FISH and FISHERIES, 2008, **9**, 106–115

Ghoti

Ghoti papers

Ghoti aims to serve as a forum for stimulating and pertinent ideas. Ghoti publishes succinct commentary and opinion that addresses important areas in fish and fisheries science. Ghoti contributions will be innovative and have a perspective that may lead to fresh and productive insight of concepts, issues and research agendas. All Ghoti contributions will be selected by the editors and peer reviewed.

Etymology of Ghoti

George Bernard Shaw (1856–1950), polymath, playwright, Nobel prize winner, and the most prolific letter writer in history, was an advocate of English spelling reform. He was reportedly fond of pointing out its absurdities by proving that 'fish' could be spelt 'ghoti'. That is: 'gh' as in 'rough', 'o' as in 'women' and 'ti' as in palatial.

Introduction of non-native freshwater fish: is it all bad?

Rodolphe Elie Gozlan

School of Conservation Sciences, Bournemouth University, Talbot Campus, Fern Barrow, Poole, Dorset, BH12 5BB, UK

Abstract

Risk perceptions are important to the policy process, but there is often a well-established pattern of small risks being over assessed. This is also true with the issue of non-native freshwater fish introductions, where a great majority of research focuses on the few negative cases. The attitude towards 'non-natives' is a continually evolving process and varies according to current societal values. 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. Case studies from the African lakes are discussed in order to illustrate contrasting outcomes following fish introductions. Looking into the future, the environmental changes that freshwater ecosystems may encounter will have inevitable implications on the distribution of our native freshwater fish species and the need to rely on non-native introductions may become a growing reality. Aquaculture production is regularly increasing and our dependence on it is likely to become greater as it provides an important substitute for the declining production of capture fisheries. With it the number of freshwater fish introductions will increase and a more realistic attitude, albeit controversial, will need to be debated. This would mean protecting some introductions that present beneficial outcomes for biodiversity alongside a more systematic ban of species or families of fish presenting a higher historical ecological risk. The public perception of risk is something which cannot be ignored by any government or ruling body, but in order to gain public support in the fight for conservation of freshwater fish biodiversity, the message needs to be clear, detailed and educational.

Keywords Alien fish, aquaculture, biodiversity, ecological impact, economic value

Correspondence:
Rodolphe Elie Gozlan School of Conservation Sciences, Bournemouth University, Talbot Campus, Fern Barrow, Poole, Dorset, BH12 5BB, UK
Tel.: (+44) 01202 966780
Fax: (+44) 01202 965046
E-mail: rgozlan@bournemouth.ac.uk

Received 3 Aug 2007
Accepted 7 Nov 2007

© 2008 The Author
Journal compilation © 2008 Blackwell Publishing Ltd

Introduction

From melting pot to essence, the public view associated with the introduction of non-native species reflects our societal values towards others (Sagoff 2005, 2007) and is often a matter of risk perception rather than real risk analysis (Llewellyn 1998). The judgements that people make when asked to characterize and evaluate potential ecological risk are dictated by the scientific consensus (Wallner *et al.* 2003; Brown 2007; Sagoff 2007; Simberloff 2007). Introduction of non-native species is an issue which, since the 1970s, has generated an exponentially growing interest among the scientific community, with a general view that non-native species introduction is negative for biodiversity (Courtenay and Moyle 1992; Moyle and Leidy 1992; Cooke and Cowx 2004; Hickley and Chare 2004; Clarkson *et al.* 2005; Nishizawa *et al.* 2006; Vitule *et al.* 2006; Zimmerman and Vondracek 2006). However, this has not always been the case. In 1860 the Society for Acclimatisation of Animals, Birds, Fishes, Insects and Vegetables was created in the United Kingdom mainly as response to the formation of the Société Impériale d'Acclimatation in Paris in 1854 (Lever 1977). The sole aim of these societies was to introduce useful and ornamental species. Less than a century and a half later, the general view on introduced species has completely swung to the other side of the pendulum.

The aim of this paper is to open a critical debate on the real threat posed by the introduction of non-native fishes. Here I focus on intentional rather than accidental fish introductions and this is for two reasons. First, the introduction of fish worldwide is in its great majority the result of the globalization of the aquaculture trade for various purposes (i.e. angling or sport fishing; food, to fill an ecological niche; foraging for fisheries; biological control and ornamental) and that this tendency is likely to carry on and grow for some time. The second reason is that it is easier for scientists to develop adapted risk assessments for introductions associated with a defined trade than to forecast accidental introductions. Discussion has arisen over the ecological implications of fish introductions for commercial purposes. However, in other fields such as agronomy, research has already started to identify new species and varieties of commercial value to replace native ones which are becoming less adapted to the future changes in climate. As an example, the research focus has been on selecting more drought-resistant species as a result of hotter summers or with an earlier or later bloom to coincide with shifts in populations of polinators. The issue of whether fish introduction could be a biologically useful or even meaningful option for fish ecologists who may see some of their native species distribution retreating is controversial (Sagoff 2005, 2007; Brown 2007; Simberloff 2007). This is mainly because of the perception of risk associated with freshwater fish introduction and our research aims in assisting risk analysis and policy-making and to provide an objective understanding of risk associated to global freshwater fish introductions.

