Hydrobiologia **500:** 217–230, 2003.
K. Martens (ed.), Aquatic Biodiversity.

Impact on indigenous species biodiversity caused by the globalisation of alien recreational freshwater fisheries

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Received 18 March 2003; in revised form 30 April 2003; accepted 30 April 2003

Key words: alien invasives, anglers, aquatic biodiversity, bass, ecocentrism, environmental education, globalisation, recreational freshwater fisheries, trout

Abstract

One of the most insidious threats to fish conservation around the world is deliberate or accidental introduction of fish species. The impact of alien invasive sport fish is for the most part unpredictable in time and space, with the introduction of relatively few species having resulted in many extirpations of indigenous fish species worldwide. More nations need to quantify biodiversity loss caused by alien sport fishes. The spread of alien invasive fishes does not respect political boundaries. Therefore total global costs to aquatic biodiversity and ecosystem functioning resulting from these introductions need to be assessed. The global invasive species database of the Global Invasive Species Programme, highlights eight fish species among the one hundred 'World's Worst Invasive Alien Species'. Three of these fish species (two trout and one bass species) were introduced solely for sport. Historically the social value of recreational fishing was usually more important than conserving biodiversity. Globalisation of alien fish species for sport is best illustrated by rainbow trout – now in 82 countries, and still spreading, along with the associated expensive angling gear, magazines and accommodation infrastructure. Such sport species have become part of the global consumer society. The nature and extent of the globalisation phenomenon is addressed with regard to how introduction of alien fish for recreational angling has impacted on biodiversity; trophic cascades at a local level and the unassessed total cumulative global trophic cascades; and some of the motives that underlie promotion of this sport within the complexity of globalisation as we know it today. Alien invasive recreational fish species are now recognised as a global environmental degradation problem resulting in loss of biodiversity and therefore require a global solution. Parallel trends such as globalisation of environmental education and the internet must be encouraged to counteract the damage caused and reverse the trend. This globally concerted campaign requires utilizing environmental education forums aimed at the angling community, general public and policy makers; networking with existing alien invasive groups; legislation; better understanding of processes; development of environmental economic evaluation tools; international bio-invasion control; wider use of the precautionary approach and utilization of the present globalisation of ecological thought.

Introduction

Anthropogenic perturbations to freshwater systems over the past 100 years have escalated due to burgeoning human populations. Estimates of the number of freshwater fish species that will become extinct within the next 20–30 years run as high as 3000 species, about 30% of the 10 000 known species (Stiassny, 1998). This is why conservation of freshwater fish species is seen as a priority throughout the world.

Freshwater fish are threatened by habitat degradation and fragmentation; species introductions and translocations; impoundment of rivers (dams and weirs, water abstraction and water transfer schemes); and water quality deterioration and overexploitation (Cowx & Collares-Pereira, 2002).

At a UN conference on alien species in Norway in 1996 experts from 80 countries concluded that alien invasive species were a major threat to biodiversity conservation and probably the greatest threat after habitat destruction (Neville & Murphy, 2001). This holds true for freshwater fish species (Cambray, 2000; Cambray & Pister, 2002). Invasive aliens are known to represent a major global change issue (Mooney, 1998) and this is clearly evident in freshwater fish diversity loss. Lowe-McConnell (1990) noted that one of the most insidious threats to fish conservation around the world is deliberate or accidental introduction of new fish species. Introduced species that reproduce successfully can have major cumulative effects over time (Orians, 1995). Benefits of reducing cumulative effects of the spread and impact of alien sport fish species are long-term and societal. One third of all endangered and threatened species in the U.S.A. are listed, at least in part, due to the action of alien species (Bright, 1995). Nineteen endemic fish species are associated with the Cape Floral Kingdom of which 15 are threatened with extinction, primarily due to impacts of invasive alien sport fish species and habitat degradation (Impson et al., 2002).

The international community recognises the need to protect biodiversity (e.g. IUCN Red lists) and biodiversity conservation has become politically important (Cowx & Collares-Pereira, 2002). But very few countries actively undertake their responsibilities under Article 8(h) of the Convention of Biological Diversity (CBD) (Neville & Murphy, 2001). The CBD calls on all contracting parties to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats and species. Therefore where introductions have occurred alien invasive species need to be controlled and if possible eradicated.

Certain freshwater fish species used for recreational angling have been transported around the globe and placed in rivers, dams and lakes, frequently without environmental impact assessments or monitoring, for the sole purpose of providing 'enjoyment' for anglers. These introductions have resulted in subsequent loss of biodiversity in the receiving systems.

The introduction of alien species has dramatically changed many ecological communities and contributed to species extinctions, most notably freshwater fish (Orians, 1995). This movement of species by humans has led to a breakdown in biogeographic barriers (Elton, 1958), both within and between continents, which had previously been the reason for the distinctiveness of the world's biota.

Fish conservation requires robust, defensible, social and economic evaluations of fish populations and species diversity (Cowx, 2002a). So-called 'free services' that unperturbed aquatic biota offer must be factored in. Justification for conservation of small species, not attractive to the angling community, is difficult. Their use as forage fish for a large alien species must be discouraged. "To reverse these philosophies is going to be a major challenge to conservation managers, but will be achieved if the true economic value of conserving fish species is not enunciated or the fishing fraternity are not educated in deleterious effects of introductions and translocation of fish species" (Cowx & Collares-Pereira, 2002). Understanding the ecosystem processes involved is a way forward. Severe reduction of benthic invertebrates with resultant increase in periphyton is one way to argue for not stocking some alien species.

