

UNITED NATIONS DEVELOPMENT PROGRAMME



Control of the Spread of Invasive Species  
as a Global Public Good

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A UNDP/ODS Background Paper

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## Introduction

Global trade has enabled modern societies to move many species of plants, animals, and micro-organisms from one part of the world to another. Agriculture, forestry, fisheries, the pet trade, the horticultural industry, and many industrial consumers of raw materials today depend on species that are native to distant parts of the world. The lives of people everywhere have been greatly enriched by their access to a greater diversity of the world's biological wealth.

Some non-native species are imported intentionally for economic purposes, but many others arrive unintentionally in shipping containers, lurking under the bark of log imports, infesting fruits carried by tourists, swimming in ballast water exchanged in a harbour, quietly reproducing in the intestines or bloodstream of an unsuspecting traveller, or hidden in soil of imported ornamental plants. Most are harmless or fail to become established, but some proliferate and spread in ways that endanger native species in the invaded ecosystem, undermine agriculture, threaten public health, or create other unwanted -- and often irreversible -- disruptions.

Invasive alien species have invaded and affected native biota in virtually every ecosystem type on Earth. They occur in all major taxonomic groups, including viruses, fungi, algae, mosses, ferns, higher plants, invertebrates, fish, amphibians, reptiles, birds and mammals. Invasive species can transform the structure and species composition of ecosystems by repressing or excluding native species, either directly by out-competing them for resources or indirectly by changing the way nutrients are cycled through the system. The environmental cost is the irretrievable loss of native species and ecosystems (Rejmanek *et al.*).

These “invasive alien species” (IAS) cause billions of dollars in economic damage per year, indicating that their control is under-supplied. Under-provision of the control of invasive species will lead to very substantial costs for future generations, who have no voice in the decision and are unlikely to be compensated for their decline in welfare.

When alien species (also called non-native or exotic species) have negative impacts on ecosystems, biodiversity, health, economics or other aspects of human welfare, they are damaging public goods.

Invasive alien species are now recognized as one of the greatest biological threats to the global public good of our planet's environmental and economic well-being. IAS are recognised as the second leading cause of biodiversity loss, after habitat alteration. Most nations are already grappling with complex and costly invasive species problems. Examples include: comb-jellies from North America are devastating Black and Caspian Sea fisheries; water hyacinth from Brazil is choking African waterways; the spread of South American *Imperata* grass over an estimated 60 million hectares of Asia has removed this land from production, contributing to poverty in many locations; beetles from China are threatening North American forests while beetles from North America are threatening Chinese forests; and cholera bacteria from Asia were introduced through ballast water from ships to Peru in 1991, then spread across South America and infected more than 10 million people by 1994, killing more than

10,000. Addressing the global problem of IAS is urgent because the threat is growing daily, and the economic and environmental impacts are severe.

The trans-boundary movement of harmful invasive species can retard economic growth in the affected countries, undermining developments such as irrigation systems and leading to increases in social tensions and political conflict. If left unaddressed, invasive species can threaten international trade and investment activities. Reducing the negative cross-border externalities of the movement of potentially invasive alien species is a global public good.

The provision of the public good of controlling invasive species can be seen as the flip side of the public good of providing conservation of biological diversity. In the first case, the intention is to slow the growth rate of the population of an invasive species to zero, while the conservation objective is to ensure a healthy population of all native species.

The public policy response advocated here is a regime that permits the social benefits of new introductions while protecting society from the associated risks of harmful species. Effective control requires predicting which species are likely to cause harm and preventing their introduction, and eradicating, containing, or controlling invasive species which have already become established. These measures need to be backed up by appropriate investments in research and monitoring.

## **1. Definition of the global public good**

The global public good addressed here is providing social benefits through controlling the spread of invasive species. Despite the many threats to public welfare posed by invasive species, too few people in any part of the world consciously perceive that they have been affected negatively by IAS. Considerable technical information for addressing the problem is now available (Wittenberg and Cock 2001), but information on IAS to the general public, to businessmen importing potentially invasive species or to shippers unknowingly moving potential invaders around the world, remains under supplied. Most people have little idea of which species are invasive, what are their impacts, and what are appropriate control methods. In the absence of such information, inappropriate responses can be expected, and the public good of invasive species control will remain under-provided.

