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Alien fishes in lakes of the Doce river basin (Brazil): range, new occurrences and conservation of native communities

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Abstract

The present study shows the distribution of alien fish species in tropical lakes in the middle Doce river basin, southeastern Brazil, obtained from a rapid assessment program. The causes for their introductions were sport-fishing improvement in some specific lakes and aquaculture in the studied basin. Presently, these species have a wide distribution occurring in 41 of the 54 lakes studied, representing an actual threat to regional native fish community. The natural connection among lakes and streams during the rainy season and the dispersal mediated by local people are the main invasion agents for alien fishes. The success of these invaders is probably due to absence of pre-existing effective competitors or top-predators in the invaded communities. We consider that the eradication of alien fishes by means of the available management tools may be very difficult due to the large number of lakes invaded and to the wide spectrum of lake conditions and resources exploited by these alien species. We recommend the use of environmental education as a tool to stop the human-mediated dispersion of aliens and to improve conservation of native fish community in lakes where these alien species are not present yet.

Keywords: Alien species, biological invasions, biodiversity conservation, fish, tropical lakes.

Introduction

Physical and biotic factors and the interactions among them are the determinants of the composition and organization of any fish community (Jackson et al., 2001). Species distribution on the planet can reflect their effective niche, which can be restricted in its range due to interference of physical, biotic, and historical factors.

The advent of global transport in the last three or four centuries and the development of present global-scale transport have promoted the transfer of animal and plant species over geographical barriers and their establishment in new regions (Ricciardi & Maclssac, 2000). Alien and genetically modified species are accidentally or purposefully introduced in new regions to produce social and economic benefits (Thomas & Randall, 2000). Introduction of fish species is an old activity that can provide economical benefits such as food production – aquaculture – improvement and sport fisheries availability (Welcomme, 1988; Ferber, 2001; Latini, 2002). Nevertheless, these introductions also cause problems as economic losses (USBC, 1998) and environmental and social damage of large proportions (Zaret & Paine, 1973; Wanink & Goudswaard, 1994; Guan & Wiles, 1997; Huckins et al., 2000; Olden et al., 2004). Introduction of alien species is the second most important cause of extinctions, less important only than habitat destruction (Sala et al., 2000). The impacts caused by alien species can be severe, widespread and irreversible (Zalba et al., 2000; Woodward & Hildrew, 2001).

Global experiences show that management plans for alien species produce a set of unexpected results from uncontrolled experiments (Simberloff, 2001): numerous attempts for alien eradication have shown to be inefficient, possibly due to the large number of possible combinations (and dependent-relations) among invaders, native community and invaded

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environment, including local people (Howard, 2000). These interactions caused undesirable effects of management plans on native populations, besides local people rejection of alien-species eradication practices (Kolar & Lodge, 2001; Simberloff, 2001).

The Doce river basin, in southeastern Brazil, contains a large number of lakes originated in two geological periods, between one thousand and four hundred years ago (Tundisi & De Meis, 1985). About 142 lakes occur in this system, 72 in the right and 70 in the left margin of the Doce river. In this region, there is an Atlantic Rainforest reserve, the Parque Estadual do Rio Doce (PERD), where 42 of these lakes are located. During periods of high pluviosity, these lakes present a high connectivity, behaving as an interconnected environment, facilitating aquatic migration of specimens (Latini, 2001). Probably, these water corridors are an important factor for the dispersal of the aliens peacock bass, *Cichla* cf. *ocellaris* (Bloch & Schneider 1801), and red piranha, *Pygocentrus nattereri* (Kner 1858), among the lakes, threatening the regional native fish communities (Latini & Petrere, 2004).

In this study, we provide an assessment of the present range of alien fishes in that lake system and discuss the consequences of alien fish introductions for conservation of the native fish communities of these lakes. We also make recommendations for management and conservation research aiming to minimize the impact of alien fishes on the aquatic biota of the lakes of the Doce river basin.