Datasets

The need for independent and internationally accepted data sources was paramount to the credibility of the analysis. I used a combination of datasets from the Food and Agriculture Organisation (FAO) (http://www.fao.org/fi/statist/statit.asp; accessed on 1 August 2007) and from FishBase (http://www.fishbase.org; accessed on 1 October 2007). FishBase was developed at the World Fish Center and is supported by a consortium of several international research institutions including IFM-Geomar, Fisheries Centre University of British Columbia, Muséum National d'Histoire Naturelle, Swedish Museum of Natural History, Africa museum and Aristotle University of Thessaloniki. It provides full information on 28 500 species which are regularly updated. The other datasets from the FAO are compiled from international classifications and follow a standardized data submission procedure which ensures comparability across countries. I used the database containing statistics on aquaculture production, volume and value price per kilogram by species, country or area, fishing area and culture aquatic environment per year for a time series of 54 years ending with the latest year for which statistics are available in the database (i.e. 2004). Here aquaculture production covers fish produced for angling or sport, food, fisheries and ornamental. Because of the existence of a lag phase between time of introduction and potential ecological impact, introduction data were integrated over the 54-year period. Only freshwater species (i.e. species reproducing in freshwater) were selected for analysis (n = 164) and species names which could not confidently be linked to a Latin name were eliminated (n = 32). For the remaining 132 species, family, introduction status and

© 2008 The Author

confirmed ecological impact were obtained from scientific publications. In addition, the global introduction count produced in FishBase was used to highlight discrepancies between donor and recipient regions. For the purpose of drawing general conclusions about global fish movements, introductions and aquaculture production, the inland water FAO regions (Africa, Asia, Europe, former USSR, North America, Oceania and South America) were used for both data sources. However, translocations within a region, which are in fact introductions between countries of the same FAO region, were taken into account when calculating the total number of introductions in a given region. In this study, a non-native species was referred to as a single species introduction to a country and/or translocation across several countries within an FAO region. No measure of propagule pressure at country level is provided (number/volume of repeated introductions within the same country). Only a few countries have quantitative records of the propagule pressure associated with national fish introduction (Copp *et al.* 2007). Here, the propagule pressure is expressed at the global scale in relation to the overall number of countries where a particular species has been introduced.

Aquaculture as a source for freshwater fish introduction

By nature, people are the main vector of freshwater fish movements across river basins or countries. The general understanding is that freshwater aquaculture production is increasing (FAO sources) and is a major driver of freshwater fish introductions. The overall number of fish species introduced worldwide from known sources reaches 624 species from which 91% is explained by a need of fish for food (51%), hobbyist fish (21%), angling or sport (12%) or fisheries (7%) (Fig. 1). When compared with the first estimate nearly three decades ago (Beverton 1992; Williamson 1996), the number of species introduced worldwide has more than doubled.

However, there are discrepancies across regions in terms of import/export of non-native fish (Fig. 2) and these discrepancies are not related to the natural species richness in freshwater fish within each region. For example, South America has nearly the same number of finfish species as Asia (4103 against 4223) and nearly 10 times more than Europe (410), yet shows a much lower level of non-native fish imports (191) than these regions (Asia 957; Europe 705). The level of non-native introductions in a given region is determined by the level of aquaculture production as shown by the positive Pearson correlation between the cumulated aquaculture production between 1950 and 2004 and the number of fish species introduced to a region ($r = 0.79$, $n = 6$, $P = 0.03$). Asia, which has the highest aquaculture production of freshwater fish (about 300 million tonnes of fish in 2004), also has the highest ranking for import/export of non-native freshwater fish (Fig. 2). These results support what many authors have suggested, that aquaculture as a whole is largely responsible for the majority of fish introductions across the world (Welcomme 1988; De Silva *et al.* 2006). Although always growing, aquaculture production considerably increased during the 1970s with the positioning of South America and Oceania as serious competitors in the global market. Most aquaculture trade is for food purposes (Locwood 1999) but aquaculture of ornamental and angling/sport species is an increasing market in Asia, Europe and North America (Cooke and Cowx 2004; Hickley and Chare 2004; Clarkson *et al.* 2005).

Ecological impact and freshwater fish introduction

One of the major difficulties in science is agreeing on the definition of terms. For example, when we refer to ecological impact as a result of fish introduction, the understanding of what is meant by 'impact' is

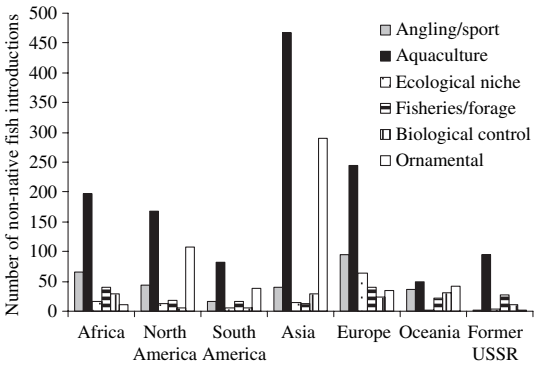

Figure 1 Histogram of the number of non-native freshwater fish introductions per sector for each Food and Agriculture Organisation (FAO) region. The same species can be introduced for different purposes in different FAO regions.