Responses need to be based on a stronger foundation of science. Despite decades of research, scientific knowledge of the biology, ecology, and human dimensions of invasive alien species remains very incomplete. Scientists are often unable to predict which species are likely to become invasive or to assess the ecological, social or economic impact they are likely to have. Unpredicted effects, such as destroyed fisheries, extinction of native species, declining agricultural yield, devastated forests, and disrupted tourist industries, have all resulted from species introductions. These global public “bads” replace global public goods. It therefore seems sensible to err on the side of precaution, perhaps on occasion sacrificing some economic profit for the businesses directly involved while helping to deliver the public good of a healthier future for all of society.

While preventive responses such as customs inspections and quarantine are generalised, each case of an established invader needs to be considered on its own merits. That said, the adequate provision of the global public good of controlling the spread of IAS has been defined by the Global Invasive Species Programme (McNeely *et al.*, 2001) to include:

1. **An effective national capacity to deal with IAS.** National capacity could include:
  - Basic border control and quarantine capacity;
  - A “rapid response mechanism” to detect and respond immediately to the presence of potentially invasive species as soon as they appear, with sufficient funding and regulatory support;
  - Training and education programmes for customs officials, field staff, managers, and policy makers; and
  - Institutions at national or regional level that bring together biodiversity specialists with agricultural quarantine specialists to collaborate on implementing national programmes on IAS.
2. **Public awareness and engagement.** A vigorous public awareness programme would involve the key stakeholders who are actively engaged in issues relevant to IAS, including shippers, pet dealers, botanic gardens, nurseries, agricultural suppliers, tourists and others. The public can also be involved as volunteers in eradication programmes of certain IAS, such as woody invasives of national parks.
3. **Fundamental and applied research, at local, national, and global levels.** Research is required on taxonomy, invasion pathways, management measures, and effective monitoring. Research can lead to improved prediction on which species have the potential to become invasive, improved understanding of lag times between first introduction and establishment of IAS, and better methods for excluding or removing alien species from traded goods, packaging material, ballast water, personal luggage, and other methods of transport. This is classic public goods research, benefitting all.
4. **Effective technical communications.** An accessible knowledge base, a planned system for review of proposed introductions, and an informed public are needed both within countries and between countries. Already, numerous major sources of information on invasive species are accessible electronically, and more could also be developed and promoted, along with other forms of media.
5. **Appropriate economic policies.** While prevention, eradication, control, mitigation and adaptation all yield economic benefits, many of these are in the form of public goods and hence are likely to be under-supplied. New or adapted economic instruments can help ensure that the costs of addressing IAS are better reflected in market prices, thereby reducing the public funds required to provide the public good. Economic measures that can be applied nationally or internationally to implement the “user pays” principle and reduce the draw on public funds include liability of those responsible for the introduction of economically harmful IAS; use rights to natural or environmental resources that

include an obligation to prevent the spread of potential IAS; and performance bonds for importers of potential IAS to cover any unanticipated costs of introductions.

6. **Effective national, regional, and international legal and institutional frameworks.** Coordination and cooperation between the relevant institutions are necessary to address possible gaps, weaknesses and inconsistencies, and promote greater mutual support among the many international instruments dealing with IAS (Shine *et al.*, 2000).
7. **A system of environmental risk analysis.** Such a system for intentional introductions could be based on existing environmental impact assessment procedures that have been developed in many countries. Risk analysis measures should be used to identify and evaluate the relevant risks of a proposed species introduction, and determine the appropriate measures that should be adopted to manage the risks. Criteria need to be developed to measure and classify impacts of alien species on natural ecosystems, including detailed protocols for assessing the likelihood of invasion in specific habitats or ecosystems.
8. **Prepare national strategies and plans.** A national strategy should promote cooperation among the many sectors whose activities have the greatest potential to introduce IAS or to benefit from improved control. The government agencies with responsibility for human health, animal health, plant health, and other relevant fields need to work toward the same broad objective of sustainable development, supported by collaboration between different scientific disciplines that can seek new approaches to dealing with IAS problems.
9. **Build IAS issues into global change initiatives.** Global change issues relevant to IAS include changes in climate, nitrogen cycles, economic development, land use, global trade, demographics, and other variables that might enhance the risks of IAS becoming established. Further, management responses to global change issues, such as sequestering carbon, generating biomass energy, and recovering degraded lands, should not increase the risk of the spread of IAS.
10. **Promote international cooperation.** Delivering the global public good of controlling IAS is fundamentally international, so international cooperation is essential to develop the necessary range of approaches, strategies, models, tools, and partners. Better international cooperation could include developing an international vocabulary, widely agreed and adopted; cross-sectoral collaboration among international organizations involved in agriculture, trade, tourism, health, and transport; and improved linkages among the international institutions dealing with phytosanitary, biosafety, and biodiversity issues related to IAS.

