# INVASIVE SPECIES:
# A GLOBAL CONCERN BUBBLING TO THE SURFACE

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Presented to
International Conference on the Impact of Global Environmental Problems
on Continental and Coastal Marine Waters
Geneva, Switzerland
16-18 July 2003

***ABSTRACT***

*Scientists working in aquatic ecosystems have long been concerned about invasive species. They may have felt that they were swimming against the tide of global forces, but the issue of invasive alien species has become much more prominent in recent years and has surfaced as a leading global concern in the past few years. For example, the 2001 World Biodiversity Day (22 May) focused on the issue of Invasive Alien Species, with workshops on the topic being held in many countries around the world. Globally, at least 45 international conventions and programmes are dealing with invasives, many of which are focussed specifically on marine invasions. While much of the attention has focused on terrestrial species, the aquatic side has also gained much greater attention, including plants such as Caulerpa, fish, invertebrates, and even disease organisms such as those causing cholera. This increasing public attention offers new opportunities for addressing the problem of aquatic invasive species including as part of the work of international agencies such as the International Maritime Organization and the World Trade Organization. The link with WTO is especially important, because global trade has increased from $192 billion in 1965 to $6 trillion in 2000. Most of this is carried by sea, with 5 billion tons of cargo being shipped annually in 165 million large containers. This flood of material has overwhelmed customs and quarantine officers, who seem powerless to stop the flood of invasive species that accompanies this trade. Solutions will come from increased awareness of the problem, improved early-warning systems, and quick response teams set up to deal with invasives before they can become established.*

## INTRODUCTION

The world has begun to pay increasing attention to the problem of aquatic invasive species. In order to build on this growing interest, it is important to be clear about the terms we use. In its "Guidelines for the prevention of biodiversity loss caused by alien invasive species" IUCN uses the following definitions for alien species and alien invasive species:

"**Alien species**" (non-native, non-indigenous, foreign, exotic) means a species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gametes or propagule of such species that might survive and subsequently reproduce.

"**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.

Because of the wider effects than only on biodiversity, another possible definition for invasive alien species is "an alien species whose establishment and spread threatens ecosystems, habitats or species with economic or environmental harm" (McNeely *et al.*, 2001). Such establishment and spread can happen after voluntary or involuntary introduction of a species.

One major new challenge to these definitions has been the spread of **biotechnology**, especially through genetic engineering that can produce fish that may grow five times faster and bigger than normal. The ecological impact of such "super fish", especially when introduced into a new environment, has not yet reached the surface. Additional characteristics, such as cold tolerance, may enable fish such as salmon to considerably extend their ranges, and could have ecosystem implications that are similar to those of invasive alien species. This is a problem of insufficient information, and ultimately of risk management, adding an additional challenge to our already overflowing bait buckets.

**Aquaculture** is also becoming a more important issue for those concerned about invasive alien species. Given the rate of over-fishing in the various fisheries of the world, it is not surprising that far greater investments are being made in aquaculture, the farming of fish, shellfish, and aquatic plants. Globally, aquaculture production has more than doubled over the past 10 years and now provides about a third of seafood consumed (Naylor *et al*., 2001). In the US, over 100 species of aquatic plants and animals are being raised, in all 50 States, and output is expected to increase 5-fold by 2025 (Goldburg *et al*., 2001). That's the good news. The bad news is that aquaculture is also leading to the introduction and establishment of many varieties of IAS, ranging from fish to pathogens, becoming a leading vector of aquatic IAS. As with most domesticated plants and animals in North America, the farmed aquatic species typically are not native to the area where they are being farmed. Some of the most difficult animal disease problems facing modern society involve the pathogens of these aquaculture species, causing economic losses to industry and spreading pathogens to the wild species in the region (Naylor *et al*., 2000). This is no trivial matter, as it affects species of considerable importance. For example, a protozoan that causes whirling disease in trout was introduced to the USA in the 1950's, apparently through European Brown Trout. Release of the latter species spread the disease throughout prize fly-fishing streams in eleven western states, devastating some wild trout populations (Moyle, 1996).

Salmon is particularly valuable and the most common species in aquaculture is the Atlantic salmon from the Eastern USA, which is now found in salmon farms from Chile to Norway; justifiable fears of escape and subsequent genetic swamping of a native species are increasingly being voiced (Naylor *et al.* 2000).