© 2008 The Author

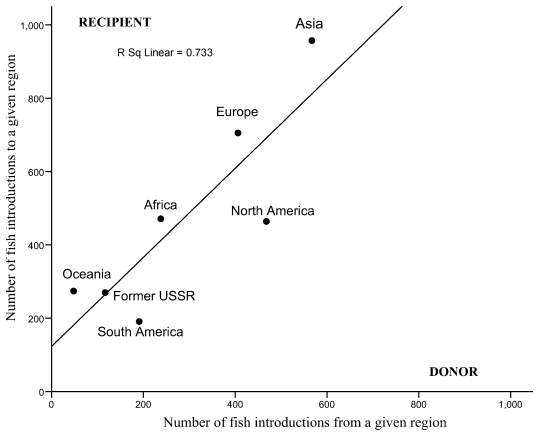

Figure 2 Number of exotic species introduced to/from a given FAO region including introductions within the region and introductions from other regions. The linear regression (solid line) is also shown ($\boldsymbol{R}^2 = 0.73$, $Y = 122.93 + 1.214X$).

relatively vague and could often depend on point of view (Sagoff 2005, 2007). Although some argue that ecological impact associated with non-native species introduction can be positive (Brown 2007; Sagoff 2007), for the purpose of this work, ecological impact has been defined as 'quantifiable negative effect' on the recipient environment and has been measured using the existence of scientific reports and publications (peer reviewed or not) associated to a particular species introduction. For example, if a fish species after its introduction in a particular country has been reported to cause habitat degradation, competition with native species for spawning ground, hybridization threatening species integrity, predation on native species population resulting in their decline or a depletion of native food resources, then this species will be considered as having had an ecological impact on the recipient ecosystem. It is assumed that in this way, over at least a 54-year period, an undisputed ecological impact following a freshwater fish introduction would have been picked up in scientific literature. Finally, introductions as well as ecological impacts are recorded and analysed as the number of countries where a given species has been introduced or was identified as having an ecological impact (i.e. not a measure of propagule pressure and/or numbers of ecological impacts per country of introduction).

Among the 132 freshwater fish species identified in the FAO aquaculture database, a subset of 103 species was introduced outside their native range and a majority of these (52%) were not reported as having an ecological impact on the native ecosystem. Although increasing with the number of introductions (Fig. 3), the risk of ecological impact after the introduction of a freshwater fish species is less than 10% for the great majority of fish species introduced (84%). This is not too dissimilar from Simberloff's (2007) estimates or from the 'tens rule' of Williamson (1996) which predicted that 10% of all introductions will get established and that 10% of those established become pests. In addition, these introductions are targeted for fish species especially well adapted to the recipient environment as the purpose is to farm them at great number with minimal effort and cost. This means that these species should be the most likely to establish and have an ecological impact (i.e. worst case scenario).

Having said that, the ecological risk associated with freshwater fish introduction is fairly variable across families of fish. Historically, this risk varies according to the life history trait characteristics of individual families (Fig. 4) as recently demonstrated for the Great lakes area (Kolar and Lodge 2002). For some, such as the Acipenseridae, the risk is fairly low regardless of the specific fish introduction, while for others, such as Percidae, every species introduction represents a high risk. Fish species belonging to these families should be good candidates for screening by robust risk assessment schemes because of their consistent historical risk (Copp *et al.* 2005). However, screening species belonging to families where the risk of ecological impact following intro-

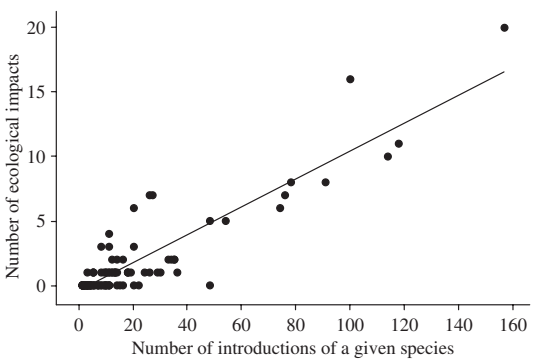

Figure 3 Relationship per given species, between the number of countries where this species has been introduced and the number of identified ecological impacts among these countries. Linear regression (solid line) is given ($R^2 = 80.9$, $Y = -0.391 + 0.108X$).

© 2008 The Author

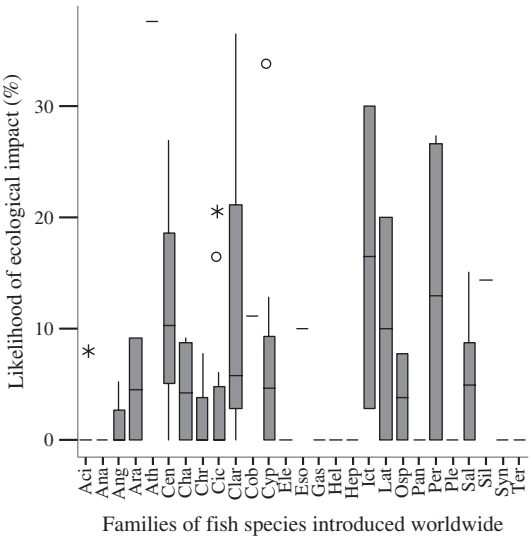

Figure 4 Box plot of the relationship between family history of introduction and associated likelihood of ecological impact (i.e. number of reported ecological impact/number of introductions). Horizontal line, whiskers, circle and star correspond respectively to the median, standard error, outliers and extremes values. Abbreviations for families as well as number of species per families are as follows: Acipenseridae, Aci (n = 5); Anabantidae, Ana (n = 1); Anguillidae, Ang (n = 3); Arapaimidae, Ara (n = 2); Atherinopsidae, Ath (n = 1); Centrarchidae, Cen (n = 3); Chanidae, Cha (n = 4); Characidae, Chr (n = 3); Cichlidae, Cic (n = 15); Clariidae, Clar (n = 4); Cobitidae, Cob (n = 1); Cyprinidae, Cyp (n = 24); Eleotridae, Ele (n = 1); Esocidae, Eso (n = 1); Gasterosteidae, Gas (n = 1); Helostomatidae, Hel (n = 1); Heptapteridae, Hep (n = 1); Ictaluridae, Ict (n = 2); Latidae, Lat (n = 2); Osphronemidae, Osp (n = 2); Pangasiidae, Pan (n = 2); Percichthyidae, Per (n = 4); Plecoglossidae, Ple (n = 1); Salmonidae, Sal (n = 14); Siluridae, Sil (n = 1); Synbranchidae, Syn (n = 2); Terapontidae, Ter (n = 1).