The angling public does not fully recognise the need to protect biodiversity therefore innovative approaches and global co-operation between countries and organisations are needed. Fish conservation officials face the problem of a multiple user environment. In many cases, indigenous fishes are considered of marginal importance (Cowx, 2002a). Alien species are better known due to their established economic value and global literature on the species compared to little known and often poorly studied indigenous species. Many members of the public, such as farmers and many freshwater anglers, still believe that we can improve on the initial biotic 'hand' (Mooney, 1998) that was dealt to any river system by translocating or importing alien sport fishes. W.R.Courtenay, Jr. (pers. comm., 1999), after dealing with alien fish problems for many years, wrote: "I never cease to be amazed that the human species in its migrations over time and particularly within the past and present century seems to feel that introductions make things 'better'. This has proven true, but for a limited number of introduced species such as crops and certain 'domesticated' livestock. Some of those, however, caused substantial damage to receiving ecosystems. The introduction frenzy went far beyond what should have happened and is now clearly proven to have been a mistake when humans introduced species for the sole purposes of 'enjoyment' (= sport, forage for sport fishes, and the aquarium hobby). Over many parts of this planet, those mistakes are now established as reproducing, often range-expanding species (plants and animals), more often than not destructive for some to most species of native organisms. Homogenizing of

the biological resources of this planet is happening and will prove to be a major error, made from stupidity of the consequences. I've been in South Africa and have seen how introduced plant species have become dominant in many areas and sampled waters there where introduced fishes are more common than native species. I've seen the same in eastern Australia and, for nearly all my life here in the U.S. (and I'm now 65)."

Definitions

Alien species (non-native, non-indigenous, foreign, exotic) means species, subspecies, or lower taxon occurring outside of their natural range (past or present) and dispersal potential (i.e. outside the range they occupy naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gamete or propagule of such species that might survive and subsequently reproduce (http://www.iucn.org/themes/ssc/pubs/policy/invasiveEng.htm#anchor392619).

Alien invasive species means an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity (http://www.iucn.org/themes/ssc/pubs/policy/invasivesEng.htm#anchor392619).

Alien transfers are any fishery practices that lead to modification of the natural composition of fish communities.

Ecocentrism is the knowledge that humanity exists within but as only one part of a larger life system.

Globalisation can be defined as "a social process in which the constraints of geography on social and cultural arrangements recede and in which people become increasingly aware that they are receding" (Waters, 1996 in Germain, 2000a), although there are critics of this definition (Germain, 2000b). The term entered our everyday vocabulary around 1960 (Waters, 1995).

Globalisation in the context of the present paper is the process of spreading various animals (e.g. alien fish) and experiences (e.g. angling for that species) to all corners of the earth. Sport fishing has an economic marketable component and is a large global industry.

Recreational angling can be defined as 'Fisheries conducted by individuals primarily for sport but with a possible secondary objective of capturing fish for domestic consumption but not for onward sale' (FAO, 1997). For the majority of anglers, fishing is a pastime for pleasure. For purposes of this paper Carlton's (1975) definition will be used: 'recreational fishing is the ritual pursuit of pleasure associated with experience.'

Zoogeographic pollution occurs when organisms are moved out of their known home range and introduced into new areas by humans. If the organisms are closely related to organisms in the new environment there can be loss of genetic integrity.

Discussion

History of recreational fishing

Angling, like hunting, had it origins as a means of obtaining food. Reference to recreational fishing date back to 1496 when angling as a sport was propounded in the 'Treatyse of Fysshynge wyth an Angle' by Dame Juliana Berners. The well known 'The Compleat Angler or Contemplative Man's Recreation' by Izaak Walton, published in 1653, set the scene for the importance of recreational fishing in the coming centuries. It was also probably the commencement of global homogenisation of freshwater angling species. Well known recreational fish species, such as rainbow trout, were introduced into 'virgin' waters as humans developed faster means of transport for themselves and their favourite angling species around the globe.

Some of the trends over time of translocating alien sport fish species are summarized in Table 1. In the 19th and early part of the 20th centuries, 'good intentions' fuelled the spread of alien recreational fish. Anthropocentrism, with the attendant drive to control nature, was clear in the early stockings of rainbow trout in many countries. Introductions were thought to 'improve the biodiversity' in local water bodies for anglers (Hey, 1926). Species were imported specifically to get rid of indigenous species, which may have 'interfered' with the success of introductions, such as trout (Hey, 1926). These 'well-intentioned introductions' have resulted in serious detrimental effects to natural ecosystems and in some cases extirpation of indigenous species resulting in trophic cascades (McDowall, 2003). In some National Parks in South Africa, the number of alien freshwater fish species exceeds the number of indigenous species (Russell, 1999, 2001).