Lax regulations and insufficient management means that many species are escaping, and becoming established in the wild, with profound ecological impacts. For example, North American bullfrogs have escaped from frog-leg ranches from Ecuador to Taiwan to Italy to become one of the world's worst invaders (Baker, 1995). Of course, measures are available to help prevent such invasions, such as culture in environments that are not suitable for reproduction, or growing sterile forms.

The **tropical fish trade** is also booming, with more than 10 million fish tanks in US homes holding 2 billion ornamental fish of 300 varieties. Most of these come from breeding farms in Florida that sell fish and aquatic plants worth $60 million per year (Pet Industry Joint Advisory Council, 2000). These fish have a notorious habit of escaping captivity or being dumped into waterways or even sewage systems. It appears that most of the 100 or so alien fish species established in Florida were released by pet owners or escaped from breeding farms.

A precautionary approach would consider all species potentially invasive, and therefore prohibit their introduction unless they are proven otherwise; but of course the expansion of global trade means that numerous species are sneaking in under our radar screen.

Finally, perhaps the main route for the spread of aquatic IAS is transport in **ballast water**, leading to a major international programme to address the problem (see below).

Technology has improved significantly in the past decade, and may be helpful in addressing the IAS issue. Clearly, information is going to be key to any success that we might have in combating the IAS problem. Fortunately, technological breakthroughs such as the Internet, coupled with improved microprocessors, are making our job at least somewhat easier. Important recent relevant websites include the Database on Introduced Aquatic Species (DIAS) set up by FAO; the Global Invasive Species Database of the IUCN Invasive Species Specialist Group, the US Government Database on non-indigenous aquatic species, and the Baltic Sea Alien Species Database. No doubt many others also exist, or are being established. The information gap is thus being narrowed.

We now need to put this information technology to work by helping us to learn when species invade the marine environment. We need to enlist members of the public as part of our early warning system. These auxiliaries can often prove extremely helpful. For example, shipwrights who were repairing an imported motor launch in Fremantle, Australia, discovered the dreaded Formosan termite on the boat, only the second known arrival in Australia; their quick action prevented the termite from spreading more widely. And a visiting marine ecologist happened to find what was apparently the first European green crab in Washington State, while doing research one exotic species of cord grass along the coast (Townsend, 2000). Mobilizing information quickly is essential to a quick response to an invasion, and experience has shown that the quicker the response, the higher the likelihood of success. In order to be able to have fast responses, a broader awareness of the IAS issue is essential.

The problem of invasive alien species is a prototypical global problem. Here in Europe, many of you may feel threatened by species from other parts of the world, as well you should. But you should also recognize that native species of fish and other aquatic organisms from our region are also invading other parts of the world. For example, the moats that ring the Imperial Palace in the heart of Tokyo are well known for the bright orange and red of the carp that are so emblematic of Japanese waterways. But virtually all of Japan has been affected by invasive species of fish from North America, including the largemouth black bass, which can grow to be 87 centimetres long and weigh 10 kilos. Brought in from California by a businessman in 1925, these are very popular with sportsmen. In 1960, the mayor of Chicago presented some bluegill to then Crown Prince Akihito, who subsequently released them; and they too have now spread widely throughout the country. They have been remarkably successful, with fisheries authorities at Lake Biwa establishing a goal of catching 300 tons of bluegill and black bass a year, in hopes of reducing their population by 50% over 10 years. Ironically, part of the problem is because of the “catch-release” ethic of sport fishermen. While the five million bass fishers of Japan think the invasives are a great advance, the invaders are crowding out native species, such as the southern top-mouthed minnow, deep crucian carp, and the northern and flat bittering (Watanabe, 2002).

As another example, over eight million red-eared slider turtles are exported from Louisiana and other southern states to various other parts of the world. The large ones may end up on Asian restaurant tables, while the small ones are popular pets in Europe and some parts of Asia. While the half-life of pet turtles at the hands of American children may be rather brief, they seem to thrive when they are dumped or escape into alien waterways and wetlands, becoming established in the wild from Malaysia to South Africa and threatening the survival of native species of turtle.