Material and methods

This study was conducted between 42º45’W and 42º25’W and 19º50’S and 19º30’S in the Atlantic Forest domain, regarded as one of the planets’ most important biodiversity hotspots (Myers et al., 2000). The lakes studied are distributed over an area of 58,000 ha, of which 36,000 ha are in the PERD, and 22,000 ha in areas owned by the Companhia Agrícola Florestal (CAF, Arcelor Group). Within the PERD area, fishing activities are only allowed for scientific purposes (except in the Dom Helvécio Lake). The CAF area is an *Eucalyptus* plantation, where fishing is allowed in some lakes. Satellite images (Landsat 7 ETM+) were used in order to locate the lakes. The 72 lakes included in this study are distributed among three small river basins: Belém, Turvo and Mombaça (Fig. 1).

In all lakes studied at PERD and CAF, data on fish communities were obtained between February and May 2002, with four different methods, to identify the occurrence of alien fishes in a rapid assessment protocol. These methods were: i) interviews with fishermen found by the lakes with non-structured questions, followed by immediate visual identification of cited species (CAF lakes); ii) visual observations in clear water lakes; iii) fishing with artificial baits (hook and line sampling) during 30 minutes; iv) fishing for 30 minutes with 6 gill-net panels with the same length (10 m) and height (1.6 m) and with mesh sizes of 15 mm, 20 mm, 30 mm, 40 mm, 50 mm and 60 mm, between adjacent knots (a sampling effort of 30 $m.h^{-1}$). This mesh interval for gill nets captured more than 99% of fish specimens and 100% of fish species obtained in a previous study made between May and August 2000, in six of the Doce river lakes (Latini & Petrere, 2004).

The advantage of this procedure is the integration of passive (gill nets) and active (visual observation, fishing with artificial baits) fishing methods and interviews that can result in a more powerful detection of alien fishes in a rapid assessment program. The use of only one of these methods, as the passive gill nets, can be too selective and less effective in detecting alien species, since different fish species are not equally susceptible to the same methods.

Most sampled fishes were identified, recorded and immediately returned to the lakes. This procedure was adopted due to the authors previous experience with species identification in this community, and because we were not examining abundance data but only the presence of species. Specimens with uncertain identity were fixed at 10% formalin and identified in the laboratory using appropriate identification keys.

The response variable used to analyze alien species distribution was the categorical presence or absence of fishes. The occurrence of an alien species was only considered after visual identification of at least one specimen. On the other hand, non-occurrence of a given species was only accepted after all sampling methods employed fail to detect it.

Results

Among the 42 lakes sampled in the PERD area, 10 (23.8%) were dry and in only three (9.4%) of the remaining 32, alien fish species were not detected. Of the 30 lakes sampled at the CAF area, six (20%) were dry. In fourteen (58.3%) of the 24 remaining lakes there was at least one alien fish species (Tab. 1).

Of the seven alien fish species occurring in the lakes studied, the red piranha *Pygocentrus nattereri*, the peacock bass (tucunaré) *Cichla* cf. *ocellaris* and the acará do Amazonas (oscar) *Astronotus ocellatus* (Agassiz, 1831) had already been recorded in previous studies (Godinho, 1994; Latini, 2001); the African catfish (bagre africano) *Clarias gariepinus* (Burchell, 1822), the Nile tilapia (tilapia) *Oreochromis niloticus* (Linnaeus, 1758), the singing catfish (tamoatá) *Hoplosternum litoralle* (Hancock, 1828) and the tambaqui *Colossoma macropomum* (Curvier, 1818) (Tab. 1) were firstly recorded during this study.

The species with widest occurrences in the region were probably the first to be introduced, the peacock bass and the red piranha, which occurred in 58.9% of the PERD lakes and 53.6% of the CAF lakes (Tab. 2). In all, 76.8% of all lakes at the left side of the Doce river (Fig. 1) have at least one alien fish species.

Discussion

Like in other regions around the world (Hall & Mills, 2000; Ferber, 2001; Katunzi et al., 2003) and in Brazil (Agostinho & Júlio, 1996), in the lakes of the Doce river basin, the introduction of alien species reduced the ecological integrity of the invaded fish communities, altering their biomass, diversity and species richness (Godinho, 1994; Latini, 2001; Latini & Petrere, 2004).

