Oecologia Australis
15(3): 631-642, Setembro 2011
doi:10.4257/oeco.2011.1503.14

ANIMAL INVADERS IN SÃO PAULO STATE RESERVOIRS

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ABSTRACT

Freshwaters are among the most vulnerable ecosystems regarding biological invasions. Reservoirs built after the last half century in São Paulo State have been continuously subjected to the introduction and establishment of alien species, both exotic and allochtonous. Here we present a short historical and the present status of some recent, still going on, biological invasion processes, for both, invertebrate and vertebrates, with emphasis on Tietê River basin. Among reservoir communities, the zooplankton has the lowest number of established exotic species, with 4 species: the cladocerans *Ceriodaphnia dubia* and *Daphnia lumnholtzi*, the cyclopoid copepod *Mesocyclops ogunnus* and the rotifer *Kellikotia bostoniensis*. Among the macroinvertebrate communities there is a fast ongoing invasion by three exotic species of mollusks, the Asian clam, *Corbicula fluminea*, the African-Asian gastropod, *Melanoides tuberculata*, and the golden mussel, *Limnoperna fortunei*, this latter a cause of greatest concern. However by far the community most affected by introduction of alien species is the ichthyofauna. In reservoirs of Tietê, Paranapanema and Rio Grande rivers, the main tributaries of the Upper Parana basin, the relative proportion of alien species vary approximately between 10 and 25% of the total number of species. Most introductions were derived from anthropic activities, either from direct local introduction, the so called *peixamento* or by accidental escape from nearby fish farming installations. Some species have profound effects on the structure of the fish community, as recently happened in Lobo (Broa) reservoir after the introduction of the *Cichla kelberi.* The African *Sarotherodon niloticus* and *Tilapia rendalli* and the allochtonous *Plagioscion squamosissimus* became the dominant species in many São Paulo state reservoirs. The complex interaction between biological invasions, water pollution and eutrophication, is the possible cause for many native species extinction going on in São Paulo State rivers and cascade of reservoirs. At short time and local scale, management actions are urgently required to eradicate or minimize the impact of exotic species in the reservoirs, especially in the small ones, and at longer time and larger scales, education and law enforcement are essential tools for both prevention of new introductions and management to the already existing problems.

Keywords: Biological invasions; exotic fishes; exotic mollusks; reservoirs; invasive species.

RESUMO

ANIMAIS INVASORES NOS RESERVATÓRIOS DO ESTADO DE SÃO PAULO. As águas doces enquandram-se entre os ecossistemas mais vulneráveis às invasões biológicas. Reservatórios construídos após a metade do último século no estado de São Paulo têm sido continuamente sujeitos à introdução e estabelecimento de espécies exóticas e alóctones. Neste trabalho nós apresentamos um breve histórico e o status atual de