In the USA, which has the most comprehensive data on freshwater species, 37% of freshwater fish, 67% of mussels, 51% of crayfish, and 40% of amphibians are threatened or have become extinct. Studies of the introduction of non-native fish in Europe, North America, Australia, and New Zealand reveal that 77% of them resulted in the drastic reduction or elimination of native fish species. In North America alone, 27 species and 13 subspecies of native fish became extinct in the last century, largely due to the introduction of non-native fish.

Some non-native species are introduced with noble intentions. For example, the Asian black carp is welcomed by catfish farmers in southern USA because it helps control trematodes that affect the catfish. On the other hand, black carp also eat molluscs, which have their global centre of diversity in the southeastern USA where most of catfish farms are located.

Ricciardi and Rasmussen (1999) report that 123 freshwater animal species have been recorded as becoming extinct in North America since 1900. Hundreds of additional species of fish, molluscs, crayfish and amphibians are seriously threatened. They report that recent and future extinction rates for North American freshwater fauna are five times higher than those for terrestrial fauna, projecting a future extinction rate of 4% per decade. This suggests that North America's temperate freshwater ecosystems are being depleted of species as rapidly as tropical forests.

Surprisingly, some of those who should know better are in fact part of the problem. For example, it appears that state Fish and Game officials in the USA still engage in an informal wildlife bazaar among themselves, swapping aquatic species such as bass and pike to "enrich" their regions (Turback, 1992).

As in most parts of life, aquatic invasive species are surrounded by conflict. Sport fishermen, for example, consider lake trout an improvement to any waterway, so fish often provide very popular opportunities for introduction, with nearly triple the number of species introduced in the second half of last century as the first half. This is no trivial matter, as the ecological damage can be considerable, and ecologists are concerned at the damage invasive sport fish inflict on native species of fish, frogs, salamanders and so forth. From example, the invasion of lake trout into Yellowstone Lake in 1994 is threatening the native cutthroat trout, with knock-on effects on many species that fatten each spring on the stream-spawning cutthroats. Species such as grizzly bears and bald eagles are likely to suffer (Varley and Schullery, 1995). Also the high-elevation lakes in the American West have become renowned as a paradise for trout fishing. But trout are an alien species in these habitats, having been introduced by the millions from hatcheries by the California Department of Fish and Game. The ecological impact of this introduction has been profound, leading to catastrophic declines in some species of amphibians.

It is clear that the risk of invasion will continue as trade, transport, travel and tourism increase. Distances that were not possible to bridge for species are no longer a barrier. New Zealand now faces a significant IAS problem, whereas in the past the 2000 kilometres that separate it from Australia kept it safe. Climate change can also facilitate invasions (Stachowicz *et al.*, 2002) by increasing environmental stress on systems, possibly reducing their resistance, and extending ranges for species.

IAS cause significant damage to the world economy. Estimates range widely, with one recent news report even putting at 400 billion USD per year the economic damage inflicted worldwide by IAS (ENS, 2003). Most information available is from information-rich developed countries, while the size of the problem in the developing world is more difficult to assess. In developing countries, the consequences for human health and well-being are also more direct, since IAS can have direct impacts on food security.

## THE ROLE OF GLOBAL TRADE

Invasive species are a seemingly inseparable companion of global trade, which increased from a relatively modest US$192 billion in 1965 to an estimated US$6.5 trillion in 2003. The vast majority of this is carried by the world's growing population of container ships, with sea-borne trade exceeding 5 billion tons in 1999. This was greatly facilitated by the growth of container transport, with 165 million 6-meter units in motion in 1998 (UNCTAD 2000). For comparison, worldwide air cargo amounted to just 27.7 million tons in 1999 (IATA 2000), a mere 0.56 percent of sea-borne cargo.

While the beneficial impact of this trade is considerable, ships are also actively involved in promoting invasive species, through both the cargo they carry and the ballast water that helps make them seaworthy. Some estimates suggest that as many as 10,000 species are on the move in ballast tanks each day on the global oceans, with most of them collected from coastal bays and estuaries, then transported across otherwise impassable oceans and released along new coastlines, bays, and estuaries, where they often find very comfortable habitats (Carlton, 1999). Ruiz *et al*. (2000) estimate that some 62,000 commercial vessels arrive in US ports each year, dumping 79 million tons of foreign ballast water at a rate of 8 million litres per hour.

