FISH and FISHERIES

FISH and FISHERIES, 2009, **10**, 98–108

Introduction of non-native freshwater fish can certainly be bad

Jean Ricardo Simões Vitule[1], *Carolina Arruda Freire*[1] *& Daniel Simberloff*[2]

[1]Departamento de Fisiologia, Setor de Ciências Biológicas, Universidade Federal do Paraná, Curitiba, PR, CEP 81531-990; [2]Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, TN 37996-1610

Abstract

In this paper, we respond to Gozlan's views of the introduction of freshwater fish, as we strongly disagree with his view and approach. We demonstrate that many real-world examples of freshwater fish introductions have catastrophic ecological consequences. We detail a few noteworthy examples, such as those of the Nile perch, carp, tilapias, catfishes, and the zebra mussel. We discuss within-nation introductions, and we explore several related problems, such as hybridization and spread of pathogens and parasites. We propose that Gozlan's analysis is biased, as more reliable data on impacts that are already widespread are urgently needed, mainly in the biologically richest areas of the world. Thus, we continue to advocate the precautionary principle, because species introductions, once established, are largely irreversible.

Keywords Aquaculture, biodiversity, economic value, freshwater fish introductions, non-native fish, risk assessment

Correspondence:
Dr Daniel Simberloff, Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, TN 37996-1610, USA
Tel.: 1-865-974-0849
Fax: 1-865-974-3067
E-mail: dsimberloff@utk.edu

Received 4 Aug 2008
Accepted 30 Sep 2008

Introduction

We wish to accept Gozlan's (2008) invitation: '*The aim of this paper is to open a critical debate on the real threat posed by the introduction of non-native fishes*' (p. 107). Gozlan (2008, p. 106) states that: '*Here I show that on the global scale, the majority of freshwater fish introductions are not identified as having an ecological impact while having great societal benefits.*' We strongly disagree with this statement, which is

DOI: 10.1111/j.1467-2979.2008.00312.x

belied by theory, practical concerns, and many empirical data (Parker *et al.* 1999; Mack *et al.* 2000; Rahel 2000; Simberloff 2001, 2003, 2004, 2005, 2006a,b, 2007; Olden *et al.* 2004; Jeschke and Strayer 2005; Ruesink 2005; Gherardi 2007). Below we demonstrate, using his own examples and some additional ones, that Dr Gozlan is treating the entire issue as if it is simply a public relations matter, and as if the public has been conned into thinking there is a problem when there really is not one. His view of a '*pendulum*' swinging from, at one extreme, the practices of the 19th century acclimatization societies introducing species indiscriminately (Lever 1992; McDowall 1994) to the other extreme, a radical and 'xenophobic' view of species introductions (Gozlan 2008), does not reflect reality. Especially in underdeveloped countries (tropical, very species-rich), there are only the first inklings of the potential harm caused by non-native introduced freshwater fish species. We are thus, here (in Brazil), far from this second extreme of the pendulum. In fact, we are closer to the 19th century side of the pendulum, in which the introduction of species is heavily favored. And this, despite reported ecological consequences caused by introductions, such as tilapias introduced to man-made lakes of the semi-arid Brazilian caatinga and other biomes (Gurgel and Fernando 1994; Menescal 2002; Starling *et al.* 2002; Dias 2006; Agostinho *et al.* 2007; Attayde *et al.* 2007; Okun *et al.* 2008) or catfishes introduced to coastal rivers of the Atlantic Forest in southern Brazil (Cambray 2005; Vitule *et al.* 2005, 2006a, 2008; Vitule 2008).

To act as if governments, responding to societal pressures, have shifted to an extreme exclusionary policy is ridiculous. In a country as diverse and large as Brazil, the introduction of freshwater fish species is encouraged by sports fishermen, and even state agencies, without concern for the ecosystem or its native fauna (e.g. Bizerril and Primo 2001; Casal 2006; Vitule *et al.* 2006a, b; Agostinho and Gomes 2002; Agostinho *et al.* 2007). This attitude is fostered by the fact that fish production in Brazil is based (87% of total production in 2002) on introduced species (Casal 2006), and total gross production of tilapias of the genera *Oreochromis* and *Tilapia* (Cichlidae) in Brazil has been increasing exponentially from 1970 to 2006 (Fig 1a). Brazil was actually the fourth leading country in growth of production from aquaculture from 2000 to 2002 (FAO 2006). In New Zealand, a proposal to introduce the channel catfish (*Ictalurus punctatus*, Ictaluridae) was firmly rejected based on a detailed risk assessment (Townsend and Winterbourn 1992). New Zealand has a case-by-case approach, and the procedures implemented by the Biosecurity Act of 1993 and revisions have minimized the number of permits and generally taken a precautionary approach. By contrast, in Brazil, the legislation is weak and law enforcement is lax. There is continuing illegal introduction of exotic species, as for example, the use of exotic fish cages in Itaipu Hydroelectric Power Plant reservoir (Agostinho and Gomes 2002), and there is intense conflict of interest between the production sectors and environmentalists. For example, in Brazil the Federal Government Environmental Agency (IBAMA, 1994) restricts introduction of channel catfish and the African catfish (*Clarias gariepinus*, Clariidae) only in the basins of the Amazon and Paraguay Rivers, leaving unprotected all the other important basins with their endangered endemic faunas (e.g. the 'hotspot' Atlantic Forest, Myers *et al.* 2000; Vitule *et al.* 2005, 2006a,b), where those introduced catfishes continue to be cultivated and to spread to the wild. This continued introduction in the Atlantic Forest of southern Brazil occurs (Vitule 2008) despite a recent directive '*portaria*' of the state of Paraná (IAP 2007) clearly indicating that these catfishes and other species are invasive. However, this directive does not prohibit introduction, it only suggests caution in the culture of those species. This is a worldwide problem, not restricted to Brazil (e.g. Cambray 2003a, b; Casal 2006; Gherardi 2007). In sum, we should ask: How many proposals to introduce fishes have been rejected recently, in Brazil or anywhere? Are there data on such matters? On a global scale, there are many more underdeveloped countries performing no risk analyses and/or implementing no control policies on introduced species, than wealthy countries with clear laws and efficient enforcement systems. Most research dealing with freshwater fish invaders is restricted to North America (>45%) and refers to salmonids, owing to their economic value (Gherardi 2007).