With the intensification of globalisation in recent decades, movement of species around the world has become much more widespread and more difficult to control. Once introduced, alien sport fish species tend

Table 1. General trends in the history of the translocation of fish for recreational angling

	19th Century	20th Century first half	20th Century second half	21st Century
Public awareness level of importance of biodiversity	Ignorance	Ignorance	Increasing awareness	Greater awareness
Impact studies before translocation	None	None	Increasing	Increasing
Knowledge of indigenous aquatic biota	None	Increasing	Good	Good
Motivation for introduction	Acceptance of what was known in country of origin	Acceptance of what has already been introduced	Acceptance of what has already been introduced	Acceptance of what has already been introduced combined with, new trend - fish indigenous
Angling population pressure	Few dedicated anglers	Increasing number of anglers	Increasing number of anglers used to alien fish, see aliens now as 'indigenous' species	Possibly - decreasing number of anglers as in California
Legislation to protect aliens	Little	Enacted	Being removed	None
Legislation to protect indigenous species	Little	Little	Increasing	Good, especially threatened species
Illegal movement of aliens	Not illegal	Not illegal	Increase	Possible decrease
Awareness campaigns	None	None	Few	Increasing globally
Removal of aliens	None	None	Few	Increasing removals

to spread either by natural means, via anglers and farmers or via engineering feats such as interbasin transfers.

It is not only the ecological processes that need to be understood (McDowall, 2003). The human factor has to be taken into the equation, as it is the sole driving force behind these introductions. An angler can now travel round the world catching the *same species* of trout in over 82 countries! This is an extreme case of 'homogenizing the biological resources' of the planet.

It is unfortunate that movement of fish around the globe has created an expectation and a desire to continue this trend amongst many anglers regardless of the impact on indigenous aquatic biodiversity. Recreational angling in fresh waters is now big business. It has thus become a sociological problem. For some cases, such as rainbow trout, a certain status has been created for angling for this species (Cowx, 2002b). Many people have grown up fishing for alien species, which they now assume, are indigenous. An extreme

case is that some anglers in South Africa want alien rainbow trout to be declared an 'honorary indigenous species' because it has been in the country for over 100 years (Hamman, 2002).

Motivation for recreational angling

Angling for most people is a pastime for pleasure. The main motivation for angling is to be able to relax in pleasant surroundings with like-minded angling friends; the number of fish caught in many cases is secondary (Steffens & Winkel, 1999). Recreational angling is therefore a complex issue involving not only the aquatic ecosystem but also what provides pleasure to humans. Angling for indigenous species can often fulfil all requirements noted above.

Driving forces

Certain driving forces promote alien fish for recreational angling.

Human migrations

As human populations colonised new territories and transport became more efficient it became easier to translocate fish species for recreational angling. This then began the process of zoogeographic pollution and homogenising what fish were acceptable to anglers on a global basis. In Italy, there are only 17 native species that have not been translocated to new localities or 'polluted' by introductions of conspecifics or alien fish species (Bianco, 1990). Major impacts have been the result of the introduction of transalpine species and translocations, river by river, of indigenous species that through movement become aliens in rivers into which they are introduced (Delmastro, 1986 in Bianco, 1990). The unique assemblage of freshwater fishes in Italy has been severely and irreversibly altered due to incorrect management practices. The result is zoogeographic pollution, loss of genetic identity of local populations, a high level of hybridisation and extinction or reduction of local communities of endemic species (Bianco, 1987 in Bianco, 1990). Most of this is the result of provincial authorities stocking public waters with a mixed bag of fish (Bianco & Ketmaier, 2001).

Angling promotion

Currently in 22 European countries there are at least 21.3 million anglers who spend large sums of money yearly on their sport (Cowx, 2002b). Marketing is a complicated network. Briefly, fishing magazines sell advertising space to sports stores and land owners whose attractive advertisements offer accommodation and 'good' fishing. In addition, magazines make fishing look enticing in articles specially written for a target group such as business executives, adventure seekers etc. Should the majority of these articles promote alien fish, then an angling population emerges who accept fishing for these fish as the *status quo*. Sport store outlets sell tackle, specifically designed to catch bass or trout. This globalisation of specialised angling equipment helps drive the spread of alien invasive fish species. Thus marketing is driving anglers' perceptions and expectations.

The type of fishing that an angler enjoys is often seen as reflecting their social status (Cowx, 2002b). Freshwater game fishing is mainly dominated by wealthier sectors of society. Game fish anglers mainly fly fish for species such as salmon and trout. It is mainly demands of this group of anglers that has resulted in rainbow trout being introduced into at least 82 countries (Welcomme, 1988).

Many angling clubs tend to focus on alien freshwater fish species. Some angling clubs are well organised and members pay to have waters stocked with their favourite angling species. Private syndicates are developed that purchase mountain catchment areas to create exclusive waters for alien trout angling. Weirs and dams may be erected for the trout thus completely altering the river system and in some cases flooding valuable wetlands.

Side-lined in this homogenisation process were many potentially excellent indigenous angling species which now face extinction or are extinct. In a tourism advertisement for New Zealand (= circa 2000), under the title 'Pure 100% New Zealand', an angler is shown catching an alien rainbow trout! A New Zealand Grayling (*Prototroctes oxyrhynchus*) being caught would have been 'Pure 100% New Zealand' but this species is now designated extinct, one of the probable causes being introduced salmonids (McDowall, 1996).