processos de invasão biológica recentes, alguns ainda em andamento, para ambos, invertebrados e vertebrados, com ênfase na bacia do Rio Tietê. Entre as comunidades presentes nos reservatórios, o zooplâncton tem o menor número de espécies exóticas estabelecidas, com apenas 4 espécies: os cladóceros *Ceriodaphnia dubia* e *Daphnia lumnholtzi*, o copépodo ciclopóide *Mesocyclops ogunnus* e o rotífero *Kellikotia bostoniensis*. Entre as comunidades de macro-invertebrados, rápidos processos de invasão estão em andamento, por três espécies de moluscos, o bivalve asiático, *Corbicula fluminea*, o gástropodo africano-asiático, *Melanoides tuberculata*, e o mexilhão dourado, *Limnoperna fortunei*, sendo este último motivo para grande preocupação. No entanto, de longe, a comunidade mais afetada pela introdução de espécies alienígenas é a ictiofauna. Nos reservatórios dos Rios Tietê, Paranapanema e Rio Grande, os principais tributários da bacia do Alto Rio Paraná, a proporção relativa de espécies alienígenas varia aproximadamente entre 10 e 25% do número total de espécies. A maioria das introduções são decorrentes de atividades antrópicas, seja pela introdução local direta, o chamado peixamento, ou pelo escape acidental de instalações de piscicultura próximas. Algumas espécies têm efeitos profundos sobre a estrutura da comunidade de peixes, como ocorrido recentente na represa do Lobo (Broa) após a introdução do tucunaré, *Cichla kelberi*. As tilápias africanas *Sarotherodon niloticus* e *Tilapia rendalli* e a espécie alóctone *Plagioscion squamosissimus* se tornaram dominantes em muitos reservatórios do estado de São Paulo. A interação complexa entre as invasões biológicas, a poluição da água e a eutrofização são a causa provável para a extinção de muitas espécies nativas que estão acontecendo em rios e cascatas de reservatórios do estado de São Paulo. Em curto prazo e em escala local, as ações de manejo são urgentemente necessárias para erradicar ou minimizar o impacto das espécies exóticas nos reservatórios, especialmente nos de menor tamanho, e em longo prazo e escalas maiores, estratégias educativas e legais são ferramentas essenciais para ambas, a prevenção de novas introduções e o manejo dos problemas já existentes.
Palavras-chave: Invasões biológicas; peixes exóticos; moluscos exóticos; reservatórios; espécies invasoras.

INTRODUCTION

Biological invasions are among the problems inherited from last century and to which ecologists and scientists from many other areas will have to join efforts to find solutions. Invasive species have been worldly recognized as a major threat to biological diversity including the aquatic biota.

Freshwaters are considered among the most invaded ecosystems on Earth (Ricciardi & McIsaac 2011) and potentially affected at all different levels of organization, from individuals to whole ecosystems (Strayer *et al.* 2006).

Technological advances developed in last century enabled men to disperse themselves moving fast through oceans and between continents and transporting materials and species to even the most remote places of the planet. Exotic species are then allowed to reach new areas that were previously beyond their own dispersal capacity. By establishing new populations in other regions or continents some of them can become equivalent and frequently more harmful to native species than the habitat destruction or fragmentation, factors that were considered the main causes of biodiversity losses in the last century (Vitousek *et al*. 1997).

Biological invasions do not operate as an isolated factor and its interactions with climate changes such as the rising of CO^2 atmosphere concentrations, temperature changes or stratospheric ozone levels can cause great impacts on the biota (Occhipinti-Ambrogi 2007, Dukes 2011)

The concern regarding invasive exotic species grows substantially as the knowledge on their increases. Some species might alter so profoundly the ecosystems and communities they infest by using resources essential to the native species or by making habitats so altered that they become unfit to them. As pointed out in recent works, the ecologists urgently need strong theory and consistent empirical data to enable them to model, predict, understand and manage adequately the effects of biological invasion events (Strayer *et al*. 2006).

Freshwater biodiversity is disproportionately imperiled when compared with its terrestrial counterpart, because besides the introduction of alien species they are also impacted by habitat

alterations, heavy pollution and overexploitation (Dextrase & Madrak 2006).

The fact that in aquatic ecosystems the water flux acts as a natural pathway that facilitates the invasion of new areas in hydrographic basins have been suggested as an important aspect for its vulnerability (Dumont 1999, Rocha *et al.* 2005).

Some aquatic ecosystems seem to be more vulnerable to invasions than others, such as the isolated lakes and small rivers. They are comparable to small oceanic marine islands that have been shown to have very little resistance to the invasion by alien species (Ricciardi & McIsaac 2011).

Reservoirs are a type of ecosystem that might be also largely vulnerable to the invasion of exotic species. Although usually placed in large rivers, they have continuous inputs of biological materials from main river and tributaries and export them downstream, being both, vulnerable themselves to invasion and a pathway to continue to spread the aliens to other places of the basin.