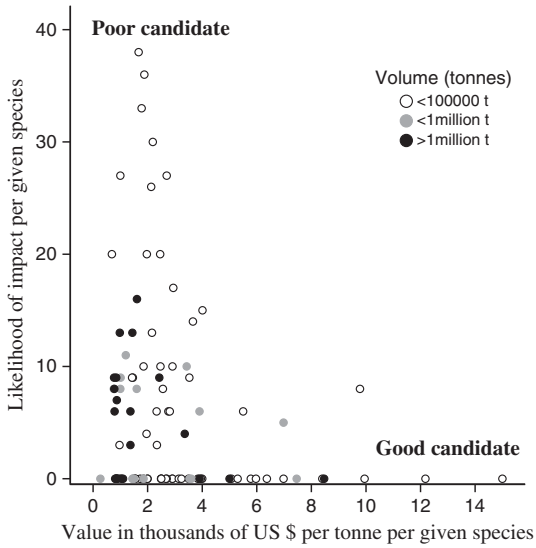

Figure 5 Relationship between economic value and likelihood of ecological impact per given species. The dashed line shows the average likelihood for all fish species introductions. White circles indicate species production in tonnes strictly below 100 000; grey circles indicate more than 100 000 and less than a million and black circles indicate strictly above a million.

duction is highly variable, such as Claridae or Ictaluridae, is more complicated and precautionary approaches banning these introductions may become the norm.

Economical aspects of fish introductions

The ecological risks taken in isolation do not reflect the complexity of the issue and a good understanding of the economics underlying freshwater fish introductions is paramount in developing sound policies. Market value as well as ecological risk is fairly variable between species (Fig. 5). When a fish presents a high risk of having an ecological impact and a poor market value, it is clearly a poor candidate for introduction elsewhere and should be prohibited. Conversely, species with high market value and little or no historical risk should be supported for further introductions. A large number of freshwater fish species (31%) hold an economical value above the average market price (mean ± SE = 2.9 ± 0.25 thousands of US dollars per tonne) and present an historical ecological risk below 10%. Among them, 24 species (23%) present no identified ecological risk. In the meantime, a minority of species (14%) in the aquaculture market presents a fair ecological risk (i.e. above 0.1) for a market value well below US$3000 per tonne. These are the poor candidates which set the trends of risk perception associated with the introduction of non-native fishes.

Discussion

The swing of opinion since the Victorian Society for Acclimatisation of Animals was created has led to the perception that all non-native freshwater fish introductions present a risk for biodiversity and should be considered guilty until proven innocent (Simberloff 2007). Generally, ecological impacts of non-native species introduction are related to

© 2008 The Author

predation, hybridization, diet overlap, habitat modification or even introduction of disease. But unless these become a problem and are associated with a quantifiable decline in native resources (i.e. habitat degradation, competition with native species for spawning ground with implication on successful reproduction of native species, hybridization threatening species integrity, predation on native species population resulting in their decline or a depletion of native food resources) should we be concerned?

Of course there is always the issue of lag phase, meaning that a species which was introduced a few years ago can suddenly become invasive and a pest. This is also referred to as the volatile ecology of alien species (Townsend 1991; Pitcher and Bundy 1994). However, there are also many non-native species that have been around for decades, sometimes even centuries, which are of little concern. Some of them are so popular that they are now generally considered by the lay man as native species. This is the case with the introduction of carp (*Cyprinus carpio*, Cyprinidae) in Europe. So when does a non-native species become part of the national patrimony? There are many factors to consider but often involves the length of time since the first introduction, the fact that there is no obvious ecological impact and that the species is the source of good economic growth. However, it is not always so straightforward.

A good example is the introduction of Nile perch (*Lates niloticus*, Latidae) in Lake Victoria (Ogutu-Ohwayo 1990; Ogutu-Ohwayo and Hecky 1991; Pitcher and Bundy 1994; Pitcher 1995). This species was introduced to support the lake economy and as such has supported a large and viable fishery (Pitcher and Bundy 1994). Over time, it has also been associated with severe ecological impact, in particular the decline of haplochromine species (Ogutu-Ohwayo 1990; Witte *et al.* 1992; Hauser *et al.* 1998). But on closer investigation, it seems that this fish introduction has been the victim of its own success. As a new and valuable source of revenue it resulted in an increase in fishing pressure and a reduction of mesh size for fishing nets (Matsuishi *et al.* 2006). In addition, the destruction of the surrounding trees to smoke and prepare the fish has increased the level of fine sediment input in the lake, and many other environmental stressors resulting from social pressure have consolidated the ecological impact on haplochromine species (Witte *et al.* 1992). However, nearly 60 years later, can the introduction of the Nile perch be seen as an economic saviour or an ecological disaster? The difficult economic situation arising in this example is more likely to have been the driver as suggested in the controversial film 'Darwin's nightmare' (http://www.darwinsnightmare.com/darwin/html/startset.htm; Pitcher and Hart 1995; Verschuren *et al.* 2002; Leveque and Paugy 2007). In contrast, the introduction of a planktivorous fish *Limnothrissa miodon* (Clupeidae) into the Democratic Republic of Congo (Lake Kivu), Tanzania (Lake Tanganyika) and Mozambique (Zambezi river) has established highly successful fisheries with little effect on the pre-existing fish community or trophic ecology (Spliethoff *et al.* 1983; Ogutu-Ohwayo and Hecky 1991; Marshall 1995; Isumbisho *et al.* 2006). Despite initial concerns that this introduction could have a detrimental impact on the mesozooplankton of Lake Kivu (Dumont 1986), a recent study showed that contrary to expectations from the food web structure, mesozooplankton dynamics were mainly bottom-up controlled (Isumbisho *et al.* 2006). This clearly highlights the fact that some introductions have positive outcomes.