In South Africa indigenous species have only recently appeared in the flyfishing spotlight due to dedication of conservation officials (Impson, 2001). Yellowfish (*Labeobarbus* species) are proving to be popular and excellent angling species and now adorn the covers of local angling magazines. In retrospect, there was no need to introduce bass and trout into South Africa where they now compete and prey on the juveniles of the indigenous angling species, some of which are now endangered (Skelton, 1987).

However, this has created a demand for yellowfish and there are now requests for private hatcheries to rear these species (Dean Impson, pers. comm.). This would over time lead to many of the problems raised by Bianco (1987 in Bianco, 1990). Movement of fish for sport fishing has a bad track record. It will not get better without a concerted educational effort together with well-enforced legislation.

Therefore, collective agents (eg. anglers, sports shops, sport magazines, hatcheries, accommodation providers etc) are encouraging the continued globalisation of these species through modern marketing practices. Environmental activists are concerned with aquatic biodiversity conservation (Cambray, 2002, 2003) and fulfilling the mandate of the Convention on Biological Diversity. A competing dynamic now exists between these groups.

Hatcheries

Hatcheries are expensive ventures (ponds, pumps, vehicles, trailers, feeds, medicines, staff etc.). In some countries, such as South Africa, conservation departments historically set up hatcheries to rear alien species such as North American bass and trout species (Cambray & Pister, 2002). Millions of alien fish were reared and demand created among farmers and anglers. Once established with 'conservation' taxpayers money such hatcheries are difficult to close down.

Alien fish introductions had a cascading effect and are now out of control in some countries. In Italy, conservation officials stocked alien trout into mountain rivers of national parks (Bianco, 1995) instead of working towards the conservation of aquatic biodiversity.

In the U.S.A., hatcheries endevouring to improve sportfishing have not taken sufficient care to protect genetic integrity of stocks of trout and salmon species. Formerly genetically distinct stocks are now genetically contaminated (Behnke, 1988).

Private fish farms are sometimes authorized to provide fish for translocation. There are 200 of such hatcheries in northern Italy (Bianco, 1995). Such hatcheries are centres for selling and distributing aliens to anyone who has the money to pay for them.

Globalisation of recreational angling species

One of the major factors driving evolution of the 10 000 freshwater fish species was the isolation of many populations. Technological advancements make it feasible to fly fertilised trout eggs by aircraft from Colorado, on the North America continent, and hatch them in Lesotho on the African continent within several days. In Lesotho the alien trout will impact local biodiversity as soon as they start feeding, or possibly earlier, through imported diseases or parasites.

In Italy, the process of change in the composition of the freshwater fish fauna has been summarized as successively as 'padanization' (the result of transplantation of native species from north to central Italy); followed by 'danubization' (introduction of Danubian species throughout Italy); and now 'globalisation' (the establishment of Iberian, Albanian, Asian and North American elements) (Bianco & Ketmaier, 2001). Many of the fish were introduced by provincial authorities to enhance 'angling species diversity'.

Stock manipulation

For recreational fisheries, attempts are made to enhance diversity of target species for anglers or to provide a species an angler would be willing to pay money to angle for. Stocking is thus a widespread, but also greatly abused, management tool in inland recreational fisheries (Cowx, 1998). Stocking of natural waters can have several aims: improve recruitment; bias fish assemblage structure to favoured species or maintain productive species that would not naturally breed in the system (Cowx, 1994). Cowx (2002b) noted that such stockings should be carried out so that there is no impact on indigenous fish populations and I add here to other aquatic biota. Cowx notes that stocking to enhance fisheries is frequently carried out with 'no due regard for the environmental or ecological consequences.' Stocked alien fish such as trout and bass species can impact indigenous species through competition, predation, loss of genetic integrity or by spread of diseases and parasites (Cowx, 1994, 1998; Cowx & Godkin, 2000 and see McDowall, 2003 below).

Catering for angling diversity by introducing alien species became a common worldwide practice in the 1960s and 1970s (Welcomme, 1988). Problems associated with this enthusiasm to cater to anglers has only fairly recently led to legislation and restrictions being placed on this 'Wild West' approach to stocking aliens in industrialized countries. 'Developing countries' were frequently targeted by fisheries agencies from the developed world leading to inappropriate stockings. Conservation money in some provinces in South Africa was still channelled into alien fish production as late as 2002 (Cambray, 2003). Cowx (1998) noted, as did Hey (1977), that some introductions,

such as rainbow trout and large mouth bass have been successful. To these two authors 'success' must mean that the introduction was economically successful and/or successful in the eyes of anglers. As for conservation of biodiversity, these introductions were bad conservation practices.

Assessing alien impacts

In many cases, it is difficult to assess, quantify or predict the impact of introducing a fish species (Fausch, 1988; Moyle & Light 1996; McDowall, 2003). Earlier studies on impacts of alien fish on indigenous fish were simplistic noting mainly competition and/or predation scenarios (McDowall, 2003). It is now apparent that there are more subtle interactions with altered animal behaviours that impact availability of resources shared with other species and also through feedback effects that influence interspecific interactions (Power et al. 1985; Wootton, 1994).

