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As the world gets smaller, the chances of invasion grow

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Summary

While the issue of invasive alien species has important biological components, economic factors such as global trade deserve much greater attention for several reasons. First, virtually all of our planet's ecosystems have a strong and increasing anthropogenic component that is being fed by increasing globalisation of the economy. Second, people are designing the kinds of ecosystems they find productive or congenial, incorporating species from all parts of the world through quicker and more efficient means of transportation. And third, growing travel and trade, coupled with weakening customs and quarantine controls, mean that people are both intentionally and inadvertently introducing alien species that may become invasive. The great increase in the introduction of alien species that people are importing for economic, aesthetic, accidental, or even psychological reasons is leading to more species invading native ecosystems, with disastrous results: they become invasive alien species (IAS) that have significant deleterious effects on both ecosystems and economies. This paper examines some of the important non-biological dimensions of the IAS problem, including historical, economic, cultural, linguistic, health, sociological, management, legal, military, ethical, and political dimensions. These are addressed in terms of the causes, consequences, and responses to the problem of IAS. These dimensions of IAS are fundamental, and successfully addressing the problem will call for greater collaboration between different economic sectors and among a wide range of disciplines. The Convention on Biological Diversity, the negotiations of the World Trade Organisation, and many other international agreements offer important opportunities for addressing the complex global problems of IAS through improved international cooperation.

Introduction

The human impacts on the ecosystems of our planet are unprecedented, leading to increasing concerns from many directions. Our increasing population and expanding levels of consumption mean that more people are consuming more of nature's goods and services, pushing against the limits of sustainability. Greatly expanding global trade is feeding this consumption, with large containers of goods moving quickly from one part of the world to another by plane, ship, train, and truck.

One critical element in this economic globalisation is the movement of organisms from one part of the world to another through trade, transport, and tourism. Many of these movements of organisms into new ecosystems where they are alien (also called non-native, non-indigenous or exotic) are generally beneficial to people. But many others have very mixed impacts, benefiting some individuals or interest groups while disadvantaging others. And in a few cases, especially disease organisms and pests of forests or agricultural crops, the alien species is clearly detrimental to all, or nearly so. This paper addresses the latter groups: "Invasive alien species" (IAS), that subset of alien species whose establishment and spread threatens ecosystems, habitats, or species with economic or environmental harm (GISP, 2001).

Farmers have been fighting weeds since the very beginnings of agriculture, but the general global problem

of invasive alien species has been brought to the world's attention only relatively recently by ecologists who were concerned that native species and ecosystems were being disrupted (e.g., Elton, 1958; Drake et al., 1989). Much of the work to date on IAS has focused on their biological and ecological characteristics, the vulnerability of ecosystems to invasions, and the use of various means of control against invasives. However, only with the clear linkage of invasive species to global trade has the issue begun to attract wider attention. An important element is the recognition that the problem of IAS is above all a human one, for at least the following reasons:

- People are largely responsible for moving eggs, seeds, spores, vegetative parts, and whole organisms from one place to another, especially through modern global transport and travel;
- While some species are capable of invading well-protected, "intact" ecosystems, IAS more often seem to invade habitats altered by humans, such as agricultural fields, human settlements, and roadways (Jenkins & Pimm, 2003);
- Many alien species are intentionally introduced for economic reasons, implying that those earning economic benefits should also be responsible for economic costs should the alien become invasive; and
- People define the dimensions of the problem of invasive alien species, and the responses are also designed and implemented by people, with differential impacts on different social groups.

People introduce organisms into new habitats non-intentionally (often invertebrates and pathogens), intentionally (usually plants and vertebrates), or by inadvertence when organisms imported for a limited purpose then subsequently spread into new habitats (Levin, 1989). Many of the deliberate introductions relate to the human interest in nurturing species that are helpful to people, for agricultural, forestry, ornamental, or even psychological purposes (Staples, 2001). The great bulk of human dietary needs in most parts of the world are met by species that have been introduced from elsewhere (Hoyt, 1992); it is difficult to imagine an Africa without potatoes, cocoa, and cassava, or a North America without wheat, soy beans, or rice, or a Europe without tomatoes, oranges, and maize, or a tropical Asia without rubber, oil palm, and chili peppers – all introduced species. Species introductions, therefore, are an essential part of human welfare and local cultures in virtually all parts of the world. Further, maintaining the health of these introduced alien species of undoubted net benefit to humans may sometimes require the introduction of additional alien species for use in biological control programmes which import natural enemies of, for example, agricultural pests (Waage, 1991; Thomas & Willis, 1998), but these biological controls may themselves sometimes become invasive.