## 2. Characterisation of the current provision status

Numerous international instruments, binding and non-binding, have been developed to provide certain elements of the public good of controlling the spread of IAS. The most comprehensive is the Convention on Biological Diversity (CBD), which calls on its Parties to "prevent the introduction of, control or eradicate those alien species

which threaten ecosystems, habitats, or species" (Article 8h). A much older instrument is the 1952 International Plant Protection Convention (IPPC) which applies primarily to plant pests, based on a system of phytosanitary certificates. Regional agreements further strengthen the IPPC. Other instruments deal with IAS in specific regions (such as Antarctica), sectors (such as fishing in the Danube), or vectors (such as IAS in ballast water, through the International Maritime Organization). Over 40 instruments or programmes are already in force, and many more are awaiting finalisation and ratification (Shine *et al.*, 2000).

The expanding negative impact of IAS on both global economies and the environment indicates that these international instruments are under-providing the public good. Furthermore, expanding international trade is moving ever more organisms more rapidly around the world, thereby increasing the risk these species pose to native ecosystems as an externality and potentially overwhelming government efforts to prevent unwanted invasions.

The 6 million or so shipping containers that are in movement at any given time around the world can be seen as a passenger service for pests, especially insects and pathogens. The use of sea containers has increased by 180% in the past decade, while biosecurity measures have failed to keep pace. One study in New Zealand, a country that takes the problem of invasive species very seriously, reported that routine inspections find only 1 in 20 insects and spiders, and fewer than 1 in 4 containers are actually inspected.

Some governments fear that controls over potentially invasive species may be considered trade restrictive, contending that the public good of invasive species control is less important than the public good of the global trading system. On the other hand, some mechanisms exist to deliver on both of these public goods simultaneously. The WTO Agreement on Sanitary and Phytosanitary Measures (SPS) is designed to ensure that sanitary and phytosanitary domestic measures are consistent with the WTO obligations prohibiting arbitrary or unjustifiable trade discrimination. Trade restrictions are consistent with the SPS agreement and the GATT 1994 agreement if they conform to international standards, guidelines and recommendations. The SPS agreement explicitly refers to several existing standards. For food safety, the reference organisation is the Codex Alimentarius Commission; for animal health and zoonoses, the International Office of Epizootics; and 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. Many governments seek mutual support among conventions and the SPS Agreement and the Agreement on Technical Barriers to Trade under the World Trade Organization may offer useful opportunities for developing ways for the CBD and the WTO to collaborate more closely to deliver on the public good of invasive alien species control.

Technology continues to improve significantly, and may be mobilized to control IAS. Technological breakthroughs such as the Internet, coupled with improved microprocessors, are facilitating information flow both within and between countries. This information technology can be used to warn when a species is invading. 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. One possibility might be to establish a central world or regional information source that could operate for invasive species in a way that is analogous to the Centres for Disease Control (CDC) operates for communicable diseases (Perrings, Dalmazzone and Williamson 2004).