Case studies, data bases and analyses

Gozlan (2008) bases his conclusions on insufficient and questionable data bases, and his methods are often unclear. Gozlan (2008) has also oversimplified the analysis. For instance, he has considered all FAO areas of the world as internally homogeneous

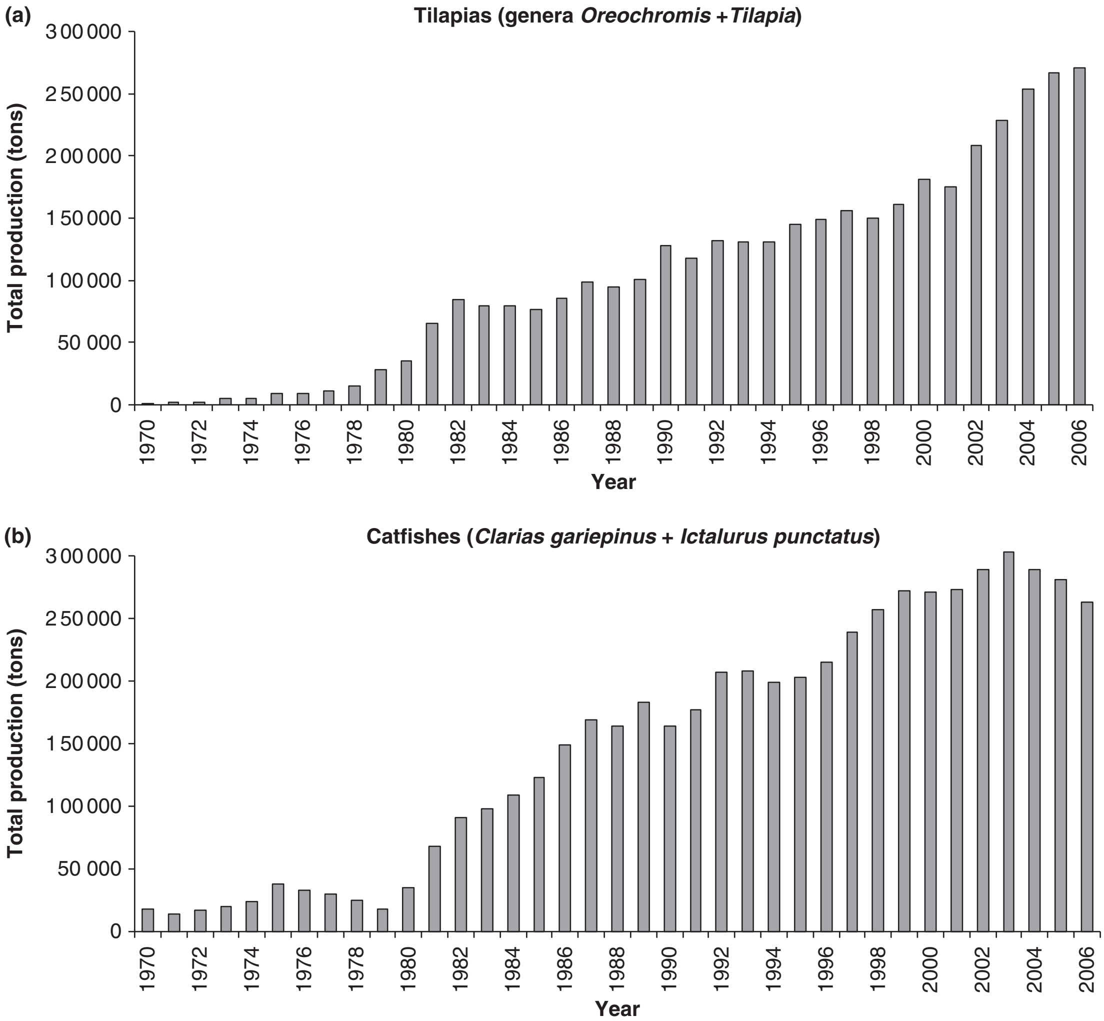

Figure 1 Examples of increasing production of introduced freshwater fish in Brazil: (a) Tilapias (genera *Oreochromis* and *Tilapia*) and (b) Catfishes (*Clarias gariepinus* and *Ictalurus punctatus*); total production (tons) in Brazil, from 1970 to 2006.

(climate, economy, culture, biological diversity) and equally diverse in freshwater fish. He overvalues FAO (http://www.fao.org/fi/statist/statit.asp) and FishBase (http://www.fishbase.org) as sources, but he does not cite Casal, who is one of the people responsible for Fish Base and who also bases her conclusions on FAO reports, but much more cautiously, emphasizing the potential danger of introduced fish species (Casal 2006).

These databases are still incomplete, for several reasons, including the fact that this matter has just begun to be investigated (Simberloff 2004, 2006a,b; Casal 2006; Gherardi 2007). Moreover, in Brazil and other 'mega-diverse' nations, researchers begin with limited knowledge of the freshwater fish fauna. Buckup *et al.* (2007) report that in Brazil, 64 new freshwater fish species were described in 2006, an average rate of 1 new species every 6 days! If our systematic knowledge is so incomplete, what can be said about the ecological impact of introduced species?

Furthermore, ecological impact is generally difficult to detect (Underwood 1992; Glasby and Underwood 1996). Often no previous studies are available in the newly invaded area, so conclusions about the impact of an introduction are underestimates. This difficulty should imply caution about the potential effects (often irreversible) of introductions. The freshwater habitat offers additional challenges, and the study of impacts on freshwater ecosystems is a recent discipline that is likely to expand greatly in the near future (Sala *et al.* 2000; Gherardi 2007; Simberloff 2007). Still, Gozlan (2008, p. 113) states that: '*Overall, the probability of an ecological impact resulting from freshwater fish introduction is relatively low (around 6%) and presents many positive aspects*.' However, Casal (2006), using FishBase, found an extreme paucity of data on fish introductions, so that, although 6% may seem to be a low value, in fact, because of the database limitations, this number is illusory. Moreover, even considering the scarce data base, other authors derive different values: Ruesink (2005) proposes that 22% of established introduced fish populations produced well-supported ecological impacts on food availability, habitat structure, nutrient dynamics, and other factors. As regards the percentages that Gozlan (2008) finds causing impacts, we would emphasize that in most cases not much effort has gone into looking for impacts. His entire economic analysis is deficient. He never discusses the cost of an impact, the difficulty of estimating such a cost, and the fact that there is bitter controversy over the degree to which this cost can be reduced to economics. Aside from the relatively meager effort that goes into looking for impacts in most cases, his interpretation of what constitutes impact (upper left, p. 111 in Gozlan 2008) is narrow. Often with introduced species, an impact is important but indirect and highly idiosyncratic. Moyle (1993) provides an excellent example concerning the woundfin minnow (*Plagopterus argentissimus*, Cyprinidae) of the Virgin River in Utah. The Asian grass carp (*Ctenopharyngodon idella*, Cyprinidae), introduced beginning in 1968 to lakes in Arkansas, spread to the Mississippi River, carrying with it an Asian tapeworm. The tapeworm infested other fishes, including the red shiner (*Cyprinella lutrensis*, Cyprinidae). Shiners introduced as bait to the Colorado River ultimately reached the Virgin River, a tributary, and infected the woundfin, already endangered by dams and water diversions. The infection precipitated a rapid decline. That an introduction of carp in Arkansas could threaten a minnow in Utah would not have been predicted even by a perceptive ichthyologist.