Thanks especially to the work of the people who attend these conferences, we all know that ballast water of ships is one of the most important mechanisms for the introduction of aquatic invasive alien species. Continuing research has led to one potential solution that can also save money for ship owners. Purging of oxygen from ballast tanks with nitrogen both reduces survival rate of the larvae of known invasive invertebrate species and is a cost-effective technique for reducing corrosion, and therefore extending the economic life of a ship (Tamburri *et al*., 2002).

As species continue moving around the world, the threat of invasives through ballast discharges continue to expand. Bigger and faster ships take in more organisms and allow more of them to survive the journey, and new trade routes connect parts of the world that previously were disconnected. And the spread of invasives means that secondary invasions also become a growing threat. The Great Lakes of the US can now be a source of European zebra mussels, Tasmania can now export northern Pacific sea stars, the Long Island Sound can be a source of Japanese crabs, and Peru has become a secondary source of Asian cholera bacteria (Carlton, 1996).

## EFFECTS OF INVASIVE SPECIES AND ECOSYSTEM SUSCEPTIBILITY

Much time and effort has been expended in investigating susceptibility of ecosystems to invasions and various factors have been implicated. A key factor in the literature is human-induced disturbance of ecosystems (Ashton and Mitchell, 1989; Arthington and Mitchell, 1986; Brooke *et al.,* 1986 ; Carlton, 1989; Elton, 1958; Myers, 1986; Neiring, 1990; Ramakrishnan and Vitousek, 1989) but successful invasions of undisturbed ecosystems are also common (Ashton and Mitchell, 1989; Macdonald and Richardson, 1986). Ecosystems of low diversity may also be susceptible (Brockie *et al.,* 1989) as well as those without predators, herbivores or competitors (Atkinson, 1985; Loope and Mueller-Dombois 1989; Mack, 1989; Macdonald *et al.,* 1989; Macdonald and Frame, 1988). Climatic and edaphic similarity between the invader's new and home environment may also be important (Diamond and Veitch, 1989; Holdgate, 1986; Myers, 1986).

Invasive species are known to have wide-ranging effects on ecosystems, affecting both ecosystem structure and function. They may eliminate native species directly through animal predation or the browsing effects of herbivores as has happened, for example, in fish, molluscs (Wells, 1995), and many bird species (Atkinson, 1985; Brockie *et al.,* 1988).

It is important to note that the many references to global extinctions due to invasives refer to islands or aquatic ecosystems and Macdonald *et al.* (1989) found no global extinction of a terrestrial, continental species as a result of an invasive species. However, many examples of local eliminations or species brought to the brink of extinction by invasives can be quoted, including:

- The elimination of the Atlantic salmon *Salmo salar* in more than 30 rivers in Norway as a result of the introduction of the conspecific Baltic salmon for aquaculture purposes. The latter carried the monogean fluke *Gyrodactylus salaris* which proved to be deadly to the Atlantic salmon (Johnsen and Jensen, 1986; Heggberget, 1993). It has also been found that their aggressiveness helps them outcompete wild salmon in mating. Hundreds of thousands of farmed salmon escape their pens every year.

- The comb jellyfish *Mnemiopsis leidyi* competes for food with species on which the beluga sturgeon (*Huso huso*) depends for food in the Caspian. It aso caused damage in the Black Sea where it arrived, probably via ballast water, in the 1980s. The fisheries in the Black Sea plummeted as a result. Losses were estimated up to US$500 million per year. But in 1997, another comb jelly *Beroe ovata* appeared in the Black Sea, also perhaps transmitted via ballast water; it preys on the *Mnemiopsis*, leading to significant reductions in its population in at least some parts of the Sea, possibly leading to the recovery of the Black Sea ecosystem, at least in the long term.

- The zebra mussels (*Dreissena polymorpha*) that have invaded the North American Great Lakes with disastrous effects are now declining because a native sponge (*Eunapius fragilis*) is growing on the mussels, preventing them from opening their shells to feed or breathe. The sponge has become abundant in some areas while the zebra mussel population has fallen by up to 40%, but it is not yet clear whether the sponges will be effective in controlling the invasive species in the long term.