### 3. The monetary impact resulting from the shortfall

The lack of control of biological invasions as a public “bad” is global and the economic cost is enormous, in both environmental and economic terms. Weeds reduce crop yields, increase control costs, and decrease water supply by degrading water catchment areas and freshwater ecosystems. Tourists unwittingly introduce alien plants into national parks, where they degrade protected ecosystems and drive up management costs. Pests and pathogens of crops, livestock and trees destroy plants outright, or reduce yields and increase pest control costs. And recently-spread disease organisms continue to kill or disable millions of people each year, with profound social and economic implications. Only some of the potential damage can be quantified in monetary terms. For example, restoration costs can be estimated, but no figure can be put on species extinction because it is irreversible. Box 1 provides some indicative costs of failing to control the spread of IAS.

**BOX 1: INDICATIVE ECONOMIC IMPACTS OF SOME INVASIVE ALIEN SPECIES  
(costs in US\$)**

Species	Economic Variable	Economic Impact	Reference
Introduced disease organisms	Annual cost to human, plant, animal health in USA	\$41 billion per year	Daszak <i>et al.</i> , 2000
A sample of alien species of plants and animals	Economic costs of damage in USA	\$137 billion per year	Pimentel <i>et al.</i> , 2000
Coypu (aquatic rodent)	Damages to agriculture and river banks in Italy.	\$2.8 million per year	Panzacchi <i>et al.</i> , 2004
Salt Cedar	Value of ecosystem services lost in western USA	\$7-16 billion over 55 years	Zavaleta, 2000
Knapweed and Leafy spurge	Impact on economy in three US states	\$40.5 million per year direct costs \$89 million indirect	Bangsund, 1999; Hirsch & Leitch, 1996
Zebra mussel	Damages to US and European industrial plants	Cumulative costs 1988-2000=\$750 million to 1 billion	National Aquatic Nuisances Species Clearinghouse, 2000
Six weed species	Costs in Australia agroecosystems	\$105 million/year	Watkinson, Freckleton & Dowling 2000
<i>Pinus</i> , <i>Hakeas</i> , and <i>Acacia</i>	Costs on South African Floral Kingdom to restore to pristine state	\$2 billion	Turpie & Heydenrych, 2000
Water hyacinth	Costs in 7 African countries	\$20-50 million/year	Joffe-Cooke, 1997

Species	Economic Variable	Economic Impact	Reference
Rabbits	Losses to agriculture in Australia	\$373 million/year	White & Newton-Cross, 2000
Varroa mite	Economic cost to beekeeping in New Zealand	\$267-602 million	Wittenberg and Cock, 2001
Comb-jelly	Lost anchovy fisheries in Black Sea	\$17 million/year	Knowler and Barbier, 2000.
Golden apple snail	Damage to rice agriculture in Philippines	\$28-45 million per year	Naylor, 1996
Introduced Pests	Economic losses in crops, pastures, forests in India	\$91 billion	Pimentel <i>et al.</i> , 2001
Introduced Pests	Economic losses in crops, pastures, forests in Brazil	\$42.6 billion	Pimentel <i>et al.</i> , 2001

In addition to the direct costs of management of invasives, other economic costs include their indirect environmental consequences and other non-market values. Most important, invasives may cause changes in the global public goods provided by ecosystem services, for example, by disturbing the operation of the hydrological cycle, including flood control and water supply; waste assimilation; recycling of nutrients; conservation and regeneration of soils; pollination of crops; and seed dispersal. Such services have both current use value and option value (the potential value of such services in the future). As just one example, in South Africa, the establishment of invasive tree species has decreased water supplies for nearby communities and increased fire hazards, justifying government expenditures of US\$40 million per year for manual and chemical control.

Most evidence of economic impact of invasive alien species comes from the developed world. However, the developing world is experiencing similar, if not proportionally greater, losses. Invasive alien insect pests, such as the white cassava mealybug and larger grain borer in Africa, pose direct threats to food security. Alien weeds constrain efforts to restore degraded land, regenerate forests and improve utilization of water for irrigation and fisheries. Water hyacinth and other alien water weeds affecting water use currently cost developing countries in Africa and Asia over US\$100 million annually. Alien invasives pose a threat to over US\$13 billion of current and planned World Bank funding to projects, including in the irrigation, drainage, water supply, sanitation and power sectors (Joffe and Cooke, 1997).