Considerable evidence indicates a rapid recent growth in the number and impact of IAS (Mooney & Hobbs, 2000). Trade, and more generally economic development, lead to more IAS; Vilà and Pujadas (2001), for example, found that countries that are more effectively tied into the global trading system tend to have more IAS, being positively linked to the development of terrestrial transport networks, migration rates, number of tourists visiting the country, and trade in commodities (Dalmazzone, 2000). The general global picture shows tremendous mixing of species, with unpredictable long-term results but a clear trend toward homogenisation (Bright, 1999; Mooney & Hobbs, 2000). The future is certain to bring considerable additional species mixing as people continue to influence ecosystems in various ways, not least through both purposeful and accidental introduction of species as an inevitable consequence of growing global trade. This mixing will yield some species that become more abundant and many others that will decline in numbers (or even become extinct). Species numbers in many locations may actually increase, but because IAS are the major factor in species extinction (Groombridge & Jenkins, 2000), the overall effect will likely be a global loss of biodiversity at species and genetic levels. But how is this mixing of species being driven by human interests and how will it affect them? What stakes are involved? Whose interests are being affected? How can scientists, resource managers, and policy makers best address the trade dimensions of IAS?

These are not trivial questions, because the issue of IAS has ramifications throughout modern economies. It involves global trade, settlement patterns, agriculture, economics, health, water management, climate change, genetic engineering, ethics and many other fields and concerns. (Levine & D'Antonio, 2002; French, 2000). Innovations in transportation, communications, and information technology are shrinking our world, enabling species to spread at the speed of transport. It therefore goes to the very heart of problems policy-makers are spending much time debating, ironically usually without reference to IAS. This paper examines some of the ramifications of IAS through many dimensions of human endeavour, including historical,

economic, cultural, health, psychological, sociological, legal, management, military, philosophical, and political components. It shows that IAS are deeply woven into the fabric of modern life. While the biological dimensions of IAS are fundamental, more effective responses to the problems they pose must incorporate the kinds of human dimensions that are discussed in this paper.

Historical dimensions

Because of a long geological and evolutionary history, our planet has very different species of plants, animals, and micro-organisms on the various continents, and in the various ecosystems. As a broad illustration, Africa has baobabs, Indonesia has dipterocarps, and Australia has eucalypts. Even within the continents, most species are confined to particular types of habitats; forests, grasslands, and deserts all have their own suite of plants. Oceanic islands and other geographically-isolated ecosystems often have their own species, many found nowhere else (termed "endemic species"); about 20% of the world's flora is made up of insular endemics, found on only 3.6% of the land surface area. Geographical barriers have ensured that most species remain within their region, thus resulting in a much greater species richness across the planet than would have been the case if all land masses were part of a single continent. This historical biogeographical framework provides the basis for defining concepts of native and alien species. It is also important to recognize that biogeography is dynamic, because species constantly expand and contract their ranges and the contents of ecosystems change as a result of factors such as climate change (Udvardy, 1969).

Trade is known far back in human prehistory, judging from the discovery of stone tools at a considerable distance from where they were quarried. But as long-distance travel became more regular, trade grew in importance. Chinese traders have spread into Southeast Asia for at least several thousand years, and trading routes between India and the Middle East stretch back at least as long. As sailing craft became larger and more reliable, trade increased further and was given a great boost with the voyages of Christopher Columbus that opened up entirely new sources of species, and led to the replacement of the rigid moral strictures of Medieval Europe by a new set of merchant values that stressed consumption (Low, 2001).

