water transfers), stocking programs, deliberate releases, use of live bait, or habitat disturbances in the natural environment, which also may increase the chances of non-native species establishment (Moyle and Light, 1996; Gido and Brown, 1999). However, the establishment of non-native species can be inhibited by the isolation of drainages; by inadequate habitat for successful reproduction of the non-native species; by interactions with native species; when the number of introduced individuals is small; or when environmental conditions such as water levels, salinity, or temperature are adverse (Ross, 1991; Baltz and Moyle, 1993; Crivelli, 1995; Gido and Brown, 1999).

The principal reasons for non-native species introductions into the natural environment and some examples of the genera introduced into Minas Gerais are listed in Table 1. Over 90% of Brazilian electricity is hydropower (Kohlhepp, 1999), and Minas Gerais is one of the states with great hydroelectric energy production potential in Brazil. That state has more than 2000 small, medium-sized, and large reservoirs. The population of Minas Gerais is growing and the increasing number of inhabitants leads to increasing energy demands. Many new dams are already under construction or are under study for their viability. Because reservoir stocking programs are among the main causes of non-native fish introductions in Brazil (Agostinho and Júlio, Jr., 1996; Vieira and Pompeu, 2001), this pathway for introductions must be an increasing concern. The creation of artificial reservoirs alters local ecosystems and the chance of invasion success can be augmented in altered ecosystems (Ross, 1991; Moyle and Light, 1996), especially when lotic environments are changed into lentic ones.

Stocking for sport fishing also occurs directly in river systems. In southern Minas Gerais, which has high-altitude (above 1300 m), cold, clear, well-oxygenated waters, trout can easily become established. There, an intense local culture linked with rainbow trout exists; it includes a sport fishery, aquaculture, and culinary art in which trout have been used in traditional dishes for almost 50 years. All trout species are non-native to Brazilian waters. Escapes of rainbow trout from fish ponds are frequent and may increase the probability that this species will definitively establish in local waters and impact the unique natural fish fauna of that region.

Table 1. Known purposes and examples of non-native fish genera introduced into Minas Gerais, Brazil (**X**). Dash = no information or not applicable

Purpose of introduction	Genus																							
	Astronotus	*Cichla*	*Carassius*	*Clarias*	*Colossoma*	*Cyprinus*	*Hoplias*	*Gymnocorymbus*	*Hyphessobrycon*	*Lepomis*	*Lophiosilurus*	*Micropterus*	*Mikrogeophagus*	*Oncorhynchus*	*Oreochromis*	*Piaractus*	*Plagioscion*	*Poecilia*	*Pseudoplatystoma*	*Pterophyllum*	*Pygocentrus*	*Salminus*	*Tilapia*	*Xiphophorus*
Accidental	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	X	–
Aquaculture	–	–	–	–	X	X	–	–	–	–	–	–	–	–	X	–	–	–	X	–	–	–	X	–
Deliberate (aquarium release)	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–	X
Fishery improvement	–	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–	X	–	–	–	–	X	–	–
Forage	–	–	–	–	X	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ornamental	–	–	–	–	–	–	–	X	X	–	–	–	X	–	–	–	–	–	–	X	–	–	–	–
Pay-to-fish ponds	–	–	–	X	X	X	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–	–	X	–
Reservoir stocking	–	–	–	–	–	–	X	–	–	–	–	X	–	–	–	–	X	–	–	–	–	–	X	–
Sport fisheries	–	X	–	–	–	–	–	–	–	–	–	X	–	X	–	–	–	–	–	–	X	X	–	–
Undesirable organisms control	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–	–

Known impacts of non-native species introductions are as follows (Kabata, 1970; Courtenay and Stauffer, 1984; Welcomme, 1988; Miller, 1989; Ross, 1991; Rosenfeld and Mann, 1992; Scribner and Avise, 1993; Hickley, 1994; Lever, 1998; Trexler et al., 2000; Tapia and Zambrano, 2003):

1. extinction of native species;
2. perturbations of limnological conditions;
3. introduction of diseases, pathogens, and parasites;
4. hybridization between native and non-native species, with the possibility of genetic introgression;
5. changes in fish assemblage structure, with altered competition and predation rates;
6. changes in fisheries composition;
7. damage to low-fecundity native species;
8. adverse effects to local or regional social–economic structure.