The second example is the case of the Great Lakes in North America. Although very well studied, the potential ecological impact of this example is less clear cut. Many refer to the Great Lakes as an ecosystem plagued by the introduction of non-native species (Beeton 2002; Mills *et al.* 2003; Perakis and Yang 2003) with severe ecological impact from organisms such as lamprey (*Petromyzon marinus*, Petromyzontidae) and round goby (*Neogobius melanostomus*, Gobiidae). Others will stress that the Great Lakes were plagued by eutrophication for decades and that the introduction of the zebra mussel *Dreissena polymorpha*, a fine particle filter, has been of great benefit to the ecosystem; bird populations have modified their flight path to feed on this new resource. Round goby feeds on zebra mussels and as round gobies are increasingly part of the native predators' diet in the Great Lakes, some could argue that their introduction is beneficial as it converts an exotic mussel into prey for native species. Does it all depend on your own perspective as Sagoff (2007) summarized? From a biodiversity point of view, it all rests on a sound definition of ecological impact which should rely on quantifiable empirical evidence and not on *a priori* statements; in the case of the Great Lakes these impacts have been well documented (Morrison 2000; Kolar and Lodge 2002; Perakis and Yang 2003).

© 2008 The Author

One concern of ecological impacts is related to hybridization between introduced and native species. A well-documented case is the hybridization between the crucian carp (*Carassius carassius*, Cyprinidae) a native of Europe, and the goldfish (*Carassius auratus*, Cyprinidae), which is native to the far east (Hanfling *et al.* 2005). However, the link between the decline of crucian carp in the wild and the introduction of goldfish has never been clearly established. Another example is the colonization by the non-native nase (*Chondrostoma nasus*, Cyprinidae) in the Rhone catchment where the French nase (*Chondrostoma toxostoma*, Cyprinidae) occurs. These two species have hybridized for decades creating a 'hybrid zone', while at the same time maintaining pure bred populations within the ecosystem. Hybridization is a natural process and is commonly found among native fish communities as exemplified by the hybrids that exist between roach (*Rutilus rutilus*, Cyprinidae), rudd (*Scardinius erythrophthalmus*, Cyprinidae) or bream (*Abranis brama*, Cyprinidae). Detrimental cases of hybridization can also be found between native farmed fish such as Atlantic salmon (*Salmo salar*, Salmonidae) and wild populations of salmon following introgression with escapees from aquaculture facilities (Gausen and Moen 1991; Hutchings 1991; Crozier 1993; Heggberget *et al.* 1993; Clifford *et al.* 1998; Fleming *et al.* 2000; Garant *et al.* 2003). It may be that hybridization is the mechanism that crystallizes other ecological issues such as reduction in availability of suitable spawning habitat and fragmentation of habitat as a result of physical barriers within the river system.

Finally, a great concern associated with the introduction of non-native species is the introduction of novel pathogens (Boxshall and Frear 1990; Kennedy *et al.* 1991; Clifford *et al.* 1998; Kirk 2003; Beyer *et al.* 2005; Gozlan *et al.* 2005, 2006). Serious consequences arise when new pathogens are introduced to naïve populations that have not co-evolved with the pathogen and where concomitant immunity does not exist in a host that would otherwise have been continuously infected. A recent example is the dramatic impact of the rosette-like agent, an emerging disease associated with the invasive topmouth gudgeon (*Pseudorasbora parva*, Cyprinidae), on native European sunbleak (*Leucaspius delineatus*, Cyprinidae). But other diseases such as proliferative kidney disease (PKD) of salmonids caused by the myxosoan parasite (*Tetracapsuloides bryosalmonae,* Saccosporidae) is among the most important diseases affecting salmonids in many European countries and North America (Henderson and Okamura 2004). This is a native European disease affecting native European salmonids and, although initially spread with the movement of salmonids in European aquaculture, is not specifically linked with the introduction of non-native fish species. A similar example is the monogean parasite (*Gyrodactylus salaris,* Gyrodactylidae) which is associated with Atlantic salmon in Sweden and many others across the world (Gozlan *et al.* 2006). Once again, although very serious in terms of ecological impact, the issue of disease introduction is not specific to the introduction of non-native species but more generally to the stocking of fish.