Gozlan (2008) writes as if risk assessment for introduced species is a real science. It is simply not possible yet to do accurate risk assessments for introduced species (Simberloff 2005). Gozlan (2008) has an idealized view of the entire introduction process, as if fishes introduced to a lake or reservoir stay there, so as not to cause trouble elsewhere. We could give many counterexamples (some carp, for example). Fish get around on their own, or people engage in rogue introductions. Once a fish species has been moved to a new continent, it is foolish to assume it will stay just in the area for which it is intended.

There is no impact without establishment of the introduced species, and establishment results from propagule pressure among other causes, such as abiotic factors including global warming (e.g., Moyle and Light 1996; Ficke *et al.* 2007). Gozlan (2008) has not considered propagule pressure in his analysis, or the number of times a species has been introduced into a certain country or region. However, propagule pressure is recognized as one of the major factors leading to the establishment of an introduced species in a new environment. This is true for environments in general (Colautti *et al.* 2006; Lockwood *et al.* 2007), for freshwater biotopes (reviewed in Gherardi 2007), and in particular for freshwater fishes (Colautti 2005; Ruesink 2005). Establishment rates for aquatic systems are in general higher than those for terrestrial systems (Gherardi 2007). Establishment rates for freshwater fishes have been reported to range between 38% and 77% (Ross 1991), or to vary from 36% to 49% after a little over 10 years. Globally, of 1424 freshwater fish introductions, 64% of them have become established (Ruesink 2005); 50% of 1205 fish introductions recorded for aquaculture have established in the wild (Casal 2006). Of established fish populations introduced from Europe to North America and vice-versa, approximately 60% are recorded as having become invasive (Jeschke and Strayer 2005). This is slightly less than the comparable figures for mammals and birds introduced from Europe to North America and for mammals introduced from North America to Europe, but more than for birds introduced from North America to Europe. As birds and mammals are far better studied in Europe and North America than are freshwater fishes, the figure for the latter is almost certainly an underestimate.

Nile perch

Some specific cases raised by Gozlan (2008) demand particular attention. One of the main examples used to support his views is the Nile perch (*Lates niloticus*, Latidae), and abundant data help answer the question he posed (Gozlan 2008, p. 111): '*However, nearly 60 years later, can the introduction of the Nile perch be seen as an economic saviour or an ecological disaster?*' As Gozlan (2008) himself notes, this introduction has had ecological impacts; specifically, he mentions the decline of haplochromine species and cites Ogutu-Ohwayo (1990a), Witte *et al.* (1992), and Hauser *et al.* (1998). However, a vast literature is available, revealing a much more catastrophic picture than the one he admits: hundreds of endemic cichlid species have gone extinct, trophic shifts have been detected in the catfish fauna (previous top predators of the ecosystem), with local catfish extinctions, and there has been extensive deforestation of the area surrounding the lakes (for smoked perch), resulting in siltation and eutrophication (Kudhongania and Cordone 1974; Barel *et al.* 1985; Acere 1988; Achieng 1990; Ogutu-Ohwayo 1990b, 1993; Ogutu-Ohwayo and Hecky 1991; Craig 1992; Kaufman 1992; Ochumba and Manyala 1992; Goldschmidt *et al.* 1993; Goudswaard and Witte 1997; Kaufman *et al.* 1997; Schofield 1997; Olowo and Chapman 1999; McNeely 2001; Gherardi 2007). An additional effect of the introduction of the Nile Perch has been to accelerate the decline of populations of carnivores, such as the African spotted-necked otter (*Lutra maculicollis*, Mustelidae) and the African clawless otter (*Aonyx capensis*, Mustelidae) (Kruuk and Goudswaard 1990). And, regarding economic consequences and societal benefits, his analysis is shallow. He writes as if this introduction were a great success from the standpoint of fishermen. This is simply wrong. It was very successful from the standpoint of a few wealthy corporations. Most of the fishermen who had subsisted on the lake before the introduction of the perch were driven out of business, with terrible social consequences (Kasulo 2000; McNeely 2001).

Common carp

The common carp (*Cyprinus carpio*, Cyprinidae) is the third species (in production, metric tons) cultivated in aquaculture worldwide (established in 91 of the 121 countries to which it has been introduced) and is recognized as having adverse ecological effects in 15 countries (Casal 2006). Along with the Nile tilapia (*Oreochromis niloticus*, Cichlidae), the common carp is one of the most widespread introduced species in the Americas, with high probability of habitat expansion (Zambrano *et al.* 2006). In Mediterranean estuaries, the invasive common carp has a central role (through competition) in structuring mullet assemblages in salinities up to 13‰ (Cardona *et al.* 2008).