In a recent discussion on the functioning of tropical reservoirs Barbosa *et al*. (1999) introduced the cascading reservoir continuum concept (CRCC) pointing out that in many hydrographic basins the construction of consecutive reservoirs can present some problems propagating impacts such as eutrophication, nuisance algal blooms or toxicants.

A worse problem in reservoir cascade systems is the spread of invasive species that can act and disperse on their own, and do not degrade with time, unlike pollutants. Once introduced, they can spread from reservoir to reservoir, tributary to tributary, reaching the whole basin.

Cascades of reservoirs were built in São Paulo State rivers in the last century, mainly devoted to hydropower generation (Tundisi *et al*. 1999, Nogueira *et al*. 2006). These systems have been greatly impacted by deforestation and erosion of marginal areas as a consequence of agricultural activities and other land uses, toxic contamination by industrial and sanitary effluents and, more recently, by biological contamination with a variety of alien species (Agostinho & Julio 1996, Tundisi 2003, Rocha *et al*. 2005, Tundisi & Matsumura-Tundisi 2008). The largest rivers draining São Paulo State (Rio Grande, Rio Tietê and Rio Paranapanema), tributaries of the Upper Paraná River basin, do present complex reservoir cascades that greatly reduced the free river stretches forming the typical cascading reservoir continuum.

The main objective of the present study was to analyze the current status of biological invasions in São Paulo State reservoirs, possible threats and possible management actions.

MATERIALS AND METHODS

In this paper the data presented and discussed are derived from empirical studies developed in the Laboratory of Limnology of the Federal University of São Carlos, in the Center of Applied Water Resources of the University of São Paulo, and in the International Institute of Ecology at São Carlos under the scope of special biodiversity conservation programs such as the Program of Excellence Nuclei (PRONEX/CNPq), the National Program of Biodiversity (PROBIO/MMA) and the Biodiversity Program of São Paulo State (BIOTA/FAPESP), besides literature data, including both articles published in specialized Journals and original Dissertations and Thesis.

The studies reported here were mainly developed inside governmental and research agencies initiatives inside three inter-institutional projects regarding freshwater biodiversity and invasive species: PRONEX (MCT/FINEP/CNPq), BIOTA (FAPESP) and PROBIO (MMA/WORLD BANK).

SAMPLING

Zooplankton samples were quantitatively collected with zooplankton nets of 40µm mesh size, preserved in formaldehyde solution 4% and identified and counted under optical microscope (Rocha *et al.* 2011). Benthic macro-invertebrates were collected with both, a Van-Veen grab and a Surber sampler (Suriani *et al.* 2007). Fishes were collected using several fishing gears (Fragoso *et al.* 2005, Smith *et al.* 2005).

RESULTS AND DISCUSSION

INVASIVE INVERTEBRATES

Based on a comprehensive inventory of freshwater zooplankton diversity in São Paulo state carried out

in the scope of the BIOTA/FAPESP biodiversity Program, up to now only two exotic species were recorded with successfully established populations in São Paulo state reservoirs: *Ceriodaphnia dubia* Richard, 1908, found in samples taken from Billings and Taiaçupeba reservoirs, both in upper Tietê River basin, and *Daphnia lumholtzi* Sars, 1668, recorded in Nova Avanhandava and Três Irmãos reservoirs, both in the low portion of Tietê River (Zanata *et al*. 2003, Rocha *et al*. 2011). Among these two species only *D. lumholtzi* is fast dispersing downstream, showing great invasive potential (Simões *et al*. 2009).

Among other zooplankton groups the exotic species *Mesocyclops ogunnus* Onabamiro, 1957, previously misidentified as *Mesocyclops kiefferi* Van De Velde, 1984, first appeared in Barra Bonita reservoir in 1985, thereafter becoming a dominant species in all Tietê River cascade of six reservoirs (Matsumura-Tundisi & Silva 2002). This species is native from African lakes, but also occurs in Southern Asia and is believed to have been introduced in Brazilian waters together with African fishes (Reid & Pinto-Coelho 1994).