The period of European colonialism ushered in a new era of species introductions, as the European settlers sought to recreate the familiar conditions of home (Crosby, 1986). They took with them species such as wheat, barley, rye, and numerous ornamentals, but in the early years their impacts were limited by the available means of transport. Once steam-powered ships came into common use, the floodgates opened and over 50 million Europeans emigrated to distant shores between 1820 and 1930, carrying numerous plants that were added to the native flora (Reichard & White, 2001). More recently, Chinese, Indian, Indo-Chinese, African, and other emigrants have carried familiar species with them to grow in their new homelands in Europe, Australia, and the Americas.

The era of European colonialism also saw the spread of plant exploration, seeking new species of ornamental plants for botanical gardens, nurseries, and private individuals back home (Reichard & White, 2001). The spread of global consumerism was given a significant boost in the early decades of the 20th century through advertising and marketing that was strategically designed to motivate the public to buy more goods (Staples, 2001). This ultimately led to an accelerating search to find new species to grow and market, creating consumer demand for products that previously were not present. The invasive characteristics of the newly introduced species often came as a surprise, because those responsible for the introduction were unaware of the possible negative ecological ramifications of the species involved.

Many invasive species of plants and animals were carried by the colonial military, especially to Pacific and Indian Ocean islands that had numerous endemic species vulnerable to these invasives. In the 17th and 18th centuries, navies introduced many plants to remote islands as future food sources, and these frequently became invasive (Binggeli, 2001). The military sometimes brought in exotic species of plants to form barriers. For example, the French introduced a cactus (*Opuntia monacantha*) to Fort Dauphin in southeast Madagascar in 1768 to provide an impregnable barrier around the fort. Later, the military also introduced a spineless variety (of *O. ficus-indica*) to feed oxen (Decary, 1947). The role of the military in the spread of IAS has continued. World War II was a particularly active time for the introduction of weeds in the Pacific. Some species, such as Bermuda grass (*Cynodon dactylon*), were deliberately introduced to revegetate islands that were devastated by military activity. In some places, woody plants were grown to hide fortresses

or to protect gun placements from attacks, but have subsequently spread and become invasive (Binggeli, 2001). For example, the Japanese used the fast-growing tree species *Leucaena leucocephala* to camouflage gun positions; it has now overgrown some of the Pacific islands, having invaded from Central America and the West Indies (Samson, 1968). Many species spread by accident, clinging to military equipment and supplies or sticking to wheels of airplanes. Some species of grasses were carried from one island to another as seeds adhering to clothing. And because many weeds do best on bare or disturbed ground, war helped to prepare a fertile ground for them.

Thus the floral assemblages found in any particular location have been profoundly influenced by past human activities, and people are likely to have an even greater impact in the future. This leads to the contemplation of whether the current episode of globalization might lead to increased diversity in at least some places after the dust settles on the current extinction spasm (Parker, 2001). As just one example, New Zealand has twice as many plants today as they did when Europeans first arrived, and California has 16% more (1023 introduced, with 34 extinctions) (Hobbs & Mooney, 1998). Further development of biotic communities as climates change will depend on organisms invading into novel habitats, sometimes hybridising with the native species, sometimes replacing them, and sometimes adding to the diversity of the ecosystem with new species interactions. Through introducing species, humans are creating their own ecosystems (Orr & Smith, 1998), often more or less by accident, and disrupting ecosystems that had evolved over millions of years.

Global trade, economics, and species invasions

Global trade has enabled modern societies to benefit from the unprecedented movement and establishment of species around the world. Agriculture, forestry, 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 share of the world's biological diversity, and expanding global trade is providing additional opportunities for further such enrichment. Most people warmly welcome this globalization of trade, and growing incomes in many parts of the world are leading to increased demand for imported products. North American nursery catalogues, for example, offer nearly 60,000 plant species and varieties to a global market, often through the Internet (Ewel et al., 1999). A generally unrecognized side effect of this globalization is the introduction of alien species, at least some of which may become invasive.