Tilapias

The tilapias, mainly the Nile tilapia, are 'the model' for fish aquaculture in Brazil (Dias 2006; Zambrano *et al.* 2006; and see above, Fig 1a). The Nile tilapia is extremely widespread and established from North America down to South America (Zambrano *et al.* 2006; Agostinho *et al.* 2007). For example, in the Brazilian semi-arid caatinga, it has been introduced to many man-made lakes, leading to low present-day levels of fish production in those lakes in comparison to fisheries production prior to its introduction (Gurgel and Fernando 1994; Dias 2006). Nevertheless, introduction of the tilapia is still promoted by state agencies throughout the country, as was noted above. Tilapias are prized for aquaculture because they are extremely hardy, physiologically tolerant, and characterized by multiple spawning, parental care, and extreme feeding plasticity (e.g., Welcomme 1988; Dias 2006; Agostinho *et al.* 2007; Attayde *et al.* 2007; Freire and Prodocimo 2007). The deleterious effect of the Nile tilapia on the native fauna of Brazil, as well as globally, has been extensively reported (Fishbase defines it as a '*potential pest*'). The Nile tilapia changes native community structure, reduces abundance of planktonic microcrustaceans, lowers water transparency, and increases the abundance of microalgae (Gurgel and Fernando 1994; Menescal 2002; Dias 2006; Attayde *et al.* 2007; Okun *et al.* 2008).

Catfishes

For catfishes of the families Ictaluridae and Claridae, Gozlan (2008, p. 110) himself advises caution: '… *such as Claridae or Ictaluridae, is more complicated and precautionary approaches banning these introductions may become the norm.*'. As was previously noted, banning of aquaculture of these species in Brazil is just beginning, and law enforcement is largely non-existent. The African catfish is also extremely hardy. It has pseudolungs and produces abundant mucus, so it can resist long periods of drought and even traverse dry ground (Cambray 2003a; Vitule *et al.* 2006a, 2008; Vitule 2008). This amphibious habit and a remarkably plastic diet give this catfish a huge advantage in establishing in the wild (Cambray 2003a; Vitule 2008; Vitule *et al.* 2008). This species is widely disseminated for aquaculture, having been introduced to several countries and regions of the globe (Cambray 2003a, 2005; Vitule *et al.* 2006a, 2008). This fish was introduced to Brazil in 1986 (Agostinho *et al.* 2007), and its production in Brazil has been increasing recently, despite knowledge of its invasive potential (Vitule *et al.* 2006a, 2008; Agostinho *et al.* 2007; Vitule 2008). Its meat was not readily accepted in the internal Brazilian market, so the fishery is used primarily by sports anglers in uncontrolled private tanks located dangerously near river beds, leading to repeated spread to the wild, for example, after floods (Orsi and Agostinho 1999; Vitule *et al.* 2006a). In southern Brazil, in the Atlantic forest, this catfish is more abundant in lentic sections of streams that have suffered anthropogenic degradation (Vitule 2008). This combination of habitat destruction by humans along with the spread of hardy introduced species can lead to local extinction of native species (Ross 1991; Agostinho *et al.* 2005, 2007; Vitule 2008). The number of escape events and the number of individuals escaping (i.e., propagule pressure) are critical factors for the establishment of introduced species in the wild, as we have observed above. This African catfish represents over 60% of the recorded escapes in the basin of the Paraná River, totaling ca. 655,000 individuals that reached small streams just in one escape reported in the summer floods of 1997 (Orsi and Agostinho 1999). Similar problems with the African catfish and its hybrids have been reported for South Africa as well (Cambray 2003a,b; Cambray and van der Waal 2006; Anene and Tianxiang 2007).

The channel catfish is another highly invasive large catfish, also extremely physiologically tolerant, widely used worldwide for aquaculture (Townsend and Winterbourn 1992; Fuller *et al.* 1999; Vitule *et al.* 2005). Its introduction (along with the African catfish) in a very biodiverse area that contains a rich endemic freshwater fish fauna, such as the Brazilian Atlantic Forest, is bound to result in the decline of the native fauna. Thus, despite all the known problems with these two introduced catfishes, their production has been increasing significantly in Brazil (Fig. 1b). We again emphasize that these data bases likely underestimate real values (Casal 2006). So, to which side is the '*pendulum*' swinging now?

Zebra mussel

The introduction of freshwater fish species is not the only threat to freshwater fishes of biodiverse nations. The introduction of invertebrates can also lead to decrease and extinction of native fishes. The zebra mussel (*Dreissena polymorpha*, Dreissenidae) in the Great Lakes of North America is such an example. Gozlan's (2008) argument that the zebra mussel has been helpful to the Great Lakes (for which he gives no citation) is ludicrous. The zebra mussel is the intermediate host for a trematode, and its presence in the Great Lakes allowed the parasite to infest native fishes leading to high fish mortality (Gherardi 2007). Thus, there has been severe impact of the zebra mussel on native fishes, in addition to its catastrophic impact on native mussel species (Ricciardi 2003 and references therein), and these impacts contribute to a staggering economic cost, primarily through fouling (United States Geological Survey 2000).

Amazonian top predators

We must also highlight problems associated with fish species introduced within one country, a common phenomenon in large nations. One example is the case of species of tucunaré (*Cichla* spp., Cichlidae), an Amazonian genus introduced into lakes of southern Brazil, in the Atlantic Forest (Latini and Petrere 2004, 2007; Latini *et al.* 2004). The introduction of tucunaré has caused several problems, as they are large predators, reportedly depleting populations of smaller species (Latini and Petrere 2004; Agostinho *et al.* 2007). The tucunaré is not the only example of a within-nation introduction in Brazil. We can also cite the corvina (South American silver croaker, *Plagioscion squamosissimus*, Scianidae), introduced upstream to the main Itaipu reservoir, and which is now the main species caught in subsistence fishery (Agostinho and Gomes 2002; Agostinho *et al.* 2007).

Hybridization

Gozlan (2008) also mentions the problem of hybridization. However, he cites only cases in which there is no negative impact, such as the hybridization between two species of nase (*Chondrostoma toxostoma*, [Cyprinidae] and the introduced *C. nasus*) in the Rhone catchment. In many instances there is a huge, documented problem. For instance, introduced rainbow trout (*Oncorhynchus mykiss*, Salmonidae) hybridize with many western North American native trout species and this hybridization is partly responsible for the threatened status of two species *O. apache* and *O. gilae* and four subspecies *O. clarki stomias*, *O. clarki henshawi*, *O. clarki seleniris*, and *O. aguabonita whitei* under the Endangered Species Act of the United States. Three of the 24 species or subspecies believed to have gone extinct despite listing under the U.S. Endangered Species Act were fishes whose disappearance was partly due to hybridization with introduced species – *Cyprinodon nevadensis* (Cyprinidae), *Gambusia amistadensis* (Poeciliidae), and *Coregonus alpenae* (Salmonidae) (McMillan and Wilcove 1994). Rhymer and Simberloff (1996) list several other examples.

