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Synthesis

Biological Invasion Risks and the Public Good: an Economic Perspective

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ABSTRACT. We postulate that the causes of the problem of invasive alien species are primarily economic and, as such, require economic solutions. Invasive alien species are of increasing concern for four reasons. First, introductions are increasing sharply, while mechanisms for excluding or eradicating alien species have been either withdrawn or progressively weakened. Both trends are due to the liberalization of and increase in international travel and trade, an economic phenomenon. Second, the costs of invasions are rising rapidly due partly to increasing human population density, and partly to increasing intensity of production in genetically impoverished agricultural systems. Third, biological invasions are associated with a high degree of uncertainty both because they involve novel interactions, and because invasion risks are endogenous. Actual risks depend on how people react to the possibility of invasions. Fourth, the exclusion and control of invasive species is a "weakest-link" public good. This places the well-being of society in the hands of the least effective provider. We argue that an economic solution to the problem of invasive species has two components. One is to use incentives to change human behavior so as to enhance protection against the introduction, establishment, and spread of invasive behavior. The other is to develop institutions that support the weakest members of global society, converting a "weakest-link" to a "best-shot" public good.

INTRODUCTION

Under the Convention on Biological Diversity (CBD), invasive alien species (IAS) are those that are introduced, establish, naturalize, and spread outside of their home range, and whose impacts involve significant harm. Accordingly, when most people think of the economics of invasive species they think of the damage or control costs of weeds, pests, and pathogens. But economics is much more than just a method for calculating costs. It is a framework for understanding the complex causal interactions between human behavior and natural processes, and for finding institutional and behavioral solutions to seemingly intractable environmental problems. Biological invasions threaten societies in sometimes critical ways; for example, the spread of HIV infection in southern Africa. Economics helps us identify the social causes of such problems, and hence develop institutions and instruments capable of solving them.

The control of invasive species is a public good of a very particular kind. Biological invasions almost always involve a number of countries. One country within the home range of a species is linked to others within the invaded range by pathways involving the movement of goods or people. The level of control exercised by one country accordingly has implications for the risks faced by others. The control of invasive species is an international, indeed frequently a global, public good. However, because it is a public good, if control is left to the uncoordinated efforts of individual countries, there will be insufficient control to protect the public interest. More importantly, for IAS such as infectious and communicable diseases, the level of protection available to all countries will be constrained by the resources available to the poorest countries. For example, the global control of tuberculosis is constrained by the resources committed to its prevention and cure in the poorest, most densely populated, and least well-coordinated countries. In such cases, IAS control is said to be a "weakest-link" public good. It requires a solution to the problem that differs significantly from the currently uncoordinated combination of black lists, white lists, quarantine, and ad hoc eradication programs.

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THE COSTS OF BIOLOGICAL INVASIONS

There are only two estimates of the total cost of invasive species at the national level, both relating to the United States. In 1993, the U. S. Office of Technology Assessment (OTA) estimated damage costs from 79 particularly harmful species over the preceding 85 years to be $97 billion. Seven years later, Pimentel et al. (2000) estimated the annual damage costs from a much wider set of invasive species to be $137 billion. The difference between these estimates reflects growth in concern over the problem as much as an improvement in the accuracy of the estimate. The Pimentel et al. estimate is still likely to understate the problem, if only because it deals only with a subset of the impacts of invasive species.

At the level of individual IAS there are a number of reasonably good, if selective, estimates of damage or control costs. Estimates exist, for instance, for annual control costs for the screw worm fly, *Chrysomya bezziana*, and a range of weeds in Australia (Anaman et al. 1994, Watkinson et al. 2000); the impacts of knapweed and leafy spurge on the economy of several American states (Bangsund et al. 1999), and the impacts of the green crab, *Carcinus maenas*, on the North Pacific Ocean fisheries (Cohen et al. 1995); damages to North American and European industrial plants from the zebra mussel, (Khalanski 1997); and losses in the Black Sea fishery due to the comb-jelly, *Mnemiopsis leidyi* (Knowler and Barbier 2000). There are also estimates of the benefits from clearing a number of alien species from Fynbos ecosystems in South Africa (Higgins et al. 1997).