Linked to the growing global marketplace, the world is becoming increasingly urban, with about half the world's population living in cities at the turn of the century. Cities tend to be the focal points of the global economy and the entry points for many invasives. Many invasive species are most prolific in urban and urban-fringe environments where long histories of human disturbance have created abundant bare ground and many opportunities for invasion. Many urban dwellers seek ornamentals from a wide range of sources, and these may become invasive. For example, Berlin has 839 native species of plants and 593 aliens (Kowarik, 1990). Urbanization involves large and mobile populations that can easily escape the environmental penalties from misusing resources. Further, urban dwellers are seldom aware of the problems of invasive species because they have essentially lost their connections to the natural environment (Staples, 2001). Settlement patterns also involve transportation links, and the distribution of many invasives seem to follow transportation corridors. Thus human settlement patterns, too, are part of the invasive species issue (Marambe et al., 2001).

Many people who seek to use the global market to introduce a non-native species into a new habitat do so for an economic reason (McNeely, 1999). They may wish to increase their profits from agriculture, they may believe that the public will like a newly-discovered flower from a distant part of the globe, or they may think that non-native species will be able to carry out functions that native species cannot carry out as effectively. But few of those introducing alien species have carried out a thorough cost-benefit analysis before initiating the introduction, ignoring ("externalizing") the negative impacts that may follow from species introductions because they have not been required to recognize them. They might also be worried that they would be expected to compensate those who are negatively affected ("internalize the externality").

Similarly, those who have been responsible for inadvertently introducing species into new habitats may not have been willing to make the investment necessary to prevent such accidents from occurring. They may not have realized the dangers, and in any case the dangers would be unlikely to have much economic impact on their own welfare. Rather, the costs of such accidents

are borne disproportionately by people other than those who are permitting the accidents to happen. Thus the costs of introducing potentially invasive alien species into new habitats are externalized in considerations of the costs of global trade. The line of responsibility is insufficiently clear to bring about the necessary changes in behaviour, so the general public and future generations end up paying most of the costs.

For example, in the early 1990s, Serbian scientists discovered the western corn rootworm (a beetle *Diabrotica vigifera*, whose worm-like larvae feed on the roots of maize plants) near Belgrade airport, apparently inadvertently flown in on military aircraft from the USA. Vigorous international action might have curbed this pest's first known venture outside North America, but the turmoil of war prevented such a collaboration and now it is too late. By 1995, the pest had spread into Croatia and Hungary, subsequently spreading to Romania, Bosnia-Herzegovina, Bulgaria, and Italy (Enserink, 1999). It is likely eventually to spread into every maize-planting country in Europe, and perhaps eventually into Asia, forcing farmers to use chemical pesticides or suffer crippling economic losses. A problem that would have been relatively easy and cheap to solve if addressed quickly was prevented from being controlled due to the human factor of war that blocked the necessary collaboration, and the problem now has serious economic impacts.

One limitation of human perception of the costs of IAS is that invasions often happen almost invisibly, without any clear responsibility, and with very limited initial impacts. Further, monitoring, early detection, and containment of invaders before they cause widespread damage are unlikely to be considered to have a positive cost-benefit ratio because the costs are required now while the main benefits (at least in terms of future costs avoided) remain speculative. On the other hand, where sound cost-benefit studies have been done, they demonstrate the value of control, and prevention is shown to be the best strategy (Jenkins, 2001).

All human cultures actively modify their surroundings to achieve an environment that they find pleasing. At least part of the world's cultural diversity is due to the local patterns of distribution of plants, because the locally available resources and how they are used help to define the character of any particular cultural group. Some IAS become part of the local culture. As just one example, Blaustein (2001) describes how the Kudzu vine (*Pueraria lobata*), native to Japan and China, has entered the folklore, music, literature, advertising, and popular culture of the American South, primarily as a villain.

Some suggest that people have an innate tendency to focus on life and lifelike processes, a condition Wilson (1984) called "biophilia". This leads many people to value diversity for its own sake, perhaps seeking to enhance the options available for improving their physical or social well being. One manifestation of this tendency may be a need or desire to have other species living close to us (Mack, 2001; Staples, 2001). In many parts of the world, a thriving garden trade that answers this human need also poses continuous risks due to intentional or accidental releases by gardeners. Even people who are professional resource managers, such as the staff at South Africa's Kruger National Park, can be remarkably resistant to the idea of limiting their cultivation of potentially invasive garden plants (Foxcroft, 2001). Thus human preference rather than biological traits may be the critical factor in determining whether a plant species is introduced.