When stream invertebrates are reduced in abundance by an alien predator, their behaviour changes as they become more cryptic, leading to less periphyton grazing, which may depress production of benthic insects resulting in the benthos being less accessible to indigenous fish predators (McDowall, 2003). Introduced trout profoundly affected the structure and composition of faunal assemblages in Californian High Sierra lakes. Large and/or mobile, conspicuous taxa, including tadpoles, large-bodied microcrustacean zooplankton and many epibenthic or limnetic macroinvertebrates were rare or absent in lakes containing trout (Bradford et al., 1998).

An accurate assessment of the impact of alien sport fish species is only possible if an accurate assessment of pre-introduction ecological and socio-economic environment already existed (Bartley & Casal, 1998). A major problem exists because many introductions of aliens were carried out in the 19th century and even into the 21st century. No environmental impact studies were undertaken before or after most of these introductions making it impossible to assess potential or actual impacts.

In Italy, it is easier and cheaper, in the absence of strong laws, to introduce alien species than to conduct a study on the possible impact of the newcomer to the unit of destination (Bianco, 1995). This outdated practice may still hold for many countries. The main driving force is economics of the known alien sport fish regardless of the long-term damage the transfer may cause to the non-game indigenous species.

In New Zealand, with its abundant cool, swift-flowing rivers, introduced trout had a good 'fit' with existing habitats (Moyle & Light, 1996). This resulted in superb trout fishing (Spackman, 1892) and concern for indigenous species only began to emerge in the 1960s (McDowall, 1968) but the nature of the impact by the aliens was not fully understood (McDowall, 2003). It is now known that where alien trout densities are high there are cascading effects on stream ecosystems, such as reduced benthic invertebrates as well as behavioural changes that can result in proliferation of periphyton (Flecker & Townsend, 1994; McIntosh & Townsend, 1996). In a study on indigenous galaxiids Townsend (1996) found that the best predictor of presence of galaxiids was absence of trout in over 198 sites examined. Galaxiids only existed in 'fringe' upstream habitats to which trout were excluded by natural barriers. Galaxiids have decreased in New Zealand streams due to alien trout impact on the invertebrate production, resulting in benthic invertebrate behaviour change. Galaxiids cannot now access the best foraging areas which reduces the food available to them (McDowall, 2003). In Lesotho the same holds true for the endangered redfin minnow (*Pseudobarbus quathlambae*) (Skelton, 2000).

Global Invasives Strategy

Conservation biologists recognize the effects of alien invasives as complex with many social, ethical, and legal aspects in addition to biological and ecological dimensions (Mooney, 1998). Economic effects of removal of alien sport fish are complicated in that entire industries have been developed for these species. Areas that can be rehabilitated must be identified and prioritised and others areas possibly conceded to the industry based on the aliens.

There is unification of effort to counteract the alien invasive threat by organisations such as the Global Invasive Species Programme (GISP), coordinated by SCOPE (Scientific Committee on Problems of the Environment), in conjunction with IUCN (World Conservation Union), CAB International and UNEP (United Nations Environment Programme). Aims of the Global Invasive Species Programme (GISP) are to:

1. assemble the best information and approaches for prevention and management;
2. disseminate them in the form of databases, manuals and capacity-building training programs to governments and communities; and

3. lay the groundwork for new tools in science, information management, education, and policy that must be developed through collaborative international action.

The Invasive Species Specialist Group (ISSG) is part of the Species Survival Commission (SSC) of IUCN. ISSG is a global group of 146 scientific and policy experts on invasive species from 41 countries. ISSG provides advice on threats from invasives and control or eradication methods to IUCN members, conservation practitioners, and policy-makers. The group's activities focus primarily on invasive species that cause biodiversity loss (*http://www.issg.org/index.html*).

One hundred of the world's worst invasive alien species

The Global Invasive Species Database (*http://www.issg.org/*) states: 'It is very difficult to choose 100 invasive species, from around the world, which really are 'worse' than any others. Species and their interactions with ecosystems are very complex. Some species may have invaded only a restricted region, but have a huge probability of expanding, and causing further great damage (e.g. see *Boiga irregularis*: the brown tree snake). Other species may already be globally widespread, and causing cumulative but less visible damage. The one hundred species aim to collectively illustrate the range of impacts caused by biological invasion.'

An analysis undertaken for the present paper indicates that the species ranged from three microorganisms to 14 mammals. All eight fish species noted are freshwater species (Table 2). Of the 100 species, five were introduced for sport (two mammals and three fish species). Four other fish species are used for angling enjoyment, which means they can be spread by the angler pathway (Table 3). That such a relatively high percentage of these 100 worst invasive aliens are freshwater sport fish is cause for concern.

Table 2. Number of species introduced for sport in the list of the 'One Hundred of the World's Worst Invasive Alien Species'. (Analysed from the Global Invasive Species Database: *http://www.issg.org/database/species/*)

Group	Number	Number for sport
Micro-organisms	3	0
Fungus	5	0
Land plants	32	0
Land invertebrates	17	0
Mammals	14	2 (deer and fox)
Reptiles	2	0
Birds	3	0
Aquatic plants	5	0
Aquatic invertebrates	8	0
Amphibians	3	0
Fish (all freshwater)	8	3 mainly for sport but 4 others also are used for sport as well as food fish

Ecological integrity

Environmental issues have gained prominence on the contemporary security agenda (Scholte, 2000). There is now a spotlight on many environmental issues, maintained by civic groups, think tanks, official agencies, NGO's etc. There is a wider acceptance of the fragility of life on earth with associated feelings of insecurity for humanity.