The full economic costs of biological invasions include more than the direct damage or control costs of invasive species. They also include the effects of invasives on host ecosystems, and on the human populations dependent on them. That is, they reflect the nature of interspecific interactions, and the way that different species support economic activities. No estimates currently exist concerning the value of the more widespread effects of invasions. Invasive species are, for example, assumed in the CBD to be one of the main proximate causes of extinctions world wide (Glowka et al. 1994). They have also disrupted key ecological functions in many systems, with far-reaching implications for economic activities supported by those systems (Heywood 1995). Indeed, most ecosystem types (terrestrial, freshwater and marine, animal, plant, and microbial) have been impacted to a greater or lesser extent by invasions (Williamson 1998, Parker et al. 1999). But the economic implications of these indirect impacts have yet to be identified.

THE SOCIAL AND ECONOMIC CAUSES OF BIOLOGICAL INVASIONS

There has also been relatively little research into the social and economic causes of biological invasions outside a selected set of agricultural pests. Invasions are generally the intended or unintended consequence of decisions involving the use of exotic species in production and consumption, conversion and fragmentation of habitat, or movement of goods and people (Mack et al. 2000). Such decisions reflect social customs and norms, as well as the incentive effects of existing institutions, property rights, trade rules and regulations, relative prices, and wealth (Perrings et al. 2000).

In many cases, the spread of an invasive species reflects the fact that people's behavior does not change or at least does not change quickly in response to a change in the risks associated with that behavior. The spread of HIV and other communicable diseases are classic examples, but there are many others. The spread of the rusty crayfish and Eurasian millfoil in North America, or the water hyacinth in Africa, is almost entirely due to the use of bait buckets and boat movements by recreational and commercial fishermen. In all such cases, social or cultural norms of behavior are relatively insensitive to new risks. From an economic perspective, people ignore changes in the cost of their behavior. This may be because they do not themselves confront those costs, or because they discount them.

The important point here is that the probability of both establishment and spread of invasive species depends on human behavior. In particular, it depends on the way that people respond to the threat of invasive species. Most responses can be classified as either mitigation or adaptation. Mitigation includes eradication and action to prevent the spread of invasive species. Such a response has the effect of reducing the likelihood that a species will establish or spread. Adaptation, on the other hand, implies some change in behavior to reduce the impact of invasion. Changing the crop mix to reduce the severity of a pest invasion is an example of this. Such actions are designed to work on the value of the effect, rather than the likelihood of the effect. There are quite complex interactions between the decisions that people take, given their perceptions of the risks of invasions, and the nature of those risks. The introduction of specific disease- or pest-resistant crops, for example, selects in favor of other pests and predators in a way that is well understood (Heywood 1995). The risks of invasions are not independent of the relative net benefits of mitigation or adaptation (Shogren 2000, Shogren and Crocker 1999).

In the case of human diseases, the probability of infection influences human behavior in various ways. Human responses to the threat of disease reflect social norms and customs, as we have already remarked. They also reflect peoples' attitudes to risk—whether they are risk-averse or risk-avid (risk loving)—and the rate at which they discount the future effects of their behavior. In turn, their responses affect the epidemiology of the disease, at least within the constraints imposed by general social and economic conditions. The virulence of infectious and communicable diseases is not independent of the density of infected and susceptible populations, the pattern of settlement, and the level of development (Delfino and Simmons 2000).

At the macro level, the openness of a country's economy, the composition of its trade flows, its regulatory regimes, and the importance of agriculture, forestry, or tourism all make it more or less vulnerable to invasions by alien species. Island ecosystems, for example, are considered to be susceptible to invasions because of a particularly vulnerable native biodiversity. But island states are generally small, open economies, often geared to the production of primary products. In a sample of 26 countries considered in Dalmazzone (2000), the average percentage of merchandise imports as a share of the GDP is 43% for islands, against an average of 32% for the whole sample, and 27% for continental countries. These characteristics predispose island states to invasion.

Ecosystems vary in their natural susceptibility to invasion. Deserts, semi-deserts, tropical dry forests and woodlands, arctic systems, and pelagic marine systems appear to be least susceptible, while mixed island systems, and lake, river, and near-shore marine systems appear to be most susceptible (Heywood 1995). Similarly, systems with low natural diversity (especially if they are without existing predators or competitors) appear to be more susceptible than systems with high natural diversity (Rejmanek 1989). But susceptibility also depends on land use, on demographic, market, and institutional circumstances, and on the regulatory framework and control strategies adopted by different countries. Habitat fragmentation, habitat conversion, and agricultural disturbance have all been blamed for increasing susceptibility to invasion (Williamson 1996, 1999).