Economic consequences of invasive alien species

IAS have many negative impacts on human economic interests. Weeds reduce crop yields, increase control costs, and decrease water supply by degrading catchment areas and freshwater ecosystems. Alien plants unwittingly introduced into national parks by tourists degrade protected ecosystems and drive up management costs. Pests and pathogens of crops and trees destroy plants outright, or reduce yields and increase pest control costs. While considerable uncertainty remains about the total economic costs of invasions, estimates of the economic costs of particular invasive species to particular sectors indicate the seriousness of the problem. Some of these are summarized in Table 1. Many of these estimates remain controversial among economists.

Responding to the problems

This paper says relatively little about the actual management of IAS, leaving that important topic in the hands of other contributors to this volume. But generally speaking, GISP (2001) advocates four main management approaches: first, subject all alien species proposed for introduction to expert consideration, following the precautionary principle; second, improve the scientific basis for predicting which species

Table 1. Indicative costs of some alien invasive species (costs in US $)

Species	Economic variable	Economic impact	Reference(s)
A sample of alien species of plants and animals	Economic costs of damage in USA	$ 137 billion per year	Pimentel et al. (2000)
Salt Cedar (*Tamarix*)	Value of ecosystem services lost in western USA	$ 7–16 billion over 55 years	Zavaleta (2000)
Knapweed (*Centaurea* spp.) and leafy spurge (*Euphorbia escula*)	Impact on economy in three US states	$ 40.5 million per year direct costs $ 89 million indirect	Bangsund et al. (1999); Hirsch and Leitch (1996)
Most serious invasive alien plant species	Costs 1983–92 of herbicide control in Britain	$ 344 million/year for 12 species	Williamson (1998)
Six weed species	Costs in Australian agroecosystems	$ 105 million/year	CSIRO (1997) (cited in Watkinson et al., 2000)
Pinus, Hakea, Acacia, and lowland acacias	Costs on South African fynbos to restore pristine conditions	$ 2 billion	Turpie and Heydenrych (2000)
Water hyacinth (*Eichhornia crassipes*)	Costs in 7 African countries	$ 20–50 million/year	Joffe-Cook (1997), (cited in Kasulo, 2000)

proposed for deliberate introduction are likely to become invasive and which are likely to be beneficial; third, improve control of pathways for unplanned introductions (through international trade, wooden packing material, and so forth); and fourth, improve management techniques to eradicate or control invasive alien species once prevention has failed or become impractical.

Human societies seem to have a great capacity for contradiction, with quarantine inspections, for example, being the responsibility of the same governments that promote globalization that undermine government capacity to apply effective quarantine measures (Low, 2001). Governments have a responsibility to provide regulations in the public interest, but current economic orthodoxy argues that global trade is fostered through removing regulations that may constrain such trade, such as restrictions that may restrict the introduction of a potentially invasive alien species. These contradictions help to underline the conflict of interests between global trade and the control of IAS, and the challenges to current management measures and legal frameworks.

The human dimension is the most unpredictable variable in any management programme to control IAS. Reaser (2001) and Mack (2001) go into considerable detail about the psychological factors motivating people to import or use alien species that sometimes become invasive, and show how a more thorough understanding of these psychological factors can slow further invasions and promote the control of the existing ones. They demonstrate that IAS are a by-product of human values, decisions, and behaviours, suggesting that a focus on human beliefs and resultant behaviour might be more effective than focusing primarily on IAS themselves as the problem. Resource managers must therefore generate public support and understanding for any control programme before a project begins. Thus, "social embedding" of management actions, as through the "Working for Water Programme" in South Africa (Noemdoe, 2001), can foster effective management intervention.

Economic arguments have much to contribute to programmes to address the problems of IAS (Perrings et al., 2000). Decision-makers often find arguments couched in economic terms to be more convincing than those cast in emotive or ethical terms, and economics-based arguments of costs and benefits can be used to support stronger programmes to deal with invasive species.