- An example of purposeful introduction gone wrong is the extensive stocking programme that introduced African tilapia (*Oreochromis*) into Lake Nicaragua in the 1980s, resulting in the decline of native populations of fish and leading to the imminent collapse of one of the world's most distinctive freshwater ecosystems (McKaye *et al.*, 1995). Local people have avoided fishing for the introduced tilapia because they do not like their "muddy taste". At the same time people are happy with the Nile perch *Lates niloticus* in Lake Victoria which has led to the loss of some 70% of the cichlid species of fish in the lake. The local people know the Nile perch as *Mkombosli,* "the Saviour", because it is a superb source of food, the basis of a rapidly developing local industry, and an important economic asset.

- The Golden Mussel *Limoperna fortunei* is a freshwater species transported from estuarine ports that is now invading South American rivers at 240 kilometres per year. It is threatening the Amazon basin.

- Ruiz et al. (2000) showed that the global movement of ballast water by ships creates a long-distance dispersal mechanism for human pathogens (e.g. the bacteria *Vibrio cholerae* 01 and 0139, which cause human epidemic cholera).

- The European green crab *Carcinus maenas* left parasites behind and invaded US fisheries on Atlantic and Pacific coast (Torchin et al., 2003).

Certain species have been shown to have a range of indirect effects which can have an impact on several species and sometimes whole ecosystems. Invading aquatic macrophytes such as *Salvinia molesta* and *Eichhornia crassipes* (arguably the world's most aggressive aquatic weeds) can spread prolifically by virtue of their rapid growth and relatively high biomass. While they may displace native plant species they may also impede water flow, inhibit the penetration of light, increase evapotranspiration and alter water chemistry to such an extent that the water body no longer supports a functioning aquatic community (Humphries, Groves and Mitchell, 1994).

Other examples of indirect effects include the probable extinction of the snail *Bulimulus darwini* on Galapagos as a result of the destruction of its habitat through the effects of introduced goats (Coppois, 1995); and the reduction in the bird community around Lake Atitlan as a result of the introduction of the predatory fish species *Cichla ocellaris* which dramatically altered the trophic structure of the lake (Zaret and Paine, 1973).

Another serious effect at the ecosystem structure level is the genetic effect on species through hybridization or serious losses in genetic diversity. Invasive hybridization with local species has been recorded in ducks, wild cats, donkeys, fish, birds and grasses (Brooke *et al.,* 1986; Hammer *et al.,* 1993; Holcik, 1991; MacDonald *et al.,* 1989; Moyle, 1976; Ryman, 1991).

The consequences of invasions on ecosystem function are generally less well studied than those on ecosystem structure (Ramakrishnan and Vitousek, 1989). This is a vital area since such changes can alter the conditions of life for all of the organisms in an ecosystem, often to the detriment of many native species. Effects of invasive species on ecosystems can alter soil erosion rates and other geomorphological processes (affecting such ecosystems as sand dunes, rivers, estuaries, etc), biogeochemical cycles, hydrological cycles, nutrient cycles and fire regimes (Macdonald and Jarmen, 1984; Macdonald *et al.,* 1989). In summary, virtually all of the myriad of ecosystem functions have been affected by introduced species (Macdonald *et al.,* 1989).

## RESPONSES

Interventions to prevent damage caused by invasion can be at the species level or vector level. Prevention is better than cure and therefore prevention of invasion should be a priority. A number of responses to the problem will briefly be discussed.

### 1. International legal and policy responses

Doelle (2003) gives an overview of international legal responses. We focus here on the Convention on Biological Diversity, on some trade aspects and on the sectoral IMO ballast water programme.

Given the international dimension of the problem, several international fora have adopted decisions on IAS. The **Convention on Biological Diversity (CBD)** in 1992 recognised the effect of IAS on biodiversity and included an obligation for its parties to “Prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species” (article 8(h)). Decision VI/23 of the Sixth Conference of the Parties (COP) recognised the work done by other organisations but found that some gaps were left in that work, concerning the effect of IAS on biodiversity in particular. The COP laid out guiding principles and other options for an effective implementation of article 8(h) of the convention. The CBD Secretariat considers the creation of a future international instrument as one option to address the problem of IAS internationally.