Each of the major anthropogenic global environmental changes of contemporary history has presented threats to ecological integrity. Declining biological diversity might even take the earth to a species depletion threshold beyond which the entire biosphere would collapse (Scholte, 2000). On a small scale this is what is happening with introduction of alien angling species in some rivers in New Zealand. Introduction of alien recreational fish species is resulting in behavioural changes and trophic cascades that are not fully understood (McDowall, 2003).

Global consciousness has promoted greater ecological awareness. Global environmental issues have become a prime source of insecurity in the contemporary human condition (Scholte, 2000). This is most clearly seen in such issues as the oil crisis, genetically engineered foodstuffs, globally transmitted diseases etc. Potential exists for global governance on environmental matters, e.g. 1987 Montreal protocol on ozone reduction.

Codes of conduct for hatcheries and global angling equipment suppliers should include specific and enforceable environmental clauses. Ultimately the end consumer, the angler, needs to be educated to conserve biodiversity.

Ecocentrism

Ecocentrism (Eckersley, 1992) opposes anthropocentrism as humanity is seen to exist within, but as

Table 3. Analysis of the eight fish species listed in the 'One Hundred of the World's Worst Invasive Alien Species' list: (Analysed from the Global Invasive Species Database (*http://www.issg.org/database/species/*)

Species	Reason for introduction	Impact
Clarias batrachus	Aquaculture but also for **sport** fishing	**Indigenous fish** and other aquatic biota
Cyprinus carpio	Aquaculture but also for **sport** fishing	Reduces water quality and destroys aquatic vegetation by uprooting it
Gambusia affinis	**Mosquito control, (indigenous species could also have done this!)**	**Harmful due to predaceous habits**
Lates niloticus	Food and **sport**	Contributed to extinction of 200 fish species in Lake Victoria resulting in devastating environmental impacts (Barel et al., 1985)
Micropterus salmoides	**Sport**	Impact on indigenous fish, crayfish, amphibians and insects
Oncorhynchus mykiss	**Sport**	Displace indigenous species by competition and predation, also impact on aquatic invertebrates
Oreochromis mossambicus	Aquaculture also for **sport** fishing	Omnivorous eats almost anything from algae to insects
Salmo trutta	**Sport**	Severe impact on indigenous fish (especially other salmonids), amphibians, invertebrates through predation, displacement and food competition

only one part, of a larger life-system. Human desires, such as stocking alien invasive angling species, need to be renounced in favour of ecological health if there is a conflict, which there surely is. Scholte (2000) noted that many indigenous people have promoted notions of aboriginal knowledge where human beings are integrated within and subservient to a natural order. The so-called 'Gaia' notion regards the planet earth as a living creature to which humanity owes its responsibility (Lovelock, 1979). Globalisation has been one of the forces in promoting ecocentrist knowledge.

Global ecological changes have raised awareness of damages that anthropocentric rationalism can inflict (Scholte, 2000). Some global ecological changes have been due to movement of plants and other species. Climate change and rapid loss of biodiversity reinforce that humanity depends on ecological conditions. Policy makers opt for a rationalist response of sustainable development. This approach then perpetuates humanity's subordination of nature in its hope to find techno-scientific solutions to environmental problems.

Due to the past anthropocentric approach there can be no doubt that techno-scientific solutions are now needed to combat alien sport fish introductions that are destroying freshwater biodiversity around the globe.

Ways forward

Understanding processes

Behavioural and dietary interactions, between alien and indigenous species, must be understood (McDowall, 2003). These processes form a basis for informed conservation protocols to explain why the eradication of alien sport fishes is required.

Precautionary approach

When new species are considered for introduction there should be a proper protocol carried out by trained staff within an appropriate government organisation. Guidelines are available from the United Nations Food and Agricultural Organisation (FAO, 1996). The precautionary approach (FAO, 1996, 1997) must be followed when there is insufficient data on the impact a proposed alien fish introduction will have on the receiving system.

There are four options with regard to movement of species around the globe (Ruesink et al., 1995):

1. let everything in;
2. keep everything out;
3. experimentally test everything before entry (essential); and
4. utilize available information for a risk analysis decision (crucial).

Option 1 happened during the 19th and early part of the 20th century. Option 2 should be applied on a global basis as sport fish can be viewed as non-essential so the risk is not worth any further movement of these species. However, as Option 2 is often impractical (Ruesink et al., 1995), Option 4 is the most realistic and similar to the precautionary approach. The exercise will provide reasons why the fish should not be moved that reasonable people would accept.

A moratorium should be imposed on all sport fish translocations solely for angler enjoyment. Angling for indigenous fish species should be promoted instead.

Legislation and environmental education

An 'integrated alien fish management system' must be developed that includes control options, details of the biology of alien sport fish, impact of the aliens and the economic, social and ecological impacts of control efforts that would be required.

In those countries with limited resources the power of globalisation should assure that trained staff and funds are made available.