But while it is important to identify costs and benefits of IAS, such determination does not automatically determine a decision because politically-charged value judgements and issues about distribution of benefits are nearly always involved. Further, the magnitude of the costs may sometimes be so high as to render an action politically unacceptable, even when the benefits are likely to be even greater; part of the problem is that the benefits may be widely spread throughout the public over a period of many years, while the costs of control may need to be paid rather quickly by taxpayers. It appears that conflicts of interest between various sectors of society regarding the costs and benefits of IAS are an inevitable fact of modern life. Such conflicts might

be mediated through a more thorough identification of the full costs of the IAS. However, the value of an alien species to any particular interest group may change over time, complicating the determination of costs and benefits.

Cultural factors also affect the perceptions different people have of the benefits and costs of IAS. Luken and Thieret (1996), for example, report that within less than a century after the deliberate introduction of Amur honeysuckle (*Lonicera maackii*) into North America to improve habitat for birds, serve ornamental functions in landscape plantings, and stabilize and reclaim soil, the shrub had become established in at least 24 states in the eastern USA. While many resource managers perceive the plant as an undesirable element, gardeners and horticulturists consider it useful. And St. John's Wort (*Hypericum perforatum*), which is a noxious weed with harmful effects on livestock in North America, is also gaining popularity in the natural pharmaceutical trade as an anti-depressant and is being grown legally as an agricultural crop in northwest USA (Reichard & White, 2001). Thus the "noxious invasive" of one cultural group is the "desirable addition" of other groups.

The perception that local people have of introduced species may be different from that of conservationists, affecting how they respond. For example, in recent years, the people living on Pitcairn Island – descendants of the *Bounty's* mutineers – have not considered *Lantana camara* as a major weed, as conservationists have done, but believe the shrub to be a soil improver. On the other hand, they view the tree *Syzygium jambos* as a major pest, not because of its impact on the native flora and fauna, but rather because of its heavy shading and its spreading, shallow and dense rooting system which renders cultivation of gardens an arduous task. Thus the weed status of a species relates to the way it interferes with day to day activities and will change through time as society develops (Binggeli, 2001).

Some methods of controlling IAS may carry health hazards as well. For example, pesticides can have serious effects on both people and ecosystems. Between 1975 and 1985, forests in Atlantic Canada were sprayed with the insecticide Matacil to control spruce budworm (*Choristoneura fumiferana*). In the late 1990s, fisheries and environmental scientists inferred that the declines in the Atlantic salmon (*Salmo salar*) stocks in the Restigouche River that occurred at that time were related to the exposures of the smolt to nonylphenol used as an inert solvent in the pesticide (Fairchild et al., 1999).

Once public enthusiasm to control IAS has been generated, it must be channelled in the right direction. For example, gorse (*Ulex europeus*) has become invasive in montane grasslands of Sri Lanka following its introduction about 150 years ago. Recently, several local NGOs have launched volunteer programmes to remove gorse. However, several species of endemic reptiles and amphibians have found gorse a congenial habitat, providing food and cover. When the eradication programmes removed this habitat virtually overnight, the endemic species were exposed to native opportunistic predators such as crows (Marambe et al., 2001). Therefore, programmes to eradicate invasive species of plant also need to consider restoring the ecological functions of the species that are removed.

Over 40 international conventions, agreements, and guidelines have been enacted for addressing the problem of IAS, at least in part, and many more are being prepared (Shine et al., 2000). For example, the International Plant Protection Convention, enacted in 1951 established an International Commission on Phytosanitary Measures, which is a highly relevant instrument for the issue of alien invasive species. The IPPC standards for ensuring plant health are based primarily on the economically important species, primarily in agriculture, but could also be relevant to plants in the horticultural trade. Governments more recently have expressed their concerns about the problem of IAS especially through the Convention on Biological Diversity (CBD), which calls on the Parties to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats, or species" (Article 8h). But the expanding impact of IAS on both global economies and the environment implies that these international instruments have been insufficient to prevent and combat IAS effectively, suggesting that additional measures, such as a protocol under the CBD, are advisable.