There are definite aspects associated with the introduction of freshwater fish which clearly need to be mitigated, such as limiting the introduction of top predators in ecosystems with high conservation value, preventing or limiting escapees from aquaculture facilities or even enforcing more stringent quarantine guidelines. The focus should perhaps be on the better selection of candidate fish species for aquaculture as there are clear discrepancies in terms of risk and benefits. But beyond this, it is the attitude towards fish introduction that needs to be shifted between the enthusiastic Victorian approach and the guilty until proven innocent way of thinking (Simberloff 2007).

After all, there are clear benefits in introducing non-native species, not only economically or as a means of feeding people but also as a more forgotten benefit for biodiversity. A good example is the introduction of freshwater fish species that are considered endangered or vulnerable in their native range but become established in their introduced range. Sunbleak is a small cyprinid species which used to be abundant in central Europe but has now dramatically declined throughout its native range (Gozlan *et al.* 2003a; b). However, since it was introduced into England in the mid-1980s, it has established large populations and is now considered to be well established. It could thus be argued that, from a biodiversity point of view, it would be more valuable to develop a conservation approach to the sunbleak in England as is already the case in Sweden (Larje 1990), rather than considering sunbleak as a nuisance and trying to eradicate it on the basis that it is a non-native fish species. This approach is also valid for the nase which, despite declining in its native range, is well established in the Rhone and its tributaries in

© 2008 The Author

France (Nelva 1997). This is the type of approach and understanding of non-native freshwater fish introduction that should be promoted. This could be a very rigorous, possibly even a case-by-case approach which puts the ecological issues towards a much more pragmatic rather than didactic answer to nonetheless important ecological questions. Looking into the future, the environmental changes that freshwater ecosystems may encounter will have implications on the distribution of our native freshwater fish communities and the need to rely on non-native introductions may also become a growing reality.

Conclusion

The number of freshwater fish introductions will continue to increase (Welcomme 1988; De Silva *et al.* 2006) and a more realistic attitude, despite being sometimes controversial, will need to be adopted. This would mean protecting some introductions that present beneficial outcomes for biodiversity and a more systematic ban of species or families of fish presenting a higher historical risk. It is also important to distinguish between man-made lakes or reservoirs and natural lakes as the ecological impact resulting from an introduction is often very different. Another worthwhile aspect of fish introduction is the issue of equity, in other words who gets the benefits and who bears costs. In the case of species introduction the benefits are often limited to a small group, such as fish farmers, anglers, hobbyists, but the cost in the case of an ecological impact is supported by the society as a whole (Pimentel *et al.* 2000). For these reasons, when looking at the issue of non-native fish introductions, the ecological risk should not be taken in isolation but balanced with the benefits of the introduction as well as the aspect of equity which needs to be built into the policies regulating import of the species. Risk assessments preceding freshwater fish introductions should concern any species regardless of its origins. Overall, the probability of an ecological impact resulting from freshwater fish introduction is relatively low (around 6%, see Fig. 3) and presents many positive aspects. The public perception of risk is something which cannot be ignored by any government or ruling body (Conchie *et al.* 2006; Greenberg and Sinha 2006; Hong and Collins 2006; Nishizawa *et al.* 2006), but in order to gain public support in the fight for conservation of freshwater fish biodiversity, the message needs to be clear, detailed and educational.

Acknowledgements

The author is particularly grateful to G.H. Copp whose work on risk assessment as well as the participation in the CEAFS Technical report on Risk Identification and Assessment of non-native freshwater fishes and the DEFRA Risk Assessment Scheme for all UK non-native species in 2005, was the inspiration for this paper. The work was funded by the European Union under the work package *Biological Invasions Risk Assessment Tools* of the Framework VI project ALARM and the Centre for Ecology and Hydrology research programme on the ecological impacts of non-native fishes introductions in the United Kingdom (C02829).

References

Beeton, A.M. (2002) Large freshwater lakes: present state, trends, and future. *Environmental Conservation* **29**, 21–38.

Beverton, R.J.H. (1992) Fish resources, threats and protection. *Netherlands Journal of Zoology* **42**, 139–175.

Beyer, K., Kochanowska, D., Longshaw, M., Feist, S.W. and Gozlan, R.E. (2005) A potential role for invasive sunbleak in the further dissemination of a non-native parasite. *Journal of Fish Biology* **67**, 1730–1733.

Boxshall, G.A. and Frear, P.A. (1990) Tracheliastes-Maculatus (Kollar, 1836) (Crustacea, Lernaeopodidae) a new species for Britain. *Journal of Fish Biology* **37**, 489–491.

Brown, J.H. (2007) Do biological invasions decrease biodiversity? *Conservation Magazine* **8**, 16–17.

Clarkson, R.W., Marsh, P.C., Stefferud, S.E. and Stefferud, J.A. (2005) Conflicts between native fish and nonnative sport fish management in the southwestern United States. *Fisheries* **30**, 20–27.

Clifford, S.L., McGinnity, P. and Ferguson, A. (1998) Genetic changes in Atlantic salmon (*Salmo salar*) populations of northwest Irish rivers resulting from escapes of adult farm salmon. *Canadian Journal of Fisheries and Aquatic Sciences* **55**, 358–363.

Conchie, S.M., Donald, I.J. and Taylor, P.J. (2006) Trust: missing piece(s) in the safety puzzle. *Risk Analysis* **26**, 1097–1104.

Cooke, S.J. and Cowx, I.G. (2004) The role of recreational fishing in global fish crises. *Bioscience* **54**, 857–859.

Copp, G.H., Garthwaite, R. and Gozlan, R.E. (2005) Risk identification and assessment of non-native freshwater fishes: a summary of concepts and perspectives on protocols for the UK. *Journal of Applied Ichthyology* **21**, 371–373.