Many of these have already occurred in Minas Gerais.

The few benefits of non-native species introductions are restricted to the improvement of fish production and sport fisheries (Pullin et al., 1997; Bartley and Casal, 1998). These benefits are mainly related to the monetary return that non-native species can provide to human populations through the commercialization of fish as food, ornamental species, or sport fish. Environmentally, no introduction can be considered positive.

3.3. Case Studies

3.3.1. Changes in lower Rio Doce fisheries

The Rio Doce drains 82,000 km^2 in Minas Gerais and Espírito Santo (86% of the river system is in Minas Gerais). The great majority of its area is heavily altered by a variety of human activities, with negative consequences on the ichthyofauna. At present, anglers dominate fishery activities because low productivity precludes commercial utilization. Professional fishermen concentrate their activities on the middle and lower reaches of the main stem. Before 1970, many diadromous species in the genera *Centropomus*, *Mugil*, *Caranx*, and *Eugerres* were regularly captured by commercial fishermen in this region. They constituted a fishery of considerable value. After 1974, construction of the Mascarenhas Hydropower plant limited the distribution of such species to the stretch below the dam, i.e., outside of Minas Gerais. This change in the river channel led to a less productive fishery above the dam; however, approximately 50 fishermen continue to utilize this resource. To reduce the consequences of the dam, a fish passage has been recommended, but has not yet been constructed.

As a result of the change in fish composition and reduction in size of the commercial fishery in this portion of the Rio Doce, non-native species were stocked to increase fish availability. No official records of stocking in the Rio Doce exist except for the dourado (*Salminus brasiliensis*) (Ruschi, 1965) and the walking catfish (Alves et al., 1999). The black armored catfish (*Pogonopoma* *wertheimeri*), the last non-native species introduced, was brought into the area by local people after 1997. In Aimorés County, studies in 1997 and from 2002 to 2003 produced 50 fish species, 14 of them non-native (F. Vieira, personal observations). In the past, the local fishery was based on native catfishes and characins. Few native species are currently of commercial importance. Two native species formerly important to the local commercial fishery, the piabanha (*Brycon* cf.devillei.) and the "surubim-do-Rio-Doce" (*Steindachneridion doceanum*), are now "commercially extinct." Only the armored catfishes (Loricariidae), which are highly appreciated and demand good prices, remain in the local fishery market. The importance of the introduced species to the local fishery varies considerably among species (Table 2); most introduced species became established and now are components of the commercial catches. Four non-native species (*Hoplias lacerdae*, *Lophiosilurus alexandri*, *Oreochromis niloticus*, *Prochilodus costatus*) make up the bulk of the current fishery. The fisheries production of walking catfish is also high, but its commercial value is low. Among the exotics, the red piranha (*Pygocentrus nattereri*) is the only introduced species avoided by fishermen due to the destruction of fishing gear and handling accidents. Other introduced species are of less fisheries importance or do not contribute to fisheries. Although the composition of the species commercially fished in the Rio Doce has changed, the non-native species provide commercial fishes to professional fishermen. However, this new situation has eliminated focus on the problems caused by environmental degradation associated with construction of the dam—changes in water flow, silting, water pollution, and clearing of vegetation.