At the national level, those opposed to eradicating IAS on ethical grounds often are prepared to argue their case in court, where litigation can be effective. This challenge calls for a legal framework that clearly recognizes the need to eradicate IAS when they threaten the greater public good, and education for judges to ensure that they understand the issues before them. National and even local legislation also needs to recognize the kinds of human dimensions that are identified in this paper, including such elements as trade, ethical concerns, human health, cultural considerations, and even international obligations. Human dimensions are an essential element in trying to determine what existing regulatory, financial, and penal disincentives could

be adjusted to deter trade and transport activities that carry high risks, and to determine the specific levels of disincentives that will deter invasives (Jenkins, 2001).

Political support is clearly essential to implement coherent policies, laws, and regulations to address the problem of IAS. This depends in turn on support of the public, which ultimately depends on the quality of information that is provided on the issue and the effectiveness with which such information is transmitted. Advocates need to convince the general public that controlling an invasive species is worthwhile. For example, the programme in New Zealand to control brush-tailed possum (*Trichosurus vulpecula*) was called "Operation ForestSave" and the promotional information showed lovely flowering native trees, without a possum in sight (Low, 2001).

Some widely-held ethical values have unrecognized ramifications for IAS. For example, our world has become increasingly interconnected over both time and space, where individuals have come to expect great freedom of individual behaviour (Low, 2001). But their behaviour when introducing alien species has significant, though undefined, influences on many other people, most of whom are unknown to those who are affecting that behaviour. Ethics of obligations and responsibilities are not always easily understood against the backdrop of the ethic of "consumer freedom" to grow exotic plants that might escape captivity to become invasive.

Thus the invasive alien species issue can be seen as ultimately an ethical concern. If people are seeking to maximize their material welfare, or even the diversity of species with which they surround themselves, then bringing in alien species through international trade might well be a part of their rational response to the vagaries of life. But when alien species become invasive, destabilizing ecosystems and reducing diversity, then control is a far more acceptable, even necessary, response. Since invasions invariably involve trade-offs, the determination of costs and benefits of IAS becomes paramount (though this too has its ethical components).

Thus the concept of invasive alien species is not purely dependent upon objective ecological criteria, but also on human concepts used to identify origin, authenticity, and responsibility. As Hattingh (2001) advocates, we need an ethics of conceptual responsibility to become more aware of the dominant lines of argument we use in our debates about IAS, including the manner in which they function, their history, the mechanisms through which these views have been established as authoritative and through which they have become institutionalised, and their practical policy and political consequences.

Conclusions

For millennia, the natural barriers of oceans, mountains, rivers and deserts provided the isolation essential for unique species and ecosystems to evolve. In just a few hundred years these barriers have been rendered ineffective by major global forces that have combined to help alien species travel vast distances to new habitats and become invasive alien species. The globalization and growth in the volume of trade and tourism, coupled with the emphasis on free trade, provide more opportunities than ever before for species to be spread accidentally or deliberately. Customs and quarantine practices, developed in an earlier time to guard against human and economic diseases and pests, today are inadequate safeguards against species that threaten native biodiversity. Thus the inadvertent ending of millions of years of biological isolation has created major ongoing problems that affect developed and developing countries alike.

IAS are able to invade new habitats and constantly extend their distribution, thereby representing a threat to native species, human health, or other economic or social interests. One remarkable human dimension is the fact that a strong consensus can be built that many specific invasions are harmful, including water hyacinth, kudzu, various pathogens, and agricultural weeds. The issue of IAS, therefore, can bring together interest groups that might otherwise be in opposition, such as farmers and conservation groups. Bringing in the human dimensions can shift the focus from the IAS itself to the human actions that facilitate its spread or manage its control, and implies that focussing directly on the invasive species is likely to provide only symptomatic relief. A more fundamental solution requires addressing the ultimate human causes of the problem, often the economic motivations that drive or enable species introductions.

This paper has identified some of the human dimensions involved in IAS. It is apparent that these dimensions are interconnected, and are relevant in different degrees in different countries, or with different species of invasive plants. But the presence of so many human dimensions implies that approaches to management need to involve many sectors of modern society, including trade, tourism, industry, the military, public

health, and so forth. Addressing the problem will call for more collaboration between ecologists, botanists, geographers, land use planners, economists, sociologists, psychologists and horticulturists.