The jundiá catfish (*Rhamdia quellen*, Heptapteridae) cultivated in the state of Paraná, Brazil, frequently comes from other river basins, without any control over the potential risk of mixing distinct genomes. The taxonomy of this genus is not entirely resolved, with the additional potential danger of hybridization between closely related species. The introduction of species of fish from other river basins may indeed cause genetic modification in the native fauna, and this phenomenon is rarely studied in countries such as Brazil (Vitule *et al.* 2006b; Agostinho *et al.* 2007). Thus, even when 'native' fishes are cultivated in large areas, there is potential harm to local biodiversity.

Pathogens and parasites

Similarly, for pathogens, Gozlan (2008) cites only cases that exemplify situations not unique to introduced species. There are many instances of a devastating pathogen that could only have arisen through fish introduction. The most noteworthy is perhaps the whirling disease myxozoan (*Myxobolus cerebralis*, Myxobolidae), a parasite of salmonids that first appeared in North America in 1956, having been introduced in frozen rainbow trout shipped from Europe (Bergersen and Anderson 1997). Rainbow trout were introduced from North America to Europe in the 19th century, where they acquired the parasite from brown trout (*Salmo trutta*, Salmonidae), which are resistant to it. Infected remains of the frozen trout reached a hatchery in Pennsylvania, from which infected fingerlings were distributed widely in the United States, devastating rainbow trout populations in much of the West. In Brazil, there has been little research on this sort of phenomenon, despite the catastrophic consequences that may ensue. For example, the crustacean copepod parasite (*Laernea cyprinacea*, Lernaeidae) was introduced to Brazil with carp and affected a wide range of hosts. The same floods that foster the spread and establishment of the introduced exotic fish can also spread this copepod as well as other fish pathogens (Orsi and Agostinho 1999; Gabrielli and Orsi 2000; Bizerril and Primo 2001; Agostinho and Gomes 2002; Azevedo *et al.* 2006; Dansa-Petretski *et al.* 2007).

Biological control

Fishes introduced for biological control have also had disastrous impacts on native fishes and other species. For example, the grass carp (*Ctenopharyngodon idella*, Cyprinidae) was introduced to control aquatic weeds in the United States and has spread widely. This introduction has had a plethora of negative effects on many native species of fishes and invertebrates, primarily through non-selective, voracious browsing of vegetation, thereby changing habitat greatly, but also through predation and competition (Fuller *et al.* 1999). Similarly, *Gambusia affinis* (Poeciliidae) and *G. holbrooki* have been spread throughout the world for mosquito control but also prey on frogs, invertebrates, and other fish, often with devastating consequences (Hurlbert *et al.* 1972; Hurlbert and Mulla 1981; Pyke and White 2000; Mieiro *et al.* 2002).

Conclusions

More reliable data are needed, especially in the biologically richest areas of the world (that is, in tropical underdeveloped countries), so that valid risk assessments can be performed (cf. Nico *et al.* 2005; Simberloff 2005, 2006b). Until many more data are available, great caution is warranted. A safer approach, at least in the interim, would be to foster research on culturing local native species, rather than to continue introducing a few robust species. We believe that the depiction by Gozlan (2008), of inevitable confrontation between conservationists and aquaculture producers of species with high market value, is inaccurate. Research on effective production of native species will provide food for an increasing human population while still conserving local biodiversity. Use of the precautionary principle need not, therefore, constitute a barrier to aquaculture. On the contrary, it can be viewed as an incentive to discover the possible use of additional (native) species of high economic and societal value. If freshwater fish continue to be introduced at such high rates, species with high potential for aquaculture may even be driven to extinction without being known and studied. Surely the precautionary principle is what should be stressed here, because introductions, once established, are largely irreversible.

References

Acere, T.O. (1988) Recent trends in the fisheries of Lake Victoria (Uganda Northern part), in Report of the 4th session of the Sub-committee for the Development and Management of the Fisheries of Lake Victoria, Kisumu, Kenya, 6–10 April 1987. *FAO Fisheries Report* **388**, 36–45.

Achieng, A.P. (1990) The impact of the introduction of Nile perch, *Lates niloticus* (L) on the fisheries of Lake Victoria. *Journal of Fish Biology* **37**(Suppl. A), 17–23.

Agostinho, A. and Gomes, L. (2002) *Biodiversity and Fisheries Management in the Paraná River Basin: Successes and Failures*. Blue Millenium-World Fisheries Trust-CRDI-UNEP, Universidade Estadual de Maringá, Maringá, Brazil. http://www.unep.org/bpsp/Fisheries/Fisheries%20Case%20Studies/AGOSTINHO.pdf (retrieved on November 2005).

Agostinho, A.A., Thomaz, M.S. and Gomes, L.C. (2005) Conservation of the biodiversity of Brazil's inland waters. *Conservation Biology* **19**, 646–652.

Agostinho, A.A., Gomes, L.C. and Pelicice, F.M. (2007) *Ecologia e Manejo de Recursos Pesqueiros em Reservatórios do Brasil*. EDUEM, Maringá.

Anene, N.S. and Tianxiang, G. (2007) Is the Dutch domesticated strain of *Clarias gariepinus* (Burchell, 1822) a hybrid? *African Journal of Biotechnology* **6**, 1072–1076.

Attayde, J.L., Okun, N., Brasil, J., Menezes, R.F. and Mesquita, P. (2007) Impactos da introdução da tilápia do Nilo, *Oreochromis niloticus*, sobre a estrutura trófica dos ecossistemas aquáticos do Bioma Caatinga. *Oecologia Brasiliensis* **11**, 450–461.

Azevedo, J.S., Bizerril, C.R.S.F., Lima, N.R.W. and Dansa-Petretski, M. (2006) Infestation pattern and parasitic castration of the crustacean *Riggia paranensis* (Crustacea: Cymothoidae) on the fresh water fish *Cyphocarax gilbert* (Teleostei: Curimatidae). *Neotropical Ichthyology* **4**, 363–369.

Barel, C.D.N., Dorit, R., Greenwood, P.H. *et al.* (1985) Destruction of fisheries in Africa's lakes. *Nature* **315**, 19–20.