© 2008 The Author

Copp, G.H., Templeton, M. and Gozlan, R.E. (2007) Propagule pressure and the occurrence of non-native fishes in regions of England. *Journal of Fish Biology*, **71, Suppl. D**, 148–159.

Courtenay, W.R. and Moyle, P.B. (1992) Crimes against biodiversity – the lasting legacy of fish introductions. In: *Transactions of the Fifty-Seventh North American Wildlife and Natural Resources Conference* (ed R.E. McCabe). Wildlife Management Institute, Washington, pp. 365–372.

Crozier, W.W. (1993) Evidence of genetic interaction between escaped farmed salmon and wild Atlantic salmon (*Salmo-Salar* L) in a northern Irish river. *Aquaculture* **113**, 19–29.

De Silva, S.S., Nguyen, T.T.T., Abery, N.W. and Amarasinghe, U.S. (2006) An evaluation of the role and impacts of alien finfish in Asian inland aquaculture. *Aquaculture Research* **37**, 1–17.

Dumont, H.J. (1986) The Tanganyika Sardine in Lake Kivu – another ecodisaster for Africa. *Environmental Conservation* **13**, 143–148.

Fleming, I.A., Hindar, K., Mjolnerod, I.B., Jonsson, B., Balstad, T. and Lamberg, A. (2000) Lifetime success and interactions of farm salmon invading a native population. *Proceedings of the Royal Society of London Series B – Biological Sciences* **267**, 1517–1523.

Garant, D., Fleming, I.A., Einum, S. and Bernatchez, L. (2003) Alternative male life-history tactics as potential vehicles for speeding introgression of farm salmon traits into wild populations. *Ecology Letters* **6**, 541–549.

Gausen, D. and Moen, V. (1991) Large-scale escapes of farmed Atlantic salmon (*Salmo-Salar*) into Norwegian rivers threaten natural populations. *Canadian Journal of Fisheries and Aquatic Sciences* **48**, 426–428.

Gozlan, R.E., Flower, C.J. and Pinder, A.C. (2003a) Reproductive success in male sunbleak, a recent invasive fish species in the UK. *Journal of Fish Biology* **63**, 131–143.

Gozlan, R.E., Pinder, A.C., Durand, S. and Bass, J. (2003b) Could the small size of sunbleak, *Leucaspius delineatus* (Pisces, Cyprinidae) be an ecological advantage in invading British waterbodies? *Folia Zoologica* **52**, 99–108.

Gozlan, R.E., St-Hilaire, S., Feist, S.W., Martin, P. and Kent, M.L. (2005) Biodiversity – disease threat to European fish. *Nature* **435**, 1046–1046.

Gozlan, R.E., Peeler, E.J., Longshaw, M., St-Hilaire, S. and Feist, S.W. (2006) Effect of microbial pathogens on the diversity of aquatic populations, notably in Europe. *Microbes and Infection* **8**, 1358–1364.

Greenberg, M.R. and Sinha, R. (2006) Government risk management priorities: a comparison of the preferences of Asian Indian Americans and other Americans. *Risk Analysis* **26**, 1275–1289.

Hanfling, B., Bolton, P., Harley, M. and Carvalho, G.R. (2005) A molecular approach to detect hybridisation between crucian carp (*Carassius carassius*) and non-indigenous carp species (*Carassius spp.* and *Cyprinus carpio*). *Freshwater Biology* **50**, 403–417.

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.

Heggberget, T.G., Johnsen, B.O., Hindar, K., Jonsson, B., Hansen, L.P., Hvidsten, N.A. and Jensen, A.J. (1993) Interactions between wild and cultured Atlantic salmon – a review of the Norwegian experience. *Fisheries Research* **18**, 123–146.

Henderson, M. and Okamura, B. (2004) The phylogeography of salmonid proliferative kidney disease in Europe and North America. *Proceedings of the Royal Society of London Series B – Biological Sciences* **271**, 1729–1736.

Hickley, P. and Chare, S. (2004) Fisheries for non-native species in England and Wales: angling or the environment? *Fisheries Management and Ecology* **11**, 203–212.

Hong, S. and Collins, A. (2006) Societal responses to familiar versus unfamiliar risk: comparisons of influenza and SARS in Korea. *Risk Analysis* **26**, 1247–1257.

Hutchings, J.A. (1991) The threat of extinction to native populations experiencing spawning intrusions by cultured Atlantic salmon. *Aquaculture* **98**, 119–132.

Isumbisho, M., Sarmento, H., Kaningini, B., Micha, J.C. and Descy, J.P. (2006) Zooplankton of Lake Kivu, East Africa, half a century after the Tanganyika sardine introduction. *Journal of Plankton Research* **28**, 971–989.

Kennedy, C.R., Hartvigsen, R. and Halvorsen, O. (1991) The importance of fish stocking in the dissemination of parasites throughout a group of reservoirs. *Journal of Fish Biology* **38**, 541–552.

Kirk, R.S. (2003) The impact of *Anguillicola crassus* on European eels. *Fisheries Management and Ecology* **10**, 385–394.

Kolar, C.S. and Lodge, D.M. (2002) Ecological predictions and risk assessment for alien fishes in North America. *Science* **298**, 1233–1236.

Larje, R. (1990) Rare fish in Sweden – Nemacheilus survey and public reactions. *Journal of Fish Biology* **37**, 219–221.