No exotic species of cladocerans were recorded in Paranapanema River (Sampaio *et al*. 2002, Nogueira *et al*. 2006) and in Rio Grande River reservoirs so far (Rocha *et al.* 2011, Santos-Wisniewski *et al.* 2011).

There are nevertheless records of the rotifer *Kellikotia bostoniensis* (Rousselet, 1908), a native species from North America, in some reservoirs (Billings, Águas Claras, Taiaçupeba and Pedro Beitch) in the upper portion of the Tietê River basin (Lucinda 2003, Lucinda *et al*. 2004). This species was first reported in the state of Paraná (Lopes *et al*. 1997) and recently in Minas Gerais state in natural lakes of Middle Rio Doce Valley (Peixoto *et al*. 2010), but were not yet reported in Paranapanema or Rio Grande reservoirs inside São Paulo state territory.

Species of Mollusca are indeed, the most invasive invertebrates in Brazilian freshwaters in general and in São Paulo state rivers and reservoirs in particular. Three species of great invasiveness have spread out the reservoirs of São Paulo state: *Melanoides tuberculata* (Muller, 1774) (Thiaridae, Gastropoda); *Corbicula fluminea* (Muller, 1774) (Corbiculidae, Bivalvia) and *Limnoperna fortunei* (Dunker, 1857) (Mytilidae, Bivalvia).

Melanoides tuberculata is a native gastropod from North and Eastern Africa and Southeastern Asia. It was recorded in Brazil by the first time in 1967, in Santos, São Paulo state (Vaz *et al*. 1986, Abílio 1997). It was non-intentionally introduced by ballast water or as the accompanying fauna of exotic aquarium fishes spreading out into rivers and reservoirs. It is the dominant species, representing 86% of all mollusks that were present in benthic macro-invertebrates of Salto Grande reservoir (Pamplin 1999, Pamplin & Rocha 2005), and between 65% and 99 % in Middle and Low Tietê reservoirs (França *et al*. 2005, Pamplin & Rocha 2005, Suriani *et al*. 2005).

Corbicula fluminea, was first recorded in South America in the late sixties (Ituarte 1981) and it is believed to have been introduced by ballast water through the La Plata estuary (Oliveira *et al*. 2010). In the state of Rio Grande do Sul its arrival was first recorded in Jacuí River, in the early seventies (Veitenheimer-Mendes 1981), dispersing upstream in Paraná River basin. Its establishment and population build up took around 10 years, since it was only in 1994 that a dense population was recorded throughout Itaipu reservoir (Okada 2001, Takeda *et al*. 2004). In the Upper Paraná floodplain near Porto Rico, Paraná, this species was not recorded in a study of benthic macro-invertebrates carried out between 1986 and 1988 by Takeda *et al*. (1997). In São Paulo state this species was first recorded in Mogi-Guaçu River, a tributary of Rio Grande River, in 1997 (Avelar 1999).

In the reservoirs this species was reported in Salto Grande reservoir in the year 1998 (Pamplin 1999) and in the years 2000 and 2001 (Dornfeld *et al*. 2004), occurring in large numbers at the riverine portion of Atibaia River. *Corbicula fluminea* is completely established in the cascade of six reservoirs in the middle and low portions of Tietê River (França *et al*. 2005, Suriani *et al*. 2005). *Corbicula fluminea* is also widespread in the benthic communities of the cascade of reservoirs in Paranapanema River as reported by Jorcin & Nogueira (2008). In this basin this species reached highest abundance in Pardo River station, corroborating its preference for lotic environments, although occurring in the reservoirs in lower density (Table 1).