Bergersen, E.P. and Anderson, D.E. (1997) The distribution and spread of *Myxobolus cerebralis* in the United States. *Fisheries* **22**(8), 6–7.

Bizerril, C.R.S.F. and Primo, P.B.S. (2001) *Peixes de Águas Interiores do Estado do Rio de Janeiro*. PLANAGUA – FEMAR/SEMADS, Rio de Janeiro.

Buckup, P.A., Menezes, N.A. and Ghazzi, M.S. (2007) *Catálogo das Espécies de Peixes de Água Doce do Brasil*. Museu Nacional, Rio de Janeiro.

Cambray, J.A. (2003a) The need for research and monitoring on the impacts of translocated sharptooth catfish, *Clarias gariepinus*, in South Africa. *African Journal of Aquatic Science* **28**, 191–195.

Cambray, J.A. (2003b) Impact on indigenous species biodiversity caused by the globalisation of alien recreational freshwater fisheries. *Hydrobiologia* **500**, 217–230.

Cambray, J.A. (2005) African's *Clarias gariepinus* (Teleostei: Clariidae) appears in rivers in Brazil. *African Journal of Aquatic Science* **30**, 201–202.

Cambray, J.A. and van der Waal, B.C.W. (2006) Dutch domesticated *Clarias* with mixed genetic background now used in aquaculture in South Africa, with unpredictable consequences for biodiversity. *African Journal of Aquatic Science* **31**, 151–153.

Cardona, L., Hereu, B. and Torras, X. (2008) Juvenile bottlenecks and salinity shape grey mullet assemblages in Mediterranean estuaries. *Estuarine, Coastal and Shelf Science* **77**, 623–632.

Casal, C.M.V. (2006) Global documentation of fish introductions: the growing crisis and recommendations for action. *Biological Invasions* **8**, 3–11.

Colautti, R.I. (2005) Are characteristics of introduced salmonid fishes biased by propagule pressure? *Canadian Journal of Fisheries and Aquatic Sciences* **62**, 950–959.

Colautti, R.I., Grigorovich, I.A. and MacIsaac, H.J. (2006) Propagule pressure: a null model for biological invasions. *Biological Invasions* **8**, 1023–1037.

Craig, J.F. (1992) Human induced changes in the composition of fish communities in the African Great Lakes. *Reviews in Fish Biology and Fisheries* **2**, 93–124.

Dansa-Petretski, M., Lima, N.R.W., Azevedo, J.S. and Silva, L.G. (2007) Parasitic castration, growth, and sex steroids in the freshwater bonefish *Cyphocharax gilbert* (Curimatidae) infested by *Riggia paranensis* (Cymohoitea). *Neotropical Ichthyology* **5**, 471–478.

Dias, J.B. (2006) *Impactos Sócio-Econômicos e Ambientais da Introdução da Tilápia do Nilo, Oreochromis niloticus, em Açudes Públicos do Semi-Árido Nordestino, Brasil*. MSc Dissertation, Universidade Federal do Rio Grande do Norte (PRODEMA-UFRN), Rio Grande do Norte, Brazil.

FAO (2006) *The State of World Fisheries and Aquaculture. Part 1: World Review of Fisheries and Aquaculture*. FAO, Rome.

Ficke, A.D., Myrick, C.A. and Hansen, L.J. (2007) Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries* **17**, 581–613.

Freire, C.A. and Prodocimo, V. (2007) Special challenges to teleost fish osmoregulation in environmentally extreme or unstable habitats. In: *Fish Osmoregulation* (eds B. Baldisserotto, J.M. Mancera and B.G. Kapoor). Science Publishers, Enfield, pp. 249–276.

Fuller, P.L., Nico, L.G. and Williams, J.D. (1999) *Nonindigenous Fishes Introduced into Inland Waters of the United States*. American Fisheries Society, Bethesda.

Gabrielli, M.A. and Orsi, M.L. (2000) Dispersão de *Lernaea cyprinacea* (Linnaeus) (Crustacea, Copepoda) na região norte do estado do Paraná, Brasil. *Revista Brasileira de Zoologia* **17**, 395–399.

Gherardi, F. (2007) Biological invasions in inland waters: an overview. In: *Biological Invaders in Inland Waters: Profiles, Distribution, and Threats, Vol. 2. Book Series Invading Nature - Springer Series in Invasion Ecology* (ed. F. Gherardi). Springer, Amsterdam, pp. 3–25.

Glasby, T.M. and Underwood, A.J. (1996) Sampling to differentiate between pulse and press perturbations. *Environmental Monitoring and Assessment* **42**, 241–252.

Goldschmidt, T., Witte, F. and Wanink, J. (1993) Cascading effects of the introduced Nile perch on the detritivorous/phytoplanktvorous species in the sublittoral areas of Lake Victoria. *Conservation Biology* **7**, 686–700.

Goudswaard, K.P.C. and Witte, F. (1997) The catfish fauna of Lake Victoria after the Nile perch upsurge. *Environmental Biology of Fishes* **49**, 21–43.

Gozlan, R.E. (2008) Introduction of non-native freshwater fish: is it all bad? *Fish and Fisheries* **9**, 106–115.

Gurgel, J.J.S. and Fernando, C.H. (1994) Fisheries in semiarid northeast Brazil with special reference to the role of tilapias. *Internationale Revue der gesamten Hydrobiologie* **79**, 77–94.

Hauser, L., Carvalho, G.R., Pitcher, T.J. and Ogutu-Ohwayo, R. (1998) Genetic affinities of an introduced predator: Nile perch in Lake Victoria, East Africa. *Molecular Ecology* **7**, 849–857.

Hurlbert, S.H. and Mulla, H.S. (1981) Impacts of mosquitofish (*Gambusia affinis*) predation on plankton communities. *Hydrobiologia* **83**, 125–151.

Hurlbert, S.H., Zedler, J. and Fairbanks, D. (1972) Ecosystem alteration by mosquitofish (*Gambusia affinis*) predation. *Science* **175**, 639–641.

IAP, 2007. *'Portaria' (directive) 074 from IAP - Instituto Ambiental do Paraná, Environmental Institute of Paraná*, of April 19, 2007. Instituto Ambiental do Paraná, Curitiba, Paraná.