Table 2. Relevance to professional fishing of exotic fish species in the Aimorés region, Rio Doce basin, Minas Gerais, Brazil

Species	Abundance	Professional fishing relationship	Local importance to fishermen's gains
Astronotus ocellatus	Low	Positive	No importance
Cichla spp.	Medium	Positive	Low
Clarias gariepinus	Low	Positive	Low
Hoplias lacerdae	High	Positive	High
Hoplosternum littorale	Medium	Neutral	No importance
Lophiosilurus alexandri	High	Positive	Very high
Oreochromis niloticus	High	Positive	Very high
Pimelodus maculatus	Low	Positive	Low
Pogonopoma wertheimeri	Low	Neutral	No importance
Prochilodus costatus	High	Positive	High
Pseudoplatystoma sp.	Low	Positive	Low
Pygocentrus nattereri	High	Negative	No importance
Salminus brasiliensis	Low	Positive	Low
Tilapia rendalli	Low	Positive	Low

3.3.2. The ornamental fish trade and the introduction of non-native species

In Muriaé County, the Rio Glória, which flows into the Rio Muriaé (Rio Paraíba do Sul basin), is the most important aquarium fish production area in South America (Vidal, Jr. and Costa, 2000). The substantial ornamental fish-culture industry there has resulted in a fish assemblage that is composed of up to 50% non-native species, and recent studies show an increasing rate of new records for aquarium species in the environment (Magalhães et al., 2002b). Non-native aquarium species are continuously escaping into the wild from the high concentration of small ornamental fish farms (more than 250 farmers and about 3000 production ponds; Vidal, Jr. and Costa, 2000) located on or near the river. Through international and intercontinental shipping and movement of living organisms, including fish, into the area, the ornamental fish trade could threaten the native fauna (Andrews, 1990). For example, in this river, there are two species of tetras—the native yellow tetra (*Hyphessobrycon bifasciatus*) and the non-native common serpa tetra (*H. eques*), which has a natural range in the Rio Paraguay basin. These species have the same body size, feed on the same items, share the same habitat, and probably have the same reproductive strategy. The non-native species is now more abundant than the native species. At Itamuri, a small district of Muriaé County, the livelihoods of at least ten families are maintained by fishing only the common serpa tetra, using fish traps. They can catch more than 2000 specimens in a few days. The fish are sold in São Paulo and Rio de Janeiro ornamental fish markets. Experimental fishing has shown that *H. eques* occurs in high numbers whereas *H. bifasciatus* occurs in low numbers (LIMIAR, 2004; C.B.M. Alves, personal observation), but abundance studies in areas without *H. eques* are needed to determine if *H. bifasciatus* naturally occurs at low densities and if *H. eques* is displacing *H. bifasciatus*.

In the same river, the red piau (*Leporinus copelandii*), an attractive native fish species that can attain a weight of up to 4 kg, is one of the most important species in commercial and angler catches. Recently, another anostomid, the piauçu (*Leporinus macrocephalus*) was introduced into the region by a local sport fishermen's association. This species, which is native to the Pantanal (West-central Brazil), is bigger than the native species. Both species are migratory and have the same feeding habits and habitat requirements. Thus, they could compete for space, food, and shelter. Similarly, in the Córrego Santo Antônio and Córrego Boa Vista, tributaries of Rio Glória, both native (*Phalloceros caudimaculatus*, *Poecilia vivipara*) and non-native (*Poecilia reticulata*, *P. sphenops*, *Xiphophorus hellerii*, *X. maculatus*, *X. variatus*) poeciliids co-occur and have similar reproductive strategies, feeding habits, and habitat requirements. These species could compete, with unknown consequences.

3.3.3. Local extinctions in lakes

Local fish species extinctions in Minas Gerais have been documented. In a Rio Doce valley lake, 50% of the native fish species disappeared after introduction of a piscivorous peacock bass (*Cichla ocellaris*) and the red piranha (*Pygocentrus nattereri*) (Godinho et al., 1994). Data provided by Sunaga and Verani (1991), who studied the lakes (biannually) from 1983 to 1987, were the basis for such comparisons. The effects of these introductions were not restricted to reduced species richness. In lakes with peacock bass and red piranha, small-sized individuals of native species are absent and the piscivorous native trahira (*Hoplias malabaricus*) switched its diet of principally small fishes to a higher component of macroinvertebrates and insects, probably to avoid competition (Pompeu and Godinho, 2001).

Damages caused by *C. ocellaris* introductions are well known in other tropical lakes, such as Gatun Lake, Panama (Zaret and Paine, 1973). This species radically changed the fish composition of the lake by eliminating six of the eight most common native species. Molina et al. (1996) reported the extinction of a native species of pacu (*Metynnis* cf. *roosevelti*) caused by introduced peacock bass in Northeastern Brazil.