Table 1. Population densities (ind.m^{-2}) recorded for invasive mollusk species in São Paulo State reservoirs compiled from different authors: (1) Pamplin & Rocha 2005; (2) Suriani *et al.* 2005; (3) França *et al.* 2005; (4) Dornfeld *et al*. 2004; (5) Pareschi *et al*. 2008; (6) Garcia *et al.* 2009. Numbers in parentheses denote the source-authors as described.

Tabela 1. *Densidades populacionais (ind.m^{-2}) registradas para as espécies de moluscos invasores nos reservatórios do Estado de São Paulo, compilada de diversos autores: (1) Pamplin & Rocha 2005; (2) Suriani et al. 2005; (3) França et al. 2005; (4) Dornfeld et al. 2004; (5) Pareschi et al. 2008; (6) Garcia et al. 2009. Os números em parênteses denotam os autores-fonte conforme descrito.*

Reservoir	*Melanoides tuberculata*	*Corbicula fluminea*	*Limnoperna fortune*
Bariri	186 – 478 (1)	12 – 26 (1)	8 – 12 (5)
Barra Bonita	40 – 110 (2)	-	32 – 6267 (5)
Bariri	30 – 1100 (2)	20 – 950 (2)	
Ibitinga	40 – 2045 (2)	70 – 150 (2)	
Promissão	1194 – 3200 (3)	3 – 529 (3)	
Nova Avanhandava	1500 – 9310 (3)	1 – 100 (3)	
Tres Irmãos	1500 – 2400 (3)	1 – 50 (3)	
Salto Grande	40 – 4756 (4)	1 – 267 (1)	
Canoas I	-	-	300 (6)
Canoas II	-	-	300 (6)
Capivara	-	-	3 (6)

Limnoperna fortunei, the golden mussel, is the most recent invader mollusk in South America and also in São Paulo state reservoirs. Its invasion was first reported in La Plata River estuary in 1991 (Pastorino *et al*. 1993) from where it has dispersed upwards into Paraná and Paraguai River basins. It was recorded in Paraná River near the city of Rosana, São Paulo, in 2002 (Avelar 2004) and in Jupiá reservoir in 2004 (Vercillo 2005). Usually there is a lag time between the arrival and the establishment of an exotic species in a new habitat. Therefore it is probable that its arrival occurred in the turning of the century.

Its occurrence in the Middle Tietê reservoirs was first reported by Pareschi *et al*. (2008), in Bariri and Ibitinga reservoirs, showing that invasion proceeds fast in all main tributaries of the Upper Paraná River basin.

Limnoperma fortunei was not recorded by Jorcin & Nogueira (2008) in the reservoirs of Paranapanema River in the years 2000 and 2001. Its presence was however detected in the reservoirs of Canoas I, Canoas II and Capivara in the year 2006 (Garcia *et al*. 2009) and in 2007 and 2008 in River Tibagi and Porto Amazonas, both tributaries of Paranapanema River in the state of Paraná side (Pestana *et al*. 2010).

In reservoirs of Rio Grande River, the presence of *Limnoperna fortunei* was first reported in São Simão reservoir in the year 2004 (Resende & Martinez 2008). There is no further report for upstream reservoirs, but it probable that it has already reached the middle course as observed for Paranapanema and Tietê Rivers.

Among these three invasive species, *L. fortunei* seems to be the species with highest potential for invasiveness (Avelar 2004) due to a combination of characteristics as great reproductive potential (Silva 2006), high tolerance to abiotic factors (Okumura & Rocha 2005), abyssal muscle allowing its fixation in many types of substrates and the exploration of different compartments of the aquatic ecosystems (Avelar 2004). Besides the huge economic losses related to biofouling (Ricciardi 1998), navigation and interferences with water distribution (Avelar 2004), aspects not yet evaluated in Brazilian waters, this species is a major threat at all levels of ecological organization, leading to the extinction of many native species due to changes in the structure of benthic and other freshwater communities (Avelar 2004, Molina & Paggi 2010). Actually, the real impact of invasive species cannot yet be properly assessed, if the changes

in ecological processes and the ecosystems services lost could be simultaneously measured, we could perhaps have a glimpse of it.