IBAMA (1994) – Instituto Brasileiro do Meio Ambiente e Recursos Naturais Renováveis '*Portaria*' (directive) n 142/94 de 22 de dezembro de 1994. In: *Diário Oficial da União (D.O.U) de 23 de dezembro de 1994*, seção I, Imprensa Nacional, Brasília, 20437 *P*.

Jeschke, J.M. and Strayer, D.L. (2005) Invasion success of vertebrates in Europe and North America. *Proceedings of the National Academy of Sciences USA* **102**, 7198–7202.

Kasulo, V. (2000) The impact of invasive species in African lakes. In: *The Economics of Biological Invasions*. (eds C. Perrings, M. Williamson and S. Dalmazzone), Edward Elgar, Cheltenham, pp. 183–207.

Kaufman, L. (1992) Catastrophic change in species-rich freshwater ecosystems: the lessons of Lake Victoria. *BioScience* **42**, 846–858.

Kaufman, L., Chapman, L.J. and Chapman, C.A. (1997) Evolution in fast forward: haplochromine fishes of the Lake Victoria Region. *Endeavour* **21**, 23–30.

Kruuk, H. and Goudswaard, P.C. (1990) Effects of changes in fish populations in Lake Victoria on the food of otters (*Lutra maculicollis* Schinz and *Aonyx capensis* Lichtenstein). *African Journal of Ecology* **28**, 322–329.

Kudhongania, A.W. and Cordone, A.J. (1974) Batho-spatial distribution patterns and biomass estimates of the major demersal fishes in Lake Victoria. *African Journal of Tropical Hydrobiology and Fisheries* **3**, 15–31.

Latini, A.O. and Petrere Jr, M. (2004) Reduction of a native fish fauna by alien species: an example from Brazilian freshwater tropical lakes. *Fisheries Management and Ecology* **11**, 71–79.

Latini, A.O. and Petrere Jr, M.. (2007) Which factors determine non-native fish range. A study on red piranha *Pygocentrus nattereri* (Kner 1858) introduced in Brazilian tropical lakes. In: *Biological Invaders in Inland Waters: Profiles, Distribution, and Threats, Vol. 2. Book Series Invading Nature - Springer Series in Invasion Ecology* (ed. F. Gherardi). Springer, Amsterdam, pp. 415–422.

Latini, A.O., Lima-Júnior, D.P., Giacomini, H.C. *et al.* (2004) Alien fishes in Rio Doce lakes: range, new occurrences and conservation of native community. *Lundiana* **5**, 135–142.

Lever, C. (1992) *They Dined on Eland. The Story of Acclimatisation Societies*. Quiller, London.

Lockwood, J.L., Hoopes, M.F. and Marchetti, M.P. (2007) *Invasion Ecology*. Blackwell, Malden.

Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M. and Bazzaz, F.A. (2000) Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications* **10**, 689–710.

McDowall, R.M. (1994) *Gamekeepers for the Nation: The Story of New Zealand's Acclimatisation Societies*. Canterbury University Press, Christchurch.

McMillan, M. and Wilcove, D. (1994) Gone but not forgotten: Why have species protected by the Endangered Species Act become extinct? *Endangered Species UPDATE* **11**, 5–6.

McNeely, A.J. (2001) An introduction to human dimensions of invasive alien species. In: *The Great Reshuffling: Human Dimensions of Invasive Alien Species*, (ed. A.J. McNeely). IUCN – The World Conservation Union, Cambridge, pp. 5–20.

Menescal, R.A. (2002) *Efeitos da introdução da tilápia do Nilo, Oreochromis niloticus, (Linnaeus, 1758) sobre o desembarque pesqueiro no açude Marechal Dutra, Acari, RN*. MSc Dissertation, Universidade Federal do Rio Grande do Norte, Rio Grande do Norte, Brazil, 50 pp.

Mieiro, C.L., Cabral, J.A. and Marques, J.C. (2002) Predation pressure of introduced mosquitofish (*Gambusia holbrooki* Girard) on the native zooplankton community. A case-study from representative habitats in the lower Mondego River valley (Portugal). *Limnetica* **20**, 279–292.

Moyle, P.B. (1993) *Fish. An Enthusiast's Guide*. University of California Press, Berkeley.

Moyle, P.B. and Light, T. (1996) Fish invasions in California: do abiotic factors determine success? *Ecology* **77**, 1666–1670.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A. and Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature* **403**, 853–858.

Nico, L.G., Williams, J.D. and Jelks, H.L. (2005) *Black Carp. Biological Synopsis and Risk Assessment of an Introduced Fish*. American Fisheries Society, Bethesda.

Ochumba, P.B.O. and Manyala, J.O. (1992) Distribution of fishes along the Sondu-Miriu River of Lake Victoria, Kenya, with special reference to upstream migration, biology and yield. *Aquaculture and Fisheries Management* **23**, 701–719.

Ogutu-Ohwayo, R. (1990a) The decline of the native fishes of Lakes Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile perch, *Lates niloticus* and the Nile tilapia. *Oreochromis niloticus*. *Environmental Biology of Fishes* **27**, 81–96.

Ogutu-Ohwayo, R. (1990b) Changes in the prey ingested and the variations in the Nile perch and other fish stocks in Lake Kyoga and the northern waters of Lake Victoria (Uganda). *Journal of Fish Biology* **37**(Suppl. A), 207–208.

Ogutu-Ohwayo, R. (1993) The effects of predation by Nile perch, *Lates niloticus* L., on the fish of Lake Nabugabo, with suggestions for conservation of endangered endemic cichlids. *Conservation Biology* **7**, 701–711.

Ogutu-Ohwayo, R. and Hecky, R. (1991) Fish introductions in Africa and some of their implications. *Canadian Journal of Fisheries and Aquatic Sciences* **48**(Suppl. 1), 8–12.

Okun, N., Brasil, J., Attayde, J.L. and Costa, I.A.S. (2008) Omnivory does not prevent trophic cascades in pelagic food webs. *Freshwater Biology* **53**, 129–138.

Olden, J.D., Poff, N.L., Douglas, M.R., Douglas, M.E. and Fausch, K.D. (2004) Ecological and evolutionary consequences of biotic homogenization. *Trends in Ecology & Evolution* **19**, 18–24.

Olowo, J.P. and Chapman, L.J. (1999) Trophic shifts in predatory catfishes following the introduction of Nile perch into Lake Victoria. *African Journal of Ecology* **37**, 457–470.