The fish fauna of the central lake of Lagoa Santa was originally evaluated between 1850 and 1856 (Lütken, 2001). Approximately 70% of the original fish fauna was extirpated by 2002 (Pompeu and Alves, 2003). Although other environmental impacts affected the fish assemblage of Lagoa Santa, one cause of this drastic fish diversity loss was the introduction of four non-native species: a peacock bass (*Cichla* cf. *monoculus*), the trairão (*Hoplias lacerdae*), a tilapia (*Tilapia rendalli*), and a calichtid armored catfish—the hassar (*Hoplosternum littorale*). The first two species are piscivorous and attain larger sizes than other picivorous fishes originally present in the lake. The locally extinct species included two small native piscivorous species—the dog fish (*Acestrorhynchus lacustris*) and the white piranha (*Serrasalmus brandtii*)—and *Characidium lagosantense*, which is one of three officially endangered species in Minas Gerais freshwaters (Machado et al., 1998).

3.3.4. Introductions of piscivores

Special attention must be given to the introduction of piscivores. They are commonly introduced because they have great appeal as sport fish. They tend to be very successful colonizers because they have advantages over native species that lack adaptations to avoid their predatory behavior. This is a common mechanism that leads to the extinction of fishes (Moyle and Light, 1996).

A number of Brazilian piscivores have been introduced and become established in regions of the country where they are not native. For example, the peacock basses (*Cichla* spp.), which are native to the Amazon region, caused problems in the central lake of Lagoa Santa (Pompeu and Alves, 2003), in the Rio Doce main stem and its lakes (Godinho and Formagio, 1992), and, together with the South American silver croaker (*Plagioscion squamosissimus*), in the Rio Grande (Santos et al., 1994; Santos and Formagio, 2000). *Cichla* spp. are becoming very widespread. They are stimulating changes in native fish assemblages and fisheries, such as in the Rio Piquiri in the Pantanal (Nascimento et al., 2001), Três Marias reservoir in the São Francisco basin (Magalhães et al., 1996) and Itumbiara reservoir in the Rio Paranaíba (Santos, 1999), where they are important for both commercial fishing and sport fishing. The dourado (*Salminus maxillosus*), a ferocious piscivore originally absent from the Rio Paraíba do Sul basin, was introduced in 1884, 1931, and 1945 (Moraes-Filho and Schubart, 1955) but was not present in local fish markets until 1948. The same species also was introduced and became established in the Rio Doce basin.

Piscivorous fish introductions are also likely to impact other native species in the near future. We foresee a problem with *Steindachneridion* species. In Minas Gerais, four species of this large native catfish, endemic to Eastern Brazilian river basins, are considered endangered (Lins et al., 1997). The most recent evaluation of endangered native species, to be ratified by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA), includes four *Steindachneridion* species. Based on our observations of more than ten years, we believe that these species are almost extinct throughout their natural range in the basins of Rio Doce (*S. doceanum*) and Rio Paraíba do Sul (*S. parahybae*) due to environmental disturbances, including the introduction of other piscivores in the genera *Cichla*, *Clarias*, *Hoplias*, *Lophiosilurus, Pseudoplatystoma*, and *Salminus*. Many of the non-natives are larger than the native species. They are establishing where they have been introduced and are increasing the competition for food. *Steindachneridion* spp. have natural low densities, but although increased pollution and the elimination of migratory routes through the fragmentation of the main river stem by hydropower dams (Bizerril and Primo, 2001) also impact these species, their recent extremely low captures rates (they are essentially commercially extinct) could be partially attributed to the impacts of the introductions.