INVASIVE VERTEBRATES

The most important invasive vertebrates in freshwaters are the fishes, surpassing any other group in number of species. Although the Neotropical region (Central and South America) has the highest diversity of freshwater fishes in the planet it is also the one with the largest number of introduced species (Agostinho *et al.* 2005).

Unfortunately, in most cases the result is the opposite, causing local extinction of native species, decreasing population stocks and changes in species composition without the increase in overall fish production (Latini & Petrere 2004, Agostinho *et al.* 2005, Moretto 2006). The introduction also happens accidentally, by the escape of exotic and allochtonous species from fish farming installations (Orsi & Agostinho 1999, Agostinho *et al*. 2005, Smith *et al*. 2005, Espíndola 2006).

In São Paulo state almost all rivers have species non-native to the basin, as shown for Tietê River in Table 2.

Table 2. List of fish species introduced in the cascade of reservoirs at the Middle and Low Tietê River, showing common and scientific names, continent or region of origin, year and locality of introduction in the basin (from Smith *et al.* 2005).

Tabela 2. *Lista das espécies de peixes introduzidas na cascata de reservatórios do Médio e Baixo Rio Tietê, mostrando os nomes comuns e científicos, o continente ou região de origem, o ano e a localidade de introdução na bacia (Fonte: Smith et al. 2005).*

Common name	Species	Origin	Introduction year	Introduction locality
blackbass	*Micropterus salmoides*	North America	1909	Ponte Nova reservoir
carp	*Cyprinus carpio*	Asia	1939	Many rivers of São Paulo State
tilapia	*Tilapia rendalii*	African	1952	Alto da Serra do Mar reservoir
tilapia	*Oreochromis hornorum*	African	1952	*
tilapia	*Oreochromis niloticus*	African	1952	*
apaiari	*Astronotus ocellatus*	Amazon	1938	*
corvina	*Plagioscion squamosissimus*	Amazon	1966	Itapura (mouth)
tucunaré	*Cichla* sp (1 or 2 species)	Amazon	1980-1990	Middle and Low Tietê revervoirs
freshwater sardine	*Triportheus signatus*	Northeast Brazil	1980-1990	Middle and Low Tietê revervoirs
cará	*Satanoperca jurupari*	Amazon	1980-1990	Itapura (mouth)
cará	*Geophagus surinamensis*	Amazon	1980-1990	Itapura (mouth)
pacú-prata	*Metynnis maculatus*	*	1980-1990	Itapura (mouth)
cascudo	*Lipossarcus anisitsi*	*	1980-1990	Itapura (mouth)
bagre	*Trachelyopterus coriaceus*	*	1980-1990	Itapura (mouth)
barbado	*Pinirampus pinirampus*	Low Paraná	Itaipu resesrvoir damming	Itapura (mouth)
lambari-bocarra	*Roeboides paranensis*	Low Paraná	Itaipu reservoir damming	Itapura (mouth)
caborja	*Hoplosternum litoralle*	Wide distribution	***	***
tambaqui	*Colossoma macropomum*	Amazon	***	***
trairão	*Hoplias lacerdae*	Upper Paraná	***	***