Although the loss of crops due to weeds or other alien pests may be reflected in the market prices of agricultural commodities, such costs are seldom paid by those responsible for the introductions (if indeed the responsible parties are even known). Rather, these costs are “externalities”, i.e., costs that an activity unintentionally imposes on another activity, without the latter being able to extract compensation for the damage received. One special feature of the costs of biological invasions as externalities is that they are largely self-perpetuating, once they are set in motion. Even if introduction ceases, damage from the invasives already established continues and may well increase unless public expenditure are directed to minimise the problem. This underlines the importance of treating IAS control as a public good.

The costs of accidental introductions cannot be readily reflected by prices or markets. But even in the case of introductions involving deliberate imports to support agriculture, horticulture, forestry, and fisheries, the market prices for seeds, plants, or foods seldom reflect the environmental risks associated with their introduction. Thus importers have little financial incentive to take account of the potential cost of the loss of indigenous species or disturbance to ecosystem functions (global public goods). The policies developed to deal with conventional externalities involved in the general problem of biodiversity loss -- using such economic tools as taxes, subsidies, permits, and so forth -- may not always be well suited to deal with the problems caused by invasions. This point highlights the urgent need for new approaches to deal with IAS, such as treating IAS control as a global public good.

#### 4. Estimate of the costs of corrective action to enhance the provision status of the global public good

The costs of controlling an invasive species include the expenditures required to support the means that will reduce the size of an invasion, ideally to zero. The costs of eradication tend to be lowest in the earliest phase of an invasion. One perverse problem with invasive species is that it may make more economic sense to control a species once it has invaded than to prevent its ever becoming established, because the economic damage is more apparent once the species has become established and started causing problems (as in the case of SARS or beetle species that infest forests). But it is far more economically feasible to eradicate a small population than a large one, hence the argument for a rapid response capacity. Eradicating an invasive species usually involves a higher one-time cost than control or containment, but may be significantly more cost-effective in the long term. On the other hand, removing the last one percent of an IAS may be more expensive than the first 99 percent of the target population. Costs of monitoring also become more expensive on a per unit basis when densities of the target species are very low.

#### BOX2: EXAMPLES OF COSTS OF ERADICATING INVASIVE SPECIES

Eradication Programme	Total Costs (US\$)	Reference
Screw-worm in US and Mexico	\$750 million	Reichard et al., 1992
Goats on Lord Howe Island	\$80 thousand	Parkes et al., 2002
Red mangroves on Nu'upia Pond, Hawaii (195 ha)	\$2.5 million	Rauzon & Drigot, 2002
Feral Pigs, Santa Catalina Island, USA	\$3.1 million	Garcelon & Escover
Zebra mussel from a flooded quarry, Virginia, USA	\$600 thousand	Neves, 2004
Coypu in East Anglia, UK	\$6 million	Panzacchi et al., 2004
Wild ginger on 1 ha on Reunion Island	\$25 thousand	Lavergne et al., 2003
Remove invasive plants and replace with natives in Seychelles (2 ha).	\$50 thousand	Barreau, 2002
<i>Rhododendron ponticum</i> in Snowdonia National Park, Wales.	\$8.1 million	Dehnen-Schmitz et al., 2004
Mediterranean fruitfly in Florida (two infestations)	\$50 million	Cleary, 2004

Eradication can be a realistic target for large mammals over a fairly extensive territory, and the eradication of smallpox has demonstrated that even a widespread virus can be eradicated. Another line of proof of the feasibility of eradication is the high, and growing, rate of species extinction; though extinction-prone species tend to have very different characteristics from those that are successful invaders. For plants, it is usually possible to eradicate species when the area of infestation is less than 1 hectare. Odds of success reduce to about 33% when the infestation covers up to 100 hectares, and about 25% when the area is up to 1,000 hectares (Rejmanek and Pitcairn, 2002). Eradicating invasive plants from larger areas than this becomes extremely expensive, indicating the importance of early detection.