Orsi, M.L. and Agostinho, A.A. (1999) Introdução de espécies de peixes por escapes acidentais de tanques de cultivo em rios da bacia do rio Paraná, Brasil. *Revista Brasileira de Zoologia* **16**, 557–560.

Parker, I.M., Simberloff, D., Lonsdale, W.M. (1999) Impact: toward a framework for understanding the ecological effects of invaders. *Biological Invasions* **1**, 3–19.

Pyke, G.H. and White, A.W. (2000) Factors influencing predation on eggs and tadpoles of the endangered green and golden bell frog (*Litoria aurea*) by the introduced plague minnow (*Gambusia holbrooki*). *Australian Zoologist* **31**, 496–505.

Rahel, J.F. (2000) Homogenization of fish faunas across the United States. *Science* **288**, 854–856.

Rhymer, J. and Simberloff, D. (1996) Extinction by hybridization and introgression. *Annual Review of Ecology and Systematics* **27**, 83–109.

Ricciardi, A. (2003) Predicting the impacts of an introduced species from its invasion history: an empirical approach applied to zebra mussel invasions. *Freshwater Biology* **48**, 972–981.

Ross, S.T. (1991) Mechanisms structuring stream fish assemblages: are there lessons from introduced species? *Environmental Biology of Fishes* **30**, 359–368.

Ruesink, J.L. (2005) Global analysis of factors affecting the outcome of freshwater fish introductions. *Conservation Biology* **19**, 1883–1893.

Sala, O.E., Chapin III, F.S., Armesto, J.J. *et al.* (2000) Global biodiversity scenarios for the year 2100. *Science* **287**, 1770–1774.

Schofield, P.J. (1997) *Feeding Ecology of the Introduced Nile perch (Lates niloticus) in Lake Nabugabo, Uganda: Implications for Conservation of the Indigenous Fauna*. MSc Thesis, University of Florida, U.S.A.

Simberloff, D. (2001) Inadequate solutions for a global problem? *Trends in Ecology and Evolution* **16**, 323–324.

Simberloff, D. (2003) Confronting introduced species: a form of xenophobia? *Biological Invasions* **5**, 179–192.

Simberloff, D. (2004) Community ecology: is it time to move on? *American Naturalist* **163**, 787–799.

Simberloff, D. (2005) The politics of assessing risk for biological invasions: the USA as a case study. *Trends in Ecology and Evolution* **20**, 216–222.

Simberloff, D. (2006a) Invasional meltdown 6 years later: important phenomenon, unfortunate metaphor, or both? *Ecology Letters* **9**, 912–919.

Simberloff, D. (2006b) Book review of Black Carp. Biological Synopsis and Risk Assessment of an Introduced Fish. *Biological Invasions* **8**, 1433–1434.

Simberloff, D. (2007) Given the stakes, our modus operandi in dealing with invasive species should be ''guilty until proven innocent''. *Conservation Magazine* **8**, 18–19.

Starling, F., Lazzaro, X., Cavalcanti, C. and Moreira, R. (2002) Contribution of omnivorous tilapia to eutrophication of a shallow tropical reservoir: evidence from a fish kill. *Freshwater Biology* **47**, 2443–2452.

Townsend, C.R. and Winterbourn, M.J. (1992) Assessment of the environmental risk posed by an exotic fish: the proposed introduction of channel catfish (*Ictalurus punctatus*) to New Zealand. *Conservation Biology* **6**, 273–282.

Underwood, A.J. (1992) Beyond BACI: the detection of environmental impact on populations in the real, but variable, world. *Journal of Experimental Marine Biology and Ecology* **161**, 145–178.

United States Geological Survey (2000) *Zebra mussels Cause Economic and Ecological Problems in the Great Lakes*. GLSC Fact Sheet 2000-6. Great Lakes Science Center, Michigan.

Vitule, J.R.S. (2008) *Distribuição, Abundância e Estrutura Populacional de Peixes Introduzidos no rio Guaraguaçu, Paranaguá, Paraná, Brasil*. PhD Thesis, Universidade Federal do Paraná, Curitiba, Brazil, 139P.

Vitule, J.R.S., Umbria, S.C. and Aranha, J.M.R. (2005) Registro de Ocorrência do Bagre do Canal *Ictalurus punctatus* (Rafinesque, 1818) em uma Importante Bacia Hidrográfica da Floresta Atlântica Paranaense. In: *I Simpósio Brasileiro sobre Espécies Exóticas Invasoras*. http://www.mma.gov.br/port/sbf/invasoras/index.cfm. (retrieved on December 2007). Ministério do Meio Ambiente, Brasilia.

Vitule, J.R.S., Umbria, S.C. and Aranha, J.M.R. (2006a) Introduction of the African catfish *Clarias gariepinus* (Burchell, 1822) into Southern Brazil. *Biological Invasions* **8**, 677–681.

Vitule, J.R.S., Umbria, S.C. and Aranha, J.M.R. (2006b) Introdução de Espécies, com Ênfase em Peixes de Ecossistemas Continentais. In: *Revisões em Zoologia* (eds E.L.A. Monteiro-Filho and J.M.R. Aranha). Vol. 1. *Volume Comemorativo dos 30 Anos do Curso de Pós-Graduação em Zoologia da Universidade Federal do Paraná*. Secretaria do Meio Ambiente do Estado do Paraná, Curitiba, Paraná, Brazil, pp. 217–229.

Vitule, J.R.S., Umbria, S.C. and Aranha, J.M.R. (2008) Record of native amphibian predation by the alien African catfish in the Brazilian Atlantic Rain Forest. *Pan-American Journal of Aquatic Sciences* **3**, 105–107.

Welcomme, R.L. (1988) International introductions of inland aquatic species. *FAO Fisheries Technical Paper*, FAO, Rome, p. **294**.

Witte, F., Goldschmidt, T., Wanink, J., Vanoijen, M., Goudswaard, K., Wittemaas, E. and Bouton, N. (1992) The destruction of an endemic species flock – quantitative data on the decline of the haplochromine cichlids of Lake Victoria. *Environmental Biology of Fishes* **34**, 1–28.

Zambrano, L., Martinez-Meyer, E., Menezes, N.A. and Petersen, A.T. (2006) Invasive potential of common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) in American freshwater systems. *Canadian Journal of Fisheries and Aquatic Sciences* **63**, 1906–1910.