*** unknown origin

In the cascade of reservoirs of the middle and low stretches of Tietê River the non-native species of fish in the reservoirs represent 10% to 48% of the total number of species, as shown by Smith (2004), Marciano (2006) and Moretto (2006). The most recent inventories of fishes in Tietê River reservoirs evidenced the occurrence 81 species of fish from which 19 were non-native species. Among these, 5 were exotic (*Mycropterus salmoides* Lacépède, 1802, *Cyprinus carpio* (Linnaeus 1758), *Tilapia rendalli* Boulenger, 1897, *Oreochromis niloticus* (Linnaeus, 1857) e *Oreochromis hornorum* (Trewavas, 1966) and 14 were allochtonous (*Astronotus ocellatus* (Agassiz in Spix and Agassiz, 1831), *Plagioscion squamosissimus* Heckel, 1840, *Cichla kelberi* (Kullander & Ferreira, 2006), *Triportheus signatus* Garman, 1890, *Satanoperca jurupari* Heckel, 1840, *Geophagus surinamensis* Bloch, 1791, *Metynnis maculatus* Kner, 1858, *Liposarcus anisitsi* Eigenmann & Kennedy, 1903, *Trachelyopterus coriaceus* Valenciennes, 1840, *Pinirampus pinirampus* Spix, 1829, *Roeboides paranensis* Pignalberi, 1975, *Hoplosternum litoralle* Hancock, 1828, *Colossoma macropomum* Cuvier, 1818 e *Hoplias lacerda* Bloch, 1794).

The transformation of Tietê River in a Reservoir Cascade Continuum (Barbosa *et al*. 1999), the existence of Tietê - Paraná Waterway, the accelerated eutrophication and artificial connections between basins, for example the water channel of Pereira-Barreto, besides the high number of fish farms in São Paulo state are factors that together facilitate the invasion of reservoirs by alien species. As a consequence, the Upper Paraná basin is also the portion with the highest extinction rate of native species (Smith 2004**,** Moretto 2006)

Lobo (Broa) reservoir also belongs to Tietê River basin is a water body from which long term information on fish community is available (Albino 1987, Marinelli 2002, Fragoso *et al*. 2005). The introduction of allochtonous fish species in this reservoir began in the sixties with the introduction of *Tilapia rendalli* Boulenger, 1897, (Marinelli 2002) followed by *Oreochromis niloticus* (Linnaeus, 1857) and *Cyprinus carpio* (Linnaeus1758). Although there is no precise information regarding the year of introduction of these two latter species, they are old introductions. In the year 1998 *C. kelberi* (previously reported as *Cichla cf. ocellaris* Spix, 1831 was introduced in the reservoir and became gradually established as shown by Fragoso *et al*. (2005). This study revealed that 6 years after the introduction of *C. kelberi* (Kullander & Ferreira, 2006) there were noticeably changes in native species composition and their relative abundances (Table 3). This allochtonous species, originary from Amazon River basin is a voracious top predator. In Lobo reservoir it is a competitor of the *traíra*, *Hoplias malabaricus*, a native species that has since then decreased its population size. *Cichla kelberi* also might have been responsible for the observed extinction of some native species as *Cichlasoma paranaense* Kullander, 1893, *Hyphessobrycon fasciatus* Ellis, 1911, *Cetopsorhamdia iheringi* Schubart & Gomes, 1959 and *Leporinus octofasciatus* Steindachner, 1915 (Fragoso *et al*. 2005).

Table 3. List of fish species introduced in Lobo (Broa) Reservoir, Brotas/ Itirapina, SP, showing common and scientific names, (modified from Fragoso *et al* 2005).

Tabela 3. *Lista das espécies de peixes introduzidos na represa do Lobo (Broa), Brotas/ Itirapina, SP, mostrando os nomes comuns e científicos*.

Species	Common name
Cyprinus carpio	Carp
Oreochromis niloticus	Nile tilapia
Tilapia rendalli	Tilapia
Cichla kelberi	'Tucunaré'

In Paranapanema River, Carvalho *et al*. (2005) observed a scenario similar to that found for Tietê River basin, with a high number of introduced fishes, both exotic and allochtonous. In the reservoirs Jurumirim, Capivara and Taquaruçu, the relative proportion of alien to native species of fishes varies from 14 to 22 % of the total.