The complex relationship between globalization and invasion pathways is perhaps the most important human dimension of IAS, and should be occupying the minds of policy makers in the next few decades (Carlton and Ruiz, 2002). Globalization carries with it the rise of transnational corporations, international financing, and multi-media marketing that undermine the political power of most governments, weakening their ability to regulate economic behaviour in the public benefit (Hattingh, 2001). One important implication is that concern about IAS needs to be expressed in terms of the threats to the resource base of the global economic system, which translates into monetary figures. Thus many of those who are concerned about the problems of IAS have quite properly turned to economics to argue their case.

Humans, with all their diversity of quirks, strengths, and weaknesses, are at the heart of the problem of IAS and, paradoxically, also at the heart of the solution. Given the ultimate human motivations of survival, reproduction, and perhaps spiritual fulfilment, and the more immediate economic motivations, people might be encouraged to contribute to addressing the problem of IAS by such measures as:

- Helping the public to identify and embrace values that have a direct relationship to basic needs and are environmentally sound, thereby also achieving longer term benefits. This might include promoting the concept of "community", including native species, as a value that can balance the powerful economic values of globalized trade.
- Developing conservation practices and ethics that emphasise the importance of natural ecosystems, for example by refining distinctions between natural and anthropogenic conditions, devising ways to use ecosystems without losing biological diversity, and facilitating shifts in societal values toward more respect for nature.
- Identifying measures that work within existing value systems, but encourage people to support conservation measures (for example, through the use of economic incentives and disincentives).
- Ensuring that the costs of controlling IAS are "internalized", paid by those who are benefiting from intentional introduction and those responsible for unintentional introductions.
- Linking the concern about invasive alien species to the drive for development that motivates most people, and virtually all governments, today.
- Including human dimensions in the various conventions, agreements, and guidelines on IAS, such as those developed under the Convention on Biological Diversity and potentially under the World Trade Organization.
- Using risk assessment procedures, when introducing new species, that take into account future changes in usage and demonstrate that – to the best of current knowledge – detrimental impacts will be limited.

A fundamental constraint against changing the way people behave in regard to IAS is that too few people in any part of the world consciously perceive that they have been affected negatively by IAS, either directly or indirectly. While considerable technical information is now available for resource managers (Wittenberg and Cock, 2001), the supply of information on IAS to the general public, or even to horticulturalists, remains generally poor, so that 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. On the other hand, human perceptions are filtered by the media, the availability of information, and language, and all of these can be influenced to limit the spread of IAS.

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. While the flora of the world is reasonably well described, no world list of plants yet exists, and scientists simply are unable to predict which species are likely to become invasive or to assess the precise ecological, social or economic impact they are likely to have. With such incomplete knowledge, we risk unexpected consequences any time a new species of plant is introduced into an ecosystem. Unpredicted effects, such as the hole in the ozone layer, global warming, pesticide accumulation, the impacts of hormones in the environment, and so forth, can result from seemingly beneficial products and procedures. It therefore seems sensible to do everything we can to ensure that we err on the side of precaution, perhaps on occasion sacrificing some economic profit for the businesses directly involved while helping to ensure a healthier future for all of society. Thus we should also strongly support research to assess the risks of invasive alien species

carried by global trade and to find effective means of dealing with the risks.

This paper has sought to elucidate basic economic, social, ethical, and political elements about IAS, but it appears that each case needs to be considered on its own merits. That said, in addressing any IAS problem that involves global trade, the following measures need to be considered:

- Establish a permit system for new imports of living species enabling management agencies to keep track of what is being imported.
- Ensure that those who are most directly affected by the IAS are involved in decisions about how to manage the problem.
- Build sufficient public information programmes into each effort, investing more in this regard where the problem is likely to involve controversial techniques (such as use of herbicides).
- Build linkages between the management of IAS and development, through involving economic sectors such as health, agriculture (food security), and forestry.

We should do everything possible to prevent unwanted invasions, carry out careful assessments before intentionally introducing an alien plant species into a new environment, build a stronger awareness among the general public about the problems of IAS, mobilize conservation organizations to address the problems, and build an ethic of responsibility among those most directly involved in the problem. The global trading system brings many benefits, but it needs to be managed in a way that minimizes any deleterious impacts of invasive alien species on ecosystems, human health, and economic interests.

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