3.3.5. Hybridization, genetic introgression, and stocking

Hybridization is another consequence of the introductions of non-native species that are closely related to native species (Crivelli, 1995). The closely related *Hyphessobrycon*, *Leporinus*, and poeciliid species mentioned above could hybridize, particularly if they share the same reproductive niches and timing. In addition, two of the three recognized species of the commercially valuable *Pseudoplatystoma* catfishes have been artificially hybridized (*P. corruscans* $\times$ *P. fasciatum*; Figure 3). The first species occurs naturally in the São Francisco and Paraná basins and the latter in the Paraná and Amazon basins. As the hybrid spreads to many Southeastern river-basin areas for aquaculture, there is a danger of genetic introgression and reduced fitness of the mixed stock (Scribner and Avise, 1993) or displacement of the native species (Simberloff, 1996) if reproduction between the hybrid and either parental species is possible. There are no studies yet on the reproductive capacity of these hybrids.

Genetic problems associated with non-native species introductions have not received the required attention. Even when native species have been used for

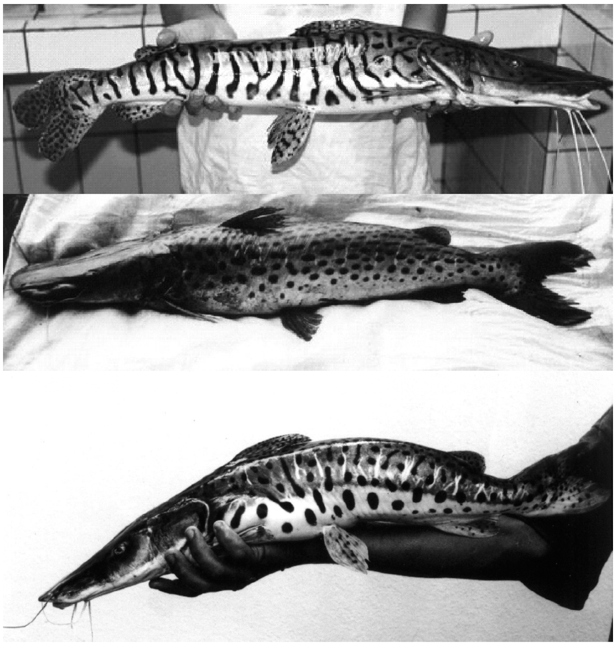

Figure 3. From the top, *Pseudoplatystoma fasciatum, Pseudoplatystoma corruscans* and the hybrid between them

stocking, there has been no evaluation of the successes or failures of stocking programs. Broodstocks in hatcheries always contain fish from a variety of different populations and the genetic composition of the broods reared for release is not examined. In addition, there are no monitoring studies to determine if introduced individuals reach reproductive age and disseminate their genetic characteristics. The possibility of genetic introgression is real because all government hatchery stations release millions of fry, alevins, and juveniles annually into existing wild populations.

4. PROSPECTS AND CONCLUSIONS

In the long term, as species spread to basins out of their natural ranges, there is a risk of fish faunal homogenization. The non-native species composition will be the same in many Brazilian river basins whereas on a broad scale, local native species could become less numerous and less abundant over time. Thus, waterways should be monitored for changes in species composition, density of native versus non-native individuals, and the appearance of hybrids.

In some important river basins of Minas Gerais, non-native fish species represent up to 40% of the total species richness (Figure 2). Certainly, many factors determine the susceptibility of an assemblage to invasions, but it is difficult to know which factors lead to the success of introduced species (Gido and Brown, 1999). Clearly the best approach is to reduce introductions altogether and to utilize the native species in the best way possible. Reducing the introduction of new species can be approached in a number of ways:

1. Consider improving regulations for the sale and transport of live organisms and clarify and enforce existing legislation. If the present laws, decrees, and rules were followed and respected, the spread of non-native fish species could be slowed or halted.
2. Publicize the adverse impacts of non-native species on the native fish fauna in audience-specific manners to politicians, legislators, decision makers, researchers, university staffs, school children, water-side communities, pet shop owners, sport fishers, etc. As an example of public misconception of the issue, many stocking programs are justified purely as environmental education instruments instead of being assessed for appropriateness and monitored for effectiveness.
3. Develop the aquaculture of native species. This could slow the spread of non-native species by providing alternatives to their culture. Although Brazil has the world's greatest freshwater fish biodiversity, fish ponds in hatcheries are dominated by exotic species. This development of native-species aquaculture would, of course, need to include the use of appropriate broodstock to reduce genetic impacts of escapes on local populations. Each river basin should have its own native cultivated stock of each species. Special concern must be given to raise public awareness regarding the non-native ornamental (Andrews, 1990) and commercial fish trades.