In September 2003 the Cartagena Protocol on Biosafety to the CBD will enter into force. This Protocol targets Genetically Modified Organisms. GMOs are non-native organisms that may be spread intentionally or unintentionally like IAS, that may become invasive in some instances, and therefore are an important subset of the discussions of the alien invasives problem (see Mackenzie *et al.*, 2003). While few governments will immediately recognise this relevance, the precedents set by the Biosafety Protocol could well guide further developments in international cooperation to address the problem of IAS.

A danger is that some of these interventions may be considered trade restrictive. The **WTO Agreement on Sanitary and Phytosanitary Measures (SPS)** ensures that sanitary and phytosanitary domestic measures are consistent with the WTO obligations prohibiting arbitrary or unjustifiable trade discrimination. SPS trade restrictions must conform with international standards, guidelines and recommendations if those exist. For food safety, the reference organisation is the Codex Alimentarius Commission; for animal health and zoonoses, the International Office of Epizootics; for plant health, the Secretariat of the International Plant Protection Convention. For matters not covered by these organisations, "appropriate standards, guidelines and recommendations promulgated by other relevant international organizations open for membership to all Members" are acceptable.

A well developed sectoral initiative in the marine field is the **IMO Ballast Water Programme** (of which IUCN is now a partner). This programme, together with the IMO guidelines and a possible future IMO convention, specifically address species transported in ships' ballast water, the largest transporter of aquatic invasive species. A number of test sites have been set up. Ballast water can be treated in a number of ways to destroy the organisms it carries (e.g. purging the water of oxygen (Tamburri *et al.*, 2002); adding chemicals; or banning discharge in harbours). A delicate balance must be found between economic aspects, effectiveness and environmental impact. Some species may be resistant to the treatments (e.g. bacteria can survive without oxygen) but treating ballast water is likely to significantly reduce the spread of aquatic IAS. The IMO Convention (now the "Draft international convention for the control and management of ships' ballast water and sediments") will contain general binding provisions as well as a number of specific operational regulations. Aquatic species also travel by attaching to the hulls of ships. An effective anti-fouling agent (TBT, Tributyl tin) is being phased out because of the negative environmental impacts it had, but new products are being developed.

## 2. Liability, insurance and taxation

These responses work indirectly at the vector level.

**Liability** for environmental damage (strict or fault-based) combined with **insurance** is complex, but with experience insurance companies are less reluctant to offer insurance products than in the past. However, in the case of IAS it is often impossible to trace back the path a species followed. Time lags make this even more complex. Whereas insurance could in theory therefore be a useful response, in practice long procedural disputes and claims are likely.

**Taxing** activities that are (from an invasives perspective) hazardous could be considered. A global fund to cover costs of invasives control could then be created with the tax revenue.

## 3. Physical control of the established IAS

Red water fern *Azolla filiculoides* can drift on air currents or via transfer by cars, trucks, trains or even shoes and clothing. In other words, greater awareness may help prevent damage, but invasions will continue to occur, so action at the species level may be required.

It has been shown (McNeely et al. 2003) that early assessment and action significantly increase the potential for successful eradication or control. Especially with aquatic species control becomes very difficult and costly once an invasive species has become established. Damage may be irreversible.

Numerous control options are available (mechanical, chemical, biological, habitat management and integrated pest management) depending on the species targeted, the area infested and its characteristics. For mobile aquatic species (as opposed to e.g. Zebra Mussel (*Dreissena polymorpha)* where local mechanical removal is often the first option) biological control may be a preferred option. When alien species become invasive one factor that helps them become established is that they leave so-called natural enemies or parasites behind. Biological control then implies bringing one or more such enemies to the location where a species has become invasive. A famous and successful example is the use of a weevil (*Neochetina eichhorniae* and *N. bruchi*) to reduce mats of water hyacinth (*Eichhornia crassipes*) in Benin. Over 1780 species have been released in the USA as biocontrol agents against insect pests since 1880. Also the use of biotechnology to genetically modify a species to make it less likely to become invasive can be considered a form of biological control.

Biological control may be the only possible option in a number of aquatic invasions, but some authors have also pointed at the risks of biocontrol (Thomas and Willis, 1998; Torchin *et al.*, 2003). The control agent must ideally be specific to the target species and must be carefully selected to prevent it also becoming invasive or has dramatic impact on other species than the target species.