Since the 1970’s, fish species were introduced in the studied lakes for sport fishery purposes (Godinho, 1996). Although we do not have bibliographic references on the

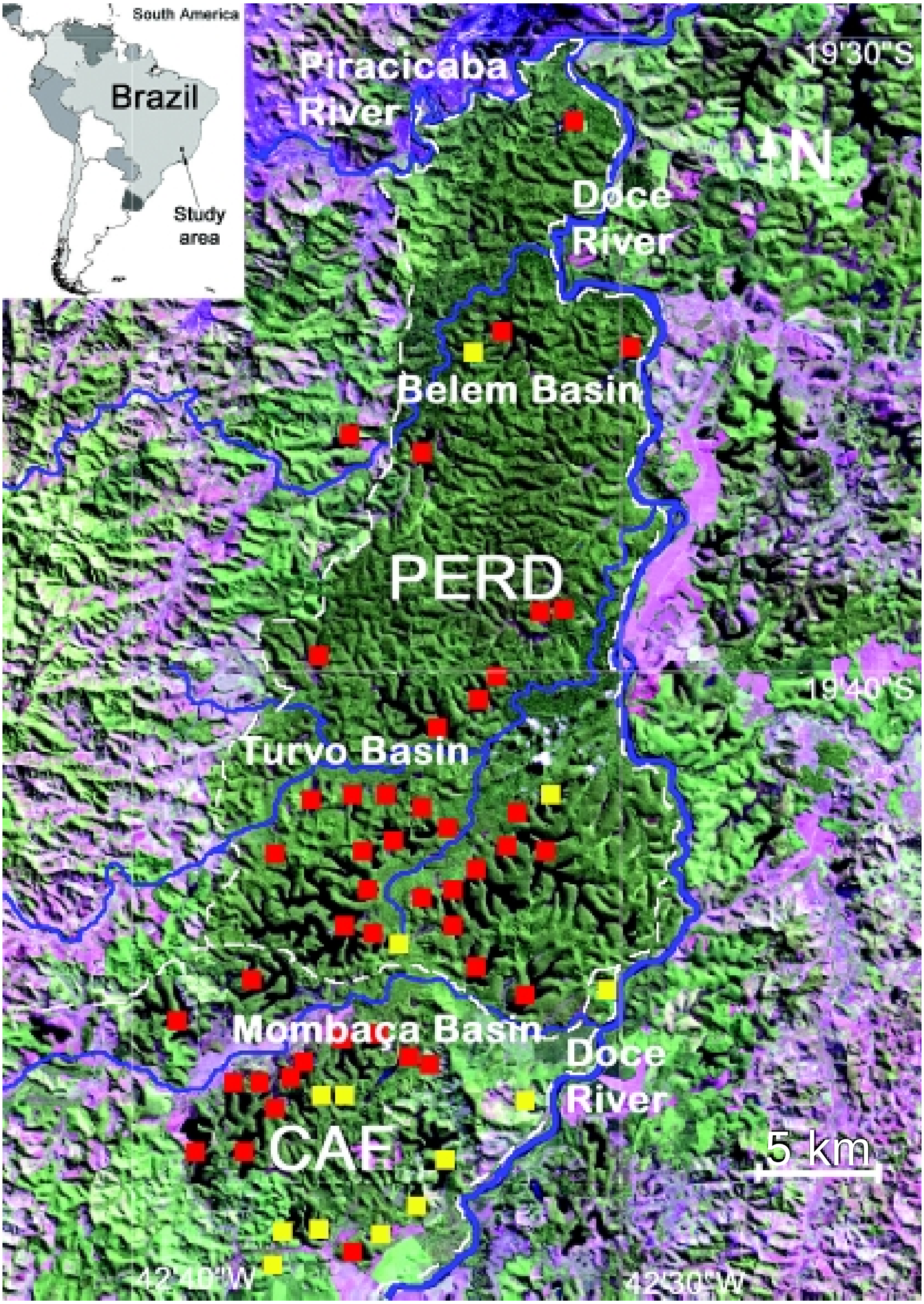

Figure 1 - Location of the lakes studied in the Doce river Basin. The image shows the Piracicaba and the Doce rivers, as well as the Belém, Turvo and Mombaça creeks. The lakes sampled are at the left margin of the Doce river in the PERD and CAF areas (limited by dotted lines). Red and yellow squares indicate lakes with and without alien fishes species, respectively.