The aim of these proposed solutions is to stop or slow the spread of non-native species. Otherwise, Brazil will be another country with a large number of well-established, non-native species (currently, N =104 [Gurgel and Oliveira, 1987; Welcomme, 1988; Orsi and Agostinho, 1999; Bizerril and Lima, 2001; Magalhães et al., 2002b; Paiva et al., 2002]). The dramatic examples of impacts observed in Africa (Barel et al., 1985; Lowe-McConnell, 1993) and Florida (Trexler et al., 2000) could thus be readily replicated in Brazil if the people do not act soon.

Minas Gerais already has a large number of non-native fish species (Table 3) compared with other Brazilian states or regions such as the northeast (N = 39 [Gurgel and Oliveira, 1987]), Rio de Janeiro state (N = 37 [Bizerril and Lima, 2001]), and Paraná state (N = 13 [Orsi and Agostinho, 1999]), and elsewhere in the world (Table 4). Removal of non-native species is practically impossible. The problems created by introduced species are difficult or impossible to solve, but can be prevented by limiting their spread, as well as avoiding new introductions. Thus, it is more critical to prevent new non-native fish introductions than to attempt to remove established non-native fishes. At the present rate of introductions, Minas Gerais and Brazil, as a state and country, will soon

Table 3. Introduced species in Minas Gerais State (Brazil)

Non-native species	Hydrographic basin (native species richness): Paraíba do Sul (59)	Doce (77)	High Paraná (140)	São Francisco (176)	Mucuri (44)	Jequitinhonha (50)
Aristichthys nobilis	–	X	X	–	–	–
Astronotus ocellatus	–	X	X	X	–	–
Callichthys callichthys	X	–	–	–	–	–
Carassius auratus	X	–	–	–	–	–
Cichla monoculus	X	–	X	X	–	–
Cichla ocellaris	–	X	–	–	–	–
Cichla temensis	–	–	–	X	X	–
Clarias gariepinus	X	X	X	X	X	X
Colisa lalia	X	–	–	–	–	–
Colossoma macropomum	X	X	X	X	X	–
Corydoras sp.	X	–	–	–	–	–
Ctenopharyngodon idella	–	X	–	–	–	–
Cyprinus carpio	X	X	X	X	X	–
Danio frankei	X	–	–	–	–	–
Danio malabaricus	X	–	–	–	–	–
Danio rerio	X	–	–	–	–	–
Gymnocorymbus ternetzi	X	–	–	–	–	–
Hemichromis bimaculatus	X	–	–	–	–	–
Hoplias lacerdae	X	X	X	X	X	X
Hoplosternum littorale	X	X	X	X	–	–
Hyphessobrycon eques	X	X	X	–	–	–
Hypophthalmichthys molitrix	–	X	–	–	–	X
Ictalurus punctatus	–	X	–	–	–	–
Laetacara curviceps	X	–	–	–	–	–
Lepidosiren paradoxa	–	–	–	X	–	–
Lepomis gibbosus	–	X	–	–	–	–
Leporinus macrocephalus	X	X	X	–	X	–
Lophiosilurus alexandri	–	X	–	–	–	–
Macropodus opercularis	X	–	–	–	–	–
Metynnis maculatus	X	X	X	–	–	–
Micropterus salmoides	–	X	X	–	–	–
Mikrogeophagus ramirezi	X	–	–	–	–	–
Misgurnus anguillicaudatus	X	–	–	–	–	–
Odonthestes bonariensis	–	–	X	–	–	–
Oncorhynchus mykiss	–	–	X	–	–	–
Oreochromis niloticus	X	X	X	X	X	–
Piaractus mesopotamicus	–	X	X	X	–	–
Pimelodus maculatus	X	X	–	–	–	–
Plagioscion squamosissimus	–	–	X	X	–	–
Poecilia reticulata	X	X	X	X	X	–
Poecilia sphenops	X	–	–	–	–	–
Pogonopoma wertheimeri	–	X	–	–	–	–
Polycentrus schomburgkii	X	–	–	–	–	–

(*Continued*)

Table 3. Introduced species in Minas Gerais State (Brazil)—cont'd.