There should be total eradication of the aliens in rivers and lakes, but this is a very costly procedure and probably impractical for large systems. Barriers can be utilised to prevent the spread of alien fish (eg. golden trout in California; Cambray & Pister, 2002). Biocontrol methods need to be explored but with great caution to avoid local extinctions of indigenous species (Bright, 1995). Fish eradication programmes utilising piscicides could kill indigenous species. After an eradication campaign constant monitoring and vigilance is required to prevent illegal re-introductions.

A more effective international system to prevent bio-invasions is required. Hamdullah Zedan, executive secretary of the Convention on Biological Diversity, believes that a 'stronger system' is required to prevent entry in the first place. But where entry has already taken place more effective measures are needed to stop invasive alien species from establishing themselves and spreading. Where eradication is not feasible or cost-effective, more needs to be invested in containment and long-term control measures (http://www.iucn.org/wssd/pressbook/news/wssd/pressihtaug2802.htm).

Legislation restricting or prohibiting introduction and movement of alien recreational fish species is not sufficient in itself, although it can be a powerful tool if there is proper enforcement and significant fines and vehicle confiscations. Cases need to be well publicised. In addition to good legislation an educational awareness programme is required. At a UN conference *on alien species held in Norway it emerged that very* few of the 80 participating countries had sufficient information or capacity to address invasive alien problems (Neville & Murphy, 2001). It is time to address this need on a global basis.

The scientific community urgently needs to articulate knowledge to a broad array of people, especially decision makers (Orians, 1995). Along with globalisation of ecological thought (Mooney, 1998) there has been development of globalisation of environmental education (EE) to educate on environmental matters that are a cause for concern, such as loss of aquatic biodiversity. Scientists concerned about the spread of alien sport fish should promote the development of suitable EE conservation tools.

Mooney (1998) stressed the need for scientists to communicate their findings to non-scientists. Good communication to the public should be seen as part of a scientific portfolio. Some non-governmental funding bodies make communication at the popular level part of research contracts (eg WWF). Communication of findings to the public and policy makers is now generally viewed as part of one's career development. Good scientific review articles, such as on impacts of brown trout (McDowall, 2003), need to receive a wider audience. Facts need to be properly packaged and disseminated by scientists to promote public awareness. Websites, such as Science-in-Africa (http://www.scienceinafrica.co.za/), provide easy ac-

cess for dissemination of research findings in a popular format.

"We need more scientists to become involved in the crucial task of making sure that the best science available is being utilized in public understanding of environmental issues, and in policy making" (Mooney, 1998: 125). If a scientist is funded solely to provide new information only published in scientific journals, with no public exposure, then we as scientists have failed. Programs to train mid-career scientists in communication skills, as initiated by the Ecological Society of America, need to be evaluated and encouraged.

There is concern that if one starts early in one's scientific career that public engagement will consume essential time that should have been spent developing one's scientific credentials (Burke & Lauenroth, 1997). Others (e.g. Mooney, 1998), as does the author, believe that a scientist needs to be aware of societal relevance of one's work and discipline and make appropriate contributions throughout one's career. In the case of freshwater fish, and many other species and their habitats, there is no time to waste.

Considering the enormity of ecological damage caused by invasives, as well as funding spent on trying to control their spread, it is surprising that more money is not spent on educating the public about this problem (Mooney, 1998). This investment in education at all levels could have an enormous economic payback by reducing further spread of aliens.

Even with heightened public awareness of the value of biodiversity this knowledge alone will not provide sufficient safeguards (Orian, 1995). Protecting biodiversity is a moral imperative, without which society would adhere to the dictum 'Preserve species when it is economically favourable to do so, but eliminate them when it is not' (Orian, 1995).

Responses to cumulative environmental effects, such as the spread of alien sport fishes, have a significant moral element. Leopold (1949) wrote "It is inconceivable to me that an ethical relation to land can exist without love, respect, and admiration for land, and a high regard for its value. By value, I of course mean something broader than mere economic value. I mean value in the philosophical sense". It is this ethical relation to aquatic biodiversity that needs to be incorporated into all people.

In South Africa, the Working-for-Water programme trains unemployed people to run a business based on removal of invasive alien plants (van Wilgen et al., 1998, 2001). This programme has made the public aware of environmental cost of these alien invaders. We now need a similar programme for alien sport fish species, not only in South Africa, but globally.

Environmental economic evaluation tools and 'free services'

A value needs to be articulated for the social and economic importance of freshwater fish biodiversity. There is an urgent need to adapt environmental economic evaluation tools (Cowx & Collares-Pereira, 2002). There are economic evaluation tools for alien sport fish and it is the economics that keeps this threat active and spreading. Information is available for indigenous commercial species but not for many of the 10 000 known freshwater fish species.

There is a need for more awareness of the value of goods and 'free services', which are provided by ecosystems (Orians, 1995). Good quality freshwater is a scarce commodity in many parts of the world. If introducing a fish species, such as brown trout into New Zealand streams, can virtually clean out the annual benthic invertebrate production, change behaviour of invertebrates and indigenous fish species resulting in a periphyton build-up (McDowall, 2003) then is it worth introducing this alien sport fish? What are the other ecological processes that could be upset by these introductions? This potential loss needs to be understood and costed into the full assessment of the impact of alien sport fish species.