Leveque, C. and Paugy, D. (2007) Talking of the film ''Darwin's Nightmare''. *Cahiers Agricultures* **16**, 49–51.

Lever, C. (1977) *The Naturalized Animals of the British Isles*. Hutchinson & Co, London.

Llewellyn, G. (1998) Strategic risk assessment – prioritising environmental protection. *Journal of Hazardous Materials* **61**, 279–286.

Locwood, J.A. (1999) Agriculture and biodiversity: finding our place in the world. *Agriculture and Human Values* **16**, 365–379.

Marshall, B.E. (1995) Why is *Limnothissa moidon* such a successful introduced species and is there anywhere else we should put it? In: *Impact of Species Change in African*

© 2008 The Author

Lakes (eds T.J. Pitcher and P.J.B. Hart). Chapman & Hall, London, pp. 527–546.

Matsuishi, T., Muhoozi, L., Mkumbo, O. *et al.* (2006) Are the exploitation pressures on the Nile perch fisheries resources of Lake Victoria a cause for concern? *Fisheries Management and Ecology* **13**, 53–71.

Mills, E.L., Casselman, J.M., Dermott, R. *et al.* (2003) Lake Ontario: food web dynamics in a changing ecosystem (1970–2000). *Canadian Journal of Fisheries and Aquatic Sciences* **60**, 471–490.

Morrison, D. (2000) Environmental and economic costs of nonindigenous species in the United States. *Bioscience* **50**, 53–65.

Moyle, P.B. and Leidy, R.A. (1992) Loss of biodiversity in aquactic ecosystems; evidence from fish fauna. In: *Conservation Biology: The Theory and Practice of Nature Conservation* (eds P.L. Fielder and S.K. Jain). Chapman and Hall, London, pp. 129–161.

Nelva, A. (1997) The penetration of the nase, *Chondrostoma nasus nasus* (Pisces, Cyprinidae), in the French hydrographic network and its consequences. *Bulletin Francais De La Peche Et De La Pisciculture* **70**, 253–269.

Nishizawa, E., Kurokawa, T. and Yabe, M. (2006) Policies and resident's willingness to pay for restoring the ecosystem damaged by alien fish in Lake Biwa, Japan. *Environmental Science and Policy* **9**, 448–456.

Ogutu-Ohwayo, R. (1990) 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. and Hecky, R.E. (1991) Fish introductions in Africa and some of their implications. *Canadian Journal of Fisheries and Aquatic Sciences* **48**, 8–12.

Perakis, A.N. and Yang, Z.Y. (2003) Options for non-indigenous species control and their economic impact on the Great Lakes and St. Lawrence seaway: a survey. *Marine Technology and Marine Technology News* **40**, 34–41.

Pimentel, D., Lach, L., Zuniga, R. and Morrison, D. (2000) Environmental and economic costs of non-indigenous species in the United States. *Bioscience* **50**, 53–65.

Pitcher, T.J. (1995) Thinking the unthinkable: a candidate model for predicting sustainable yields of introduced fish species in African Lakes. In: *Impact of Species Change in African Lakes* (eds T.J. Pitcher and P.J.B. Hart). Chapman & Hall, London, pp. 495–526.

Pitcher, T.J. and Bundy, A. (1994) Successful species introductions in the African Lakes: assessment, uncertainties and strategies for fishery management. In: *Management Strategies for Exploited Fish Populations*, Vol. 93–02 (eds G. Kruse, D.M. Eggers, R.J. Marasco, C. Pautzke and T.J. Quinn Vol. 93. Alaska Sea Grant College Program, Fairbanks, Alaska, pp. 545–572.

Pitcher, T.J. and Hart, P.J.B. (1995) *The Impact of Species Changes in African Lakes (Fish and Fisheries)*, **Vol. 18**. Chapman & Hall, London.

Sagoff, M. (2005) Do non-native species threaten the natural environment? *Journal of Agriculture and Environmental Ethics* **18**, 215–236.

Sagoff, M. (2007) Are nonnative species harmful? *Conservation Magazine* **8**, 20–21.

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.

Spliethoff, P.C., Frank, V.G. and Deiongh, H.H. (1983) Success of the introduction of the fresh-water clupeid *Limnothrissa-Miodon* (*Boulenger*) in Lake Kivu. *Fisheries Management* **14**, 17–31.

Townsend, C.R. (1991) Exotic species management and the need for a theory of invasion ecology. *New Zealand Journal of Ecology* **15**, 1–3.

Verschuren, D., Johnson, T.C., Kling, H.J. *et al.* (2002) History and timing of human impact on Lake Victoria, East Africa. *Proceedings of the Royal Society of London Series B – Biological Sciences* **269**, 289–294.

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

Wallner, A., Hunziker, M. and Kienast, F. (2003) Do natural science experiments influence public attitudes towards environmental problems? *Global Environmental Change – Human and Policy Dimensions* **13**, 185–194.

Welcomme, R.L. (1988) International introductions of inland aquatic species. *FAO Fisheries Technical Paper* **213**, 120.

Williamson, M. (1996) *Biological Invasions*. Chapman & Hall, London.

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.

Zimmerman, J.K.H. and Vondracek, B. (2006) Interactions of slimy sculpin (*Cottus cognatus*) with native and nonnative trout: consequences for growth. *Canadian Journal of Fisheries and Aquatic Sciences* **63**, 1526–1535.

© 2008 The Author

Copyright of Fish & Fisheries is the property of Blackwell Publishing Limited and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.