On the other hand, it is relatively inexpensive to remove large numbers of individuals when the invasive species has become well established, for example in the case of goats or feral dogs on the Galapagos Islands. But removing the last few percent is very difficult indeed, so the unit control costs can grow very quickly as the size of an invasion is reduced. This is a good argument for investing in preventing invasions as a public good, rather than waiting until an invasive species is so well established that a market demand is created for its removal (by which time it may be too late to do so economically).

While numerous examples of efforts to control IAS are available (e.g. Wittenberg and Cock, 2001 and Veitch and Clout, 2002), the comprehensive costs involved are seldom reported. Personnel costs may be hidden in routine budgets, volunteer labour may be used, transport costs may be covered by other budgets, etc. That said, Box 3 provides examples that may be informative.

### BOX 3: EXAMPLES OF COSTS OF CONTROLLING INVASIVE SPECIES

Species	Annual Costs (US\$)	Reference
Water hyacinth in Malaysia	\$2.7 million	Harley et al., 1997
Dutch elm disease in USA	\$100 million	Simborloff, 2002
Melaleuca in Florida, USA	\$3-6 million	Simborloff, 2002
Mongoose on Amami Island, Japan	\$50 thousand	Yamada, 2002
Golden apple snails in the Philippines	\$12.5-17.2 millions	Naylor, 1996
Leafy spurge in Fremont County, Wyoming, USA	\$400 thousand	Baker, 2004
<i>Rhododendron ponticum</i> in UK nature reserves	\$1.2 million	Dehnen-Schmitz et al. 2004

In most government jurisdictions, costs of controlling the spread of IAS are contained within other budgets, making it difficult to specify expenditures in providing this public good. However, some indications can be gained from the samples in Box 4.

**BOX 4: SOME PROGRAMME-LEVEL COSTS OF CONTROLLING THE SPREAD OF INVASIVE SPECIES**

<b>Programme</b>	<b>Costs (US\$)</b>	<b>Reference</b>
Control of IAS in the Galapagos Archipelago	\$41.92 million	GEF, 2004.
Control of IAS in the European Union through the LIFE programme	\$3.2 million per year	Scalera and Zaghi, 2004.
Control of IAS in Florida	\$90 million per year	Cleary, 2004.
Control of IAS in New Zealand (Expenditure by Dept. of Conservation)	\$8.6 million per year	Bill, 2004
Control of IAS in Victoria, Australia	\$24 million per year	Brumby, 2003.
Control of aquatic invasives in Minnesota, USA	\$1.5 million per year	Rendall, 2004

In New Zealand, the government has recently approved its national biodiversity strategy, which allocates an additional \$57 million on controlling animal pests and weeds on public conservation lands, plus \$37 million on conserving private lands, \$9.8 million on improving the protection of the marine environment from invasive marine species, and \$2.6 million for developing a comprehensive biosecurity strategy for the country and assessing the risks of non-native species to native ones ([www.biodo.govt.nz](http://www.biodo.govt.nz)).

**5. Estimate of net benefits**

Experience has shown that the most effective way to address problems of IAS is to prevent their introduction in the first place. But because this is not always possible, the second-best option is quick response, eradicating the problem species before it becomes so widespread that only the third option -- control and containment -- is economically feasible. The economics of these three options have very different characteristics.

One way to identify the most appropriate response to a problem caused by an IAS is benefit-cost analysis, which compares the expected present value of the benefits of the control programme (in other words, the net costs avoided by the programme) with the expected present value of the costs of control (in other words, the foregone benefits of the introduction). However, valuation of the costs and benefits of invasion control options typically focuses on partial damage estimates or on direct control costs, sometimes failing to distinguish capital from income and paying little attention to the interactive effects between non-native and native species (Perrings, Dalmazzone and Williamson, 2004.)