On the other side of the coin, invasion pathways and the frequency with which alien species are introduced into vulnerable ecosystems depend on patterns of trade and travel. The probability of establishment of intentionally introduced species is greater than that of unintentionally introduced species. One reason is that intentionally introduced species have been selected for their ability to survive in the environment where they are introduced (Smith et al. 1999, Lonsdale 1994). Another is the link between intentional and repeated introduction. Exotic species that are marketed over a period of time have a greater probability of establishment than those that are marketed once (Enserink 1999). Similarly, species that are repeatedly introduced as side effects of trade and travel (for example, species carried in ballast water or passengers' baggage) are more likely to establish than those introduced only once.

The risks of biological invasions depend on the use that people make of invasive species, on their predators and competitors, on demographic patterns, on transport networks, and on the structure and trade dependence of an economy. These, in turn, depend on relative prices and the incentive effects of government policies. The market prices of potentially invasive species seldom reflect the costs they may impose on society. That is, the harm inflicted by invasive species is typically external to the market. Nor is this helped by the fact that many markets have been prevented from operating efficiently by agricultural policies and institutions. Tax, price, and incomes policies have all increased the susceptibility of agroecosystems to invasion. Subsidies designed to promote the export of cash crops, for example, have reduced plant genetic diversity and encouraged the use of farm inputs (especially pesticide regimes) in a way that has made agroecosystems vulnerable to invasion. Moreover, property rights regimes have discouraged people from taking action to control invading species. Land in common property, for example, requires collective action, and open-access land militates against any significant action at all.

The net effect is that the risks of biological invasions are increasing. The current concern over the potential for species introductions to be used strategically as instruments of bio-terrorism or bio-warfare appears to be well founded. Growth in the volume and complexity of international trade, combined with the liberalization of regulatory regimes to encourage trade, has at once increased the frequency of introductions along existing pathways, the number of new pathways, and the ease with which potentially invasive species can move along those pathways. The deregulation of national and international markets has reduced both the barriers to trade and the surveillance of trade, thereby increasing the risks of invasions. At the same time, human behavior, social norms, and cultural traditions have adapted only slowly to the new risks, and this, in turn, has increased the impacts of invasions.

THE CONTROL OF INVASIVE SPECIES IS A "WEAKEST-LINK" PUBLIC GOOD

We have already made the point that there is a strong "public good" element in controlling the risks of biological invasions. A national quarantine policy to protect against invasive pathogens, for example, reduces the risk to all people in the country concerned. The benefits of quarantine are neither rival nor exclusive. If one person benefits from the protection offered by a quarantine policy, it does not affect the cost of quarantine. Nor does it reduce the benefits of quarantine to others. But because public goods are nonexclusive, any one person or any one country has a strong incentive to take a free ride on the efforts of others. If left to the market, the control of potentially invasive pests and pathogens would be undersupplied. There would be less control than is socially desirable. That is why quarantine against alien species is typically a public service, although the providers of quarantine facilities may be private.

More important still is the nature of the public good. We have argued that international control of many invasive species, such as infectious and communicable diseases, depends on the least effective provider, "*the weakest link in the chain*," (Sandler 1997). Much the same problem exists at the national level. In our quarantine example, the level of protection offered to the whole community against the effects of a species quarantined at a number of facilities depends on the least effective facility. If one quarantine facility does not contain an invasive pathogen, the fact that all others may do so is irrelevant. Similarly, control of an invasive plant involves containment (or eradication) by all landowners. It will only be as good as the containment (or eradication) activities of the least effective landowner.

The scale of the problem generally depends on the scale of the system potentially affected by invasions. In the case of the spread of *Acacia* and *Pinus* spp. in the Fynbos floral kingdom of South Africa, for example, the impacts may be contained within the Fynbos (Turpie and Heydenrych 2000). In contrast, HIV or livestock pathogens such as the foot-and-mouth virus, are clearly global problems. The commitment of resources to exclude, control, or mitigate in either case is highly sensitive to income. Poor people and poor countries may be as much alarmed by the risks posed by invasive pathogens as rich people and rich countries, but this will not necessarily be reflected in their commitment of resources to pathogen control. Indeed, the poor have consistently been shown to be willing to pay less to reduce environmental risks than the rich simply because their ability to pay is less (Smith 1997). This makes the fact that capacity is falling in many countries a matter for real concern. Falling barter and income terms of trade for many of the poorest countries have limited the resources available to screen for, monitor, eradicate, or control the effects of invasions, thus raising the risks to all (Perrings et al. 2000).