Insufficient knowledge or scientific uncertainty may make biocontrol a risky undertaking. Two examples (one terrestrial and one aquatic) can illustrate this:

- In Hawaii during the 1950s, three predatory land snails were pitted against the giant African snail (*Achatina*), an invasive species that has been a notorious agricultural pest throughout Southeast Asia and the Pacific. But one of the introduced snails, *Euglandina rosea*, also feeds on native snails, several of which are now extinct. Thus species introduced for justifiable economic and ecological reasons -- to control a harmful alien invasive species -- can themselves become problems and even lead to extinction of native species.

- Australian scientists are planning to insert a gene known as “daughterless” into invasive male carp in the Murray-Darling River, thereby ensuring that their offspring are male. The objective is to release them into the wild, sending wild carp populations into a nose dive and making room for the native species that are being threatened by the invasive carp. This is an example of using genetic modification to eradicate an invasive alien species. But if the gene is released into nature and starts to flourish, many other species could be negatively affected.

## CONCLUSIONS

It appears that invasive alien species are affecting virtually all major rivers, lakes, and coastlines in both tropical and temperate zones, making this an issue of major global concern (Bright, 2001). Conferences such as this one are major contributions to the global response that is required to deal effectively with this challenge. Another important contribution is being made by the Global Invasive Species Programme (GISP). GISP was established in 1997 to address the global threat posed by invasive alien species and to provide support to the implementation of Article 8(h) of the Convention on Biological Diversity. GISP is operated by a consortium of the Scientific Committee on Problems of the Environment (SCOPE), CAB International (CABI), and the World Conservation Union (IUCN), in partnership with the United Nations Environment Programme. GISP seeks to improve the scientific basis for decision making on invasive species; develop capacities to employ early warning and rapid assessment and response systems; enhance the ability to manage invasives; reduce the economic impacts of invasives and control methods; develop better risk assessment methods; and strengthen international agreements. GISP strives to develop public education about invasive species, improve understanding of the ecology of invasives, examine legal and institutional frameworks for controlling invasives, develop new codes of conduct for the movement of species, and design new tools for quantifying the impact of invasives. GISP involves the voluntary contributions from a substantial group of scientists, lawyers, and managers from all parts of the world. One outcome of GISP's work has been the *Global strategy on invasive alien species* (McNeely *et al.*, 2001) that recommends strategic responses to the problem of IAS (see box 1).

**Box 1 - Ten strategic responses to address the problem of invasive alien species**

1. Build management capacity
2. Build research capacity
3. Promote sharing of information
4. Develop economic policies and tools
5. Strengthen national, regional and international legal and institutional frameworks
6. Institute a system of environmental risk analysis
7. Build public awareness and engagement
8. Prepare national strategies and plans
9. Build invasive alien species into global change initiatives
10. Promote international cooperation

(McNeely *et al.*, 2001)

But GISP is only one part of the response. Given the profound impacts that invasive species are having, and their relationship with expanding global trade, it would appear that the World Trade Organization (WTO) should give this issue their highest attention, helping to build support for addressing this issue by those who are earning the greatest economic benefits from global trade.

Research is one of the top priorities. A lot is known about IAS, but there are still a lot of uncertainties in the ecology of IAS, as well as in the human dimensions of their spread. Only in February this year a paper was published in *Nature* that showed the link between invasiveness of the species and parasites, with important implications for control (Torchin *et al.*, 2003). An example of the unknowns in the human dimensions: the IMO estimates that between 3 and 10 billion tonnes of ballast water are carried around the world each year. That is a wide range, and studies are underway to get a better assessment of the exact amount.

Awareness raising is essential, even among people who are supposed to know better. For example, the July 2000 issue of the magazine *Tropical Fish Hobbyist* recommended several species of the genus *Salvinia* as aquarium plants, even though they are considered noxious weeds in the US and prohibited by Australian quarantine laws. Pet stores often advertise these species, even though they are legally controlled.

A fundamental political problem is the establishment of objectives in terms of desirable ecosystems. If, for example, the objective is to conserve native biodiversity, then any introduction is likely to be considered potentially invasive. But if the objective is to enhance productivity for human benefit, then at least some introduced species might be considered desirable.

In conclusion, the problem of invasive aquatic species is now receiving the attention it deserves. The challenge is to use this attention to generate the action required, including a new international convention on ballast water, a significantly expanded research effort, and continued public awareness campaigns that will be converted into political support for those initiatives.

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