	Hydrographic basin (native species richness)					
Non-native species	Paraíba do Sul (59)	Doce (77)	High Paraná (140)	São Francisco (176)	Mucuri (44)	Jequitinhonha (50)
Prochilodus argenteus	–	X	–	–	–	–
Prochilodus costatus	–	X	–	–	X	X
Prochilodus lineatus	–	–	–	X	–	–
Pseudoplatystoma hybrid[1]	X	X	–	–	X	–
Pterophyllum scalare	X	–	–	–	–	–
Puntius conchonius	X	–	–	–	–	–
Puntius nigrofasciatus	X	–	–	–	–	–
Puntius semifasciolatus	X	–	–	–	–	–
Puntius tetrazona	X	–	–	–	–	–
Pygocentrus nattereri	–	X	–	–	–	–
Salminus brasiliensis	X	X	–	–	X	–
Satanoperca pappaterra	–	–	X	–	–	–
Tambacu[2]	–	X	–	–	–	–
Tanichthys albonubes	X	–	–	–	–	–
Tilapia rendalli	X	X	X	X	X	X
Trichogaster chuna	X	–	–	–	–	–
Trichogaster trichopterus	X	–	–	–	–	–
Xiphophorus hellerii	X	X	–	–	–	–
Xiphophorus maculatus	X	–	–	–	–	–
Xiphophorus variatus	X	–	–	X	–	–

[1] Hybrid of *P. corruscans* × *P. fasciatum*.
[2] Hybrid of *C. macropomum* × *P. mesopotamicus*.

have the largest numbers of non-native species in the world, many of them will be well-established and reproducing in the wild.

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Table 4. Number of known introduced species in selected states, countries, or regions of the world

State, country, or region	Number of species	References
Australia	22	McKay, 1984
Brazil (all)	104	Gurgel and Oliveira, 1987; Welcomme, 1988; Orsi and Agostinho, 1999; Bizerril and Lima, 2001; Magalhães et al., 2002b; Paiva et al., 2002
Brazil (Minas Gerais)	**63**	**This paper**
Brazil (northeast)	39	Gurgel and Oliveira, 1987
Brazil (Paraná)	13	Agostinho and Júlio, 1996
Brazil (Rio de Janeiro state)	37	Bizerril and Lima, 2001
Canada	18	Crossman, 1984
Chile	21	Welcomme, 1988
Cuba	10	Wotzkow, 1998
Dominican Republic	16	Chakalall, 1993
France	26	Keith and Allardi, 1998
Greece	23	Economidis et al., 2000
Hawaii	50	Yamamoto and Tagawa, 2000
India	19	Seraji et al., 2000
Iraq	7	FAO, 1997
Israel	18	Golani and Mires, 2000
Italy	25	Bianco, 1998
Jamaica	9	Chakalall, 1993
Japan	34	Chiba et al., 1989
Madagascar	31	Stiassny and Raminosa, 1994
Mexico	55	Contreras and Escalante, 1984
Morocco	24	Azeroual et al., 2000
New Zealand	25	McDowall, 1984
Pacific islands (all)	56	Maciolek, 1984
Portugal	11	Almaça, 1995
Puerto Rico	32	Erdman, 1984
Singapore	38	Ng et al., 1993
Spain	25	Elvira and Almodóvar, 2001
Sri Lanka	15	Fernando, 1971
USA (California)	162	Fuller et al., 1999
USA (Colorado)	106	Fuller et al., 1999
USA (Florida)	127	Fuller et al., 1999
USA (Nevada)	93	Fuller et al., 1999
USA (Texas)	105	Fuller et al., 1999

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