Table 1 - Alien fish occurrence in 56 lakes of the Doce river basin distributed within the Parque Estadual do Rio Doce (PERD) and the Companhia Agrícola Florestal (CAF) areas. Presence is signed as 1, absence as 0. Last column represents total alien fish species in each lake.

Lake	Study Area	Alien fish species							Alien occurrence
		Red piranha	Peacock bass	African catfish	Singing catfish	Amazonian Acara	Nile tilapia	Tambaqui	
Aguapé	CAF	0	0	1	0	0	1	0	2
Águas Claras	CAF	1	1	0	0	0	0	0	2
Amarela	CAF	1	1	0	0	1	0	0	3
Ariranha	CAF	1	1	1	0	0	0	0	3
Baixa Verde	CAF	0	1	0	0	0	0	0	1
Barra	CAF	1	1	1	1	0	0	0	4
Bicalho	CAF	0	0	0	0	0	0	0	0
Café	CAF	0	0	0	1	0	0	0	1
Capim	CAF	0	0	0	0	0	0	0	0
Carvão Azeite	CAF	0	0	0	0	0	0	0	0
Crentes	CAF	0	0	0	0	0	1	0	1
Diquada	CAF	0	0	0	0	0	0	0	0
Ferrugem	CAF	0	0	0	0	0	0	0	0
Ferruginha	CAF	0	0	0	0	0	0	0	0
Jacarés	CAF	1	1	1	1	1	0	0	5
Malba	CAF	0	0	0	0	0	0	0	0
Mescla	CAF	0	0	1	0	0	1	1	3
Nova	CAF	0	0	0	0	0	0	0	0
Palmeiras	CAF	0	0	0	0	0	0	0	0
Palmeirinha	CAF	1	1	1	1	0	0	0	4
Poço Redondo	CAF	0	0	0	1	0	0	0	1
Romoalda	CAF	0	0	0	1	0	0	0	1
Timburé	CAF	0	0	0	1	0	0	0	1
Verde	CAF	0	0	0	0	0	0	0	0
Aceiro	PERD	1	0	0	0	0	0	0	1
Águas Claras	PERD	1	1	0	0	1	0	0	3
Amarela	PERD	1	1	0	0	0	0	0	2
Anastácia	PERD	1	1	0	0	0	0	0	2
Aníbal	PERD	0	1	0	0	0	0	0	1
Azul	PERD	0	0	0	0	0	0	0	0
Boné	PERD	1	1	0	0	0	0	0	2
Bonita	PERD	1	1	0	0	0	0	0	2
Carioca	PERD	1	1	1	1	0	0	0	4
Central	PERD	0	1	1	0	0	0	0	2
Chatinha	PERD	1	0	0	0	0	0	0	1
Comprida	PERD	1	1	0	0	0	0	0	2
Cumbaca	PERD	1	1	0	0	0	0	0	2
Dom Helvécio	PERD	1	1	0	0	1	0	0	3
Folhinha	PERD	1	1	0	0	0	0	0	2
Gambá	PERD	1	1	0	0	0	0	0	2
Gambazinho	PERD	0	0	0	0	0	0	0	0
Gancho	PERD	1	1	0	0	0	0	0	2
Juquita	PERD	0	1	0	0	0	0	0	1
Lagoinha	PERD	0	0	0	0	0	0	0	0
Marobá	PERD	1	1	0	0	0	0	0	2
Meio	PERD	1	1	0	0	0	0	0	2
Palmeiras	PERD	1	1	0	0	0	0	0	2
Patos	PERD	1	1	0	0	0	0	0	2
Piabas	PERD	1	1	0	0	0	0	0	2
Piaus	PERD	1	1	0	0	0	0	0	2
Preta	PERD	0	1	0	0	0	0	0	1
Queiroga	PERD	1	1	0	1	1	0	0	4
Santa Luzia	PERD	1	1	0	0	0	0	0	2
São José	PERD	1	1	0	0	1	0	0	3
Terceira	PERD	0	1	0	0	0	0	0	1
Vermelha	PERD	1	0	0	0	0	0	0	1