Different methods of controlling invasive species have very different economic implications. Chemical means of control (for example on invasive species of plants) tend to require considerable investments for long periods of time while biological controls (where natural enemies of the target species are used), while expensive in terms of research and development, tend to decline in price after the initial introductions. As of 2001, more than 5,000 natural enemies of insects and mites had

been introduced along with more than 900 natural enemies of weeds. Complete control of pest populations have been achieved in about 10-15% of cases. Hill and Greathead (2000) present a cost-benefit analysis for numerous biological control projects, demonstrating a highly positive cost-benefit ratio for the specific biological control projects mentioned; they do not take into account the costs of research into biological controls that proved unsuccessful, so the economics are somewhat misleading. While they do have a high failure rate, biological control projects are often a cost-effective use of public good funds. Because they are sustainable and self-renewing, successful biological control programmes can yield higher returns than those of other agricultural technology research programme and significantly higher than average returns on public good investment projects.

Given these complexities, several examples of net benefits illustrate the economic feasibility of delivering the public good of the control of invasive species:

- One study found that 17 countries spend US\$ 88 million per annum to control water weeds, mostly water hyacinth, water fern and water lettuce (Joffe & Cooke, 1997), and it is estimated that the global net economic cost avoided would “probably be measured in hundreds of millions of dollars per annum.”
- In Australia, losses to tourism, public health, and aquaculture of about US\$ 300 million could be avoided by implementing ballast water management to minimise potentially harmful introductions (Gollasch and Leppakoski, 1999).
- The benefits from eradicating the introduced species *Gyrodactylus salaris* from individual salmon rivers in Norway exceed the cost of treatment by a factor of 30 (DN 1995).
- The World Bank has estimated that it would cost about US\$ 50 million to solve the problem of water hyacinth infestation in the Niger River, as opposed to the annual economic costs of the weed of US\$ 50 million per year (World Bank, 1990).
- Tamarisk has invaded most riparian areas of the arid and semi-arid western US, disrupting the water regime causing damage of \$ 280-450 per hectare. Eradicating this invasive and restoring native communities throughout the region would cost about US\$ 7400 per hectare, with the full costs being recovered in as few as 17 years, after which the social, ecological, and economic benefits of restoration would continue to accrue indefinitely to the general public (Zavaleta, 2000).
- In a study of 12 invasive species in the US, the medium cost benefit ration was 17 to 1, with a range of 0.23/1 in one case of water hyacinth to 1,661/1 with Siberian log imports (OTA, 1993).

Many control methods have been proven effective and their potential benefits considerably outweigh the potential costs. For example, rabbit calicivirus disease (RCD) has been used to control rabbits in Australia, delivering substantial market value benefits to agriculture and forestry. On the other hand, non-market values are difficult to quantify, especially if RCD has ecosystem effects via grazing competition

and predator-prey interactions; the key unknown risk factor is the possibility of RCD jumping from rabbits to a native species, which could substantially increase the longterm costs of this control method (White and Newton-Cross, 2000).

Control methods that rely primarily on technological fixes can address one of the largest problems with aquatic invasive species, namely the treatment of ballast water. These include filtration to remove larger organisms, ultraviolet disinfection of viruses and bacteria, advanced oxidation to address the intermediate-sized organisms that are not removed by filtration or inactivated by ultraviolet light alone, ozone injection, chemical treatment, onshore treatment, centrifugal separation, and dissolved air flotation. While new ships can be fitted with such systems during the manufacturing process, the existing fleets of both commercial and military vessels would need to be retro-fitted. The Global Ballast Water Management Programme (GLOBALLAST) is working to address this global public goods problem.

Another limitation to the economic indications of costs and benefits are the potential damages to ecosystems, human health, or property through the methods used to control the IAS. In the case of biological controls, some of the early experiences led to disastrous results, such as the spread of mongooses on various islands to control introduced rats, the introduction of predatory snails in the Society Islands which led to the extinction of over 50 species of native snails, and the cane toad in Australia that was introduced to control beetles but has now become a major ecological concern in the country. Many such costs are incalculable because they have led to species extinction, an irreversibility that cannot easily be given an economic value. Other forms of damage can be given more precise values; for example, aerial spraying of insecticides to control the Mediterranean fruitfly in California led to damage to automobile paint that cost the government of California US\$ 3.7 millions (GETZ. 1989).

In conclusion, invasive alien species are causing public damages in the many billions of dollars per year, indicating that the control of these problem species is under-supplied. An increase in the delivery of the control of invasive alien species as a global public good is highly justified.

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