Orians (1995) raised an interesting point regarding responsibility. If landowners want compensation from society for conserving a wetland on their farm then they should also pay the costs if they do not conserve it. That is, they should have to pay for flood control, water purification and species conservation, provided by the wetland before they filled it. Similarly if landowners introduce alien fish into rivers which flow through their land then they should be responsible to pay for species conservation, water purification and clean-up charges if the alien sport fish species move up or down stream into a nature conservation area.

Global network of fish conservationists

Cowx & Collares-Pereira (2002) recommended a network of fish conservationists who would report successes and failures in conservation management thereby assisting removal of aliens and rehabilitation of habitats. Cambray & Pister (2002) discussed problems and successes of several conservation campaigns and this is typical of the information that needs to be more easily accessible. Similarly, Cambray & Bianco

(1998) suggested a website for the conservation of freshwater fish species as part of a conservation 'tool kit'.

As part of the global campaign to combat the impact of alien fish on aquatic biodiversity an efficient, functional network of concerned scientists and members of the public would be beneficial for conservation of fish diversity on Earth. This could work through the IUCN, with a well structured and inclusive website referring readers to other workers in the world, to their published and unpublished works and success and failures of their campaigns.

The network could work with the existing 'Global Invasive Species Programme' (GISP) that aims to forge cooperation to address a borderless issue (Neville & Murphy, 2001). GISP focuses on aliens that disrupt ecosystem processes and thereby threaten biodiversity, health and economics (Neville & Murphy, 2001). Alien sport fish fulfil these requirements. The programme is a network of scientists, lawyers, environmentalists, policy makers, economists, resource managers and others working together on the global invasive alien problem. The mission of GISP is to enable governments and organisations to use the best practices available to manage invasive alien species (IAS) and to promote development of additional tools and strategies needed to improve global management of IAS. GISP strives to promote collaboration and partnerships with a holistic and multi-sectorial approach, exactly what is required to control and eradicate alien invasive sport fish species. GISP has strong support from SCOPE, IUCN, UNEP, GEF and other national and international bodies (Neville & Murphy, 2001).

Improvement of the scientific basis for decision making on invasive species issues centred on 11 components – including establishing the background and scientific and social basis of invasive alien species problems; current status of invasives; their ecology; human dimensions of the invasive species problem; and the relationship between invasive alien species and global change. GISP addresses identification of pathways of invasion, early warning systems, methods for prevention, early detection and management, risk assessment, legal and institutional frameworks, economics of invasive alien species and educational programmes (Neville & Murphy, 2001). Some of this work on vectors and pathways of invasion has already been carried out in South Africa (Richardson et al., 2003).

Globalisation of ecological thought

In a book by Mooney (1998) entitled 'Globalization of ecological thought' it is noted that ecological research was originally global. In the middle of the 20th century it became more locally focussed, whereas today it is again more global in nature. In the 1950's ecological studies focussed on natural systems and Mooney (1998) notes human-modified systems were mainly ignored and alien organisms were generally neglected. But today many studies focus on 'untangling of the responses of biotic change to natural cycles from that of human impacts' (Mooney, 1998). Focus of ecological studies is now of a larger dimension due to the relatively recent appreciation of global impacts of humans on biotic systems, and this is what Mooney (1998) refers to as the 'globalisation of ecology.' This aspect of globalisation will help to reduce movement of invasive aliens through providing a better understanding such as outlined by McDowall (2003) for brown trout in New Zealand. Globalisation of ecological thought will help counter the present consumer society approach to alien fish introductions.

Concluding remarks

Globalisation resulted in the spread of alien freshwater sport fishes in an unprecedented and unnatural way. Globalisation and homogenisation of species is proceeding at an ever-increasing pace and have assumed their own dynamics. Only a co-ordinated counter global awareness campaign can assert the importance of indigenous freshwater fish species in the eyes of the public and policy makers.

There is a distinct need for a global assessment on impact of the most widely distributed alien recreational fish species, such as rainbow trout, on aquatic biodiversity and ecosystem functioning.

Globalisation power must be harnessed to ensure the continued survival and evolution of what remains of the world's freshwater fish fauna. Cambray & Pister (2002) noted that public support was essential and there must be education and extension programmes that become part of the total scientific study programme (as is currently happening in some of the work for European Union projects, eg Collares-Pereira et al., 2002).

Loss of aquatic biodiversity by introducing alien species solely for the pursuit of pleasure needs to be urgently halted. In many cases host countries already had, or still have, good angling species. Even if they do

not it is debatable whether a sport, mainly for pleasure, should be the cause of the loss of biodiversity in the 21st century.

The present *status quo* of alien sport fish availability drives angler expectations. Leopold (1949) wrote 'To promote perception is the only creative form of recreational engineering'. It is now time to promote the perception that conservation of biodiversity is more important than introduction of aliens for fishing pleasure.

If scientists with the facts, who work on freshwater fish species, do not encourage public awareness then who will?

Acknowledgements

I would like to dedicate this paper to the excellent work and dedication Prof. Henri Dumont has shown during his years as Editor-in-Chief of Hydrobiologia. Many of the published papers that passed through his hands have furthered our understanding of the earth's biodiversity. Eve Cambray and the two anonymous reviewers are thanked for commenting on and improving this paper.

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