Table 2 - Summary of alien fish occurrence (number and percentage of lakes) obtained in a rapid assessment program in 54 lakes in the Doce river region (Minas Gerais state, Brazil), and original range of alien species. PERD = Parque Estadual do Rio Doce; CAF = Companhia Agrícola Florestal.

Species	Original range[1]	Number of lakes with records in the area		Total regional occurrence
		PERD	CAF	
Peacock bass, *C. ocellaris* (Bloch & Schneider 1801)[a]	South America: Marowijne drainage in Suriname and French Guiana to the Essequibo drainage in Guyana. Amazon drainage in Peru, Colombia and Brazil; Oiapoque river in Brazil.	26 (81.2%)	7 (29%)	33 (58.9%)
Red piranha, *P. nattereri* (Kner 1858) [b]	South America: Amazon River basin, Paraguay-Parana River basin, northeastern Brazilian coastal rivers, Essequibo River basin.	24 (75%)	6 (25%)	30 (56.7%)
African catfish, *C. gariepinus* (Burchell, 1822)[c]	Africa: almost Pan-Africa, absent from Maghreb, the upper and lower Guinea and the Cape province and probably also Nogal province. Asia: Jordan, Israel, Lebanon, Syria and southern Turkey. Widely introduced to other parts of Africa, Europe and Asia.	2 (6.2%)	6 (25%)	8 (14.3%)
Singing catfish, *H. litoralle* (Hancock, 1828)[d]	South America: Most Cis-Andean South American river drainages north of Buenos Aires, Argentina.	2 (6.2%)	7 (29%)	9 (16%)
Amazonian Acara, *A. ocellatus* (Agassiz, 1831)[e]	South America: Amazon River basin in Peru, Colombia, Brazil. Also known from French Guiana.	4 (12.5%)	2 (8.3%)	6 (10.7%)
Nile tilapia, *O. niloticus* (Linnaeus, 1758)[c]	Asia: coastal rivers of Israel; Africa: Nile from below Albert Nile to the delta; Jebel Marra; Lake Chad basin and the rivers Niger, Benue, Volta, Gambia and Senegal.	0	3 (12.5%)	3 (5.3%)
Tambaqui, *C. macropomum* (Curvier, 1818)[c]	South America: Amazon and Orinoco basins as wild form; pisciculture form largely distributed in South America.	0	1 (4%)	1 (1.7%)
Total lakes invaded		29 (90.6%)	14 (58.3%)	

[a] Introduction for sport fishing.
[b] Introduction for sport fisheries purposes; probably to peacock bass control.
[c] Introduction by accidental escapes from aquaculture ponds.
[d] Possibly introduced as bait.
[e] Introduction causes unknown.
[1] Froese & Pauly (2004)

matter, regional fishermen believe that the first invader to arrive there was *C.* cf *ocellaris* (which was introduced by regional fishery associations) and that this caused the reduction of native fishery. Regional fishermen also declared that *P. nattereri* was introduced afterwards just for the control of *C.* cf. *ocellaris* populations and to recover native species populations. Perhaps, the long time since the introduction of these species is one of the causes for their wider distribution among these lakes, due to the possible number of events of propagule spreading.