Nevertheless, in Rosana, a large recently constructed reservoir in Paranapanema River, Ferrareze & Nogueira (2011) could not find changes in richness, species composition or population abundances comparing the fish assemblage before and after the introduction of *Cichla kelberi*. It is known that the effect of an introduced species can vary greatly due to the complexity of interactions between the invasive species and other stressors and particular

characteristics of each water body (Ricciardi and McIsaac 2011). It is possible that fish assemblages of small water bodies, such as Broa reservoir, have higher vulnerability to introduced alien species than that of large reservoirs. The response time can also be very different among communities.

CONCLUSIONS AND PROPOSAL OF MANAGEMENT ACTIONS

Although the eradication or the contention of invasive species dispersal is a huge task in freshwater systems, actions should be taken as soon as the presence of an invader is noticed. According to Pascal *et al.* (2010) the eradication of invasive species offers opportunities for both, understanding their impacts on native species and to understand how ecosystems function. They suggest that biological invasions events could be used as experiments, thus providing opportunities for more realistic insights on relevant ecological questions.

Based on the experiences obtained from studies on invasive species already developed in Brazil and those from other countries it is possible to devise some policies and actions that could be implemented at different scales and levels: local, regional and whole state.

AT LOCAL LEVEL

Research and educational institutions can work together with local administration in order to adapt and disseminate scientific information regarding invasive species present in local freshwaters. In places where information is not yet available, research and prospection must be implemented as faster as possible. Educational campaigns might be organized with participation of the local media aiming to call attention and inform the whole local community regarding many aspects of biological invasions. Efforts must be focused on alien and invasive species occurring at the local freshwaters.

A task force to solve or minimize the problems of local exotic invasive species must be created. It can be formed by organized segments of society, such as the civil defense, neighbors association, schools, firemen, football teams, or any other organized group of citizens. Progressive steps should be planned and implemented. A first step could be to produce informative material, such as folders, posters or booklets with names, photographs or drawings of the exotic species plus any other relevant information on the threat those species represent for native species.

A further step must be to implement actions to eradicate or minimize the local impact of the exotic invasive species. Actions such as to collect, use or kill invasive organisms must be taken. After reaching the objective, they must be maintained as watching and warning teams.

AT REGIONAL LEVEL

Similar actions can be taken at the regional scale, in coordinated schemes. Actions in this level are very important in preventing immediate re-colonization from adjacent areas. The hydrographic basin is an adequate unity for regional action. If too big it could be divided into sub-basins when necessary to organize similar actions as those developed in the local level. Environmental Police Force, River Basin committees or Province associations are examples of instances to develop new actions or to reinforce the local ones at larger spatial scale. They are also adequate to search for the financial support required for the eradication actions.

AT HIGHER LEVELS

State, national and international organizations need to be involved for tasks as information exchange, human resources training and prevention of new invasions. Many short-cuts and lessons can be learned from joint work at this level. The establishment of monitoring programs for international watersheds, legislation improvement, technical information and knowledge transference and human resources training are examples of actions that can be implemented at this level.

Important lessons have been learned in the last decades such as: prevention against the introduction of exotic species is the best police in dealing with invasion of exotic species in freshwaters, because once a species has successfully colonized a water basin, it might be very difficult and sometimes completely impossible to eradicate it. Prevention requires actions in distinct fields: consciousness regarding the harms

of alien species introduction including behavioral change and the inhibition of alien species introduction by legal enforcement. Another lesson to learn is that it is not possible to repair the losses of native species, for example, after a river impoundment, by introducing alien species into a recently created reservoir. Problems to the remaining species can be much worse. Education and resource investments are urgently necessary to deal with the complex problem of freshwater invasions.

ACKNOWLEDGEMENTS: We would like to thank the financial agencies FAPESP, CNPq and MMA for research financial support. The authors also would like to dedicate this paper to Drª. Takako Matsumura-Tundisi and Dr. José Galizia Tundisi, for their life devoted to scientific work and especially for leading a national'school' on Limnology.

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Submetido em 05/08/2011
Aceito em 12/08/2011