The other five alien fish species were introduced more recently (possibly in the 1990's) and this is probably one explanation for their small range among the lakes. *H. litoralle* is commonly used in some Brazilian basins as a bait for capturing other fishes, and this could be a possible reason for its introduction in the Doce river lakes. *C. macropomum*, *O. niloticus* and *C. gariepinus* are species economically important for aquaculture in this region and this is the main cause for their introduction. The reasons for the introduction of *A. ocellatus*, however, are unknown, since its ornamental use represents an inexpressive activity in this region.

In the Doce river lakes, both active and passive mediation have a considerable influence on dispersal due to the stream drainage among lakes (Latini, 2001) and the fishermen demand for sport species such as *C.* cf. *ocellaris* (Lima, 2003). If time since introduction is an important factor to explain the differences in range between the most frequent alien species (peacock bass and red piranha) and the others, then the future incidence of alien species will possibly increase their negative impact on the native fish species.

Relationships between alien species and biotic and abiotic factors in recently invaded environments are important for explaining the success of biological invasions. The original species richness of the native communities in the lakes studied apparently was very low, as suggested by data from lakes without introduced fish species (Latini & Petrere, 2004). It reached a maximum of 10-15 species per lake and a total of 25 species for all lakes together (Godinho & Vieira, 1998). This low species richness, with its consequent high probability of resources availability and lower native competitors and predators pressure, may be one factor leading to the native communities' lower resistance to alien invasions (Mack et al., 2000).

Ecological, physiological and genetic attributes are also very important to determine the invaders success (Arthington & Mitchell, 1986; Sakai et al., 2001). Among the seven fish species introduced in the Doce river lakes, at least five show parental care, which could increment their survival rates. All invaders, but *C. macropomum*, build nests where eggs develop and some of them, as *C.* cf. *ocellaris*, display parental care until the young reach 3 to 4 cm in body length (Lowe-McConnell, 1999).

Predatory behavior can be other important invader attribute, placing them on the top of the food webs at these lakes (Moyle & Light, 1996; Marchetti et al., 2004). *C. gariepinus*, *C.* cf. *ocellaris* and *P. nattereri*, have a predominantly ictiophagous diet. The other alien species (*O. niloticus*, *H. litoralle*, *A. ocellatus* and *C. macropomum*) are omnivores but some of them may display carnivorous behavior, preying on young fish phases (Lowe-McConnell, 1999). It is interesting to note that the later behavior, besides enhancing resource availability to alien fishes, also reduces the competition with other species due to direct abundance reduction.

Our categorical data are not ideal for the interpretation of biodiversity losses; however, previous studies indicate that the presence of these alien species is related to massive extinction of the native species (Latini & Petrere, 2004). This supports our ideas about the actual threat represented by the alien species to regional native fish fauna. Possibly, the firstly affected native species would be the fishes most easily detected visually. However, we have no behavioral data on this native fish fauna and this information is essential for the prediction of which would be the most fragile native species.

Management of biological communities in the invaded lakes in the Doce river basin seems to be little promising, due to the successful establishment of the alien species. Their wide range in that region suggests that they can be acclimated to or, in some cases, adapted to a large spectrum of resources and conditions. This fact can make their removal difficult by known management practices (Mack et al., 2000).

Considering that in 10 of the 24 lakes sampled in the CAF area, there are no alien fishes and that the human-mediated dispersal can be an important process to determine these alien distributions, education can be a solution to reduce the threat to native community (Latini & Petrere, 2004). Lima (2003) reported that local people do not consider alien fish introductions as a threat to the native community and also that they believe that introductions are a good means to improve sport fishery. Without education, we believe that no management activity will succeed, due to the continuity of alien introduction and dispersal by local people.

Thus, to improve native fish conservation in the region it is necessary to work on improving the awareness of the local people, and their knowledge on general aspects of the environmental sciences and on the value of native biodiversity. So, we expect an increase in the interest on fishing activities that do not represent harm to native fauna. We sustain that research activities designed to better understand the biological invasions of the Doce river lakes (from both the invaders and invaded communities' stand points) and environmental education can be significant actions for regional fish conservation.

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Zaret, T. M. & Paine, R. T. 1973. Species introductions in a tropical lake. **Science**, **182**: 449-455.**Figure Legend.**