We emphasise that the problem posed by the weakest link is not that some providers will be less effective than other providers. This will always be the case. It is that the benefits to all are determined by the efforts of the weakest. In the case of invasive species, this is a particular problem for those species with the potential to spread rapidly from even a small inoculum. That is why infectious diseases are a weakest-link problem. Given that the control of diseases is only as good as the information on infection rates, we argue that the monitoring of diseases is as much a weakest-link problem as the control of diseases. Moreover, because many other invasive species share the same characteristics as infectious diseases, monitoring and controlling them can also be defined as weakest-link public goods.

WHAT IS TO BE DONE?

Our assessment of the economics of invasive species leads us to three striking conclusions.

First, the science of biological invasions should embrace the fact that invasions are a human problem, with human causes and consequences. Invasive species that inflict appreciable harm often (but not always) do so by affecting processes and functions in heavily impacted ecosystems. Agricultural practices that simplify ecosystems by focusing on a small number of crops or livestock, and by eliminating predators and competitors, generally make those systems more vulnerable to invasion or less resilient to invasion shocks. Understanding the problem requires understanding the interactions between social and natural processes. Further scientific progress requires a genuinely interdisciplinary approach to the problem, for which the newer fields of ecological and environmental economics currently provide a better model than traditional economics, ecology, or epidemiology.

The British foot-and-mouth disease (FMD) epidemic illustrates the point. The introduction of the virus occurred in the following context: rising volumes of trade in an increasingly deregulated and complex set of global meat and livestock markets; reduced border controls and surveillance of meat products; a harmonized European policy that has excluded preventive vaccination in the integrated European market since 1991; increasing pig and, especially, sheep densities in Britain (a response to incentives under the Common Agricultural Policy); an extremely active domestic livestock market that results in very frequent livestock movements between all parts of the country; and a reduced veterinary capability. Yet FMD and its control were modelled as a traditional epidemiological problem involving only the pathogen and its hosts. The human factors behind the establishment and spread of the disease in different locations around the country were ignored. The incentive effects of the compensation mechanisms, and their impact on the model parameters were not considered. This is unsatisfactory. The modelling of IAS should incorporate the human behavior that drives and structures their introduction, establishment, and spread.

Second, as a problem with its roots in human decisions and risk perception, IAS control requires not just the provision of information but also the development of incentives to the people whose behavior is the proximate cause of the problem. In the FMD example just cited, the control strategy produced some very perverse incentives that, in all probability, extended both the geographical extent and the duration of the epidemic. For example, compensation for slaughtered livestock was paid at above-market rates, while farmers whose livestock was not slaughtered, but who nevertheless lost access to their markets, were not compensated at all. In other cases, the private costs and benefits of actions encourage people to take decisions that increase the vulnerability of ecosystems to invasions. What is needed is an appropriate set of property rights in natural resources along with their supporting institutions, a compensation mechanism, and a structure of incentives and disincentives to induce behavior that is in the public interest. The public interest will vary from one case to another. In some cases, the public interest will lie in reducing the vulnerability of systems to invasion, i.e., in increasing their resilience with respect to species introductions. In other cases, it will be served by discouraging introductions, or by preventing the spread of already established species.

The most effective incentives are those that confront the people who cause the problem with full cost of their behavior. For example, importers of potentially invasive species might be required to take out insurance against IAS risks or to post environmental bonds when commercial insurance is unavailable. Similarly, landowners might be made financially or criminally liable for containing IAS on their properties, giving neighboring property owners the right to sue if their land is affected. In South Africa, such rights currently exist for the effects of bush fires, and there is interest in extending these rights to include IAS (Preston, *personal communication*).

Third, the fact that the control of many biological invasions is a weakest-link international public good, suggests the need for a coordinated international response to the problem. In the case of communicable human diseases, the monitoring dimension of the weakest-link problem is addressed by the Center for Disease Control (CDC). The CDC is a U. S. agency, but it monitors and reports diseases globally. It does not face the resource constraints that limit the effectiveness of health authorities in the poorest countries. The information obtained benefits the United States, but simultaneously benefits the poorest countries as well.

Given the inter-relatedness of IAS of different taxa, international trade and travel, and demographic and institutional factors, we propose that there should be an international organization with responsibility for invasive species generally. This organization should develop and maintain a database that includes the species-specific data provided by monitoring bodies such as the CDC and the World Organisation for Animal Health (Office international des épizooites), together with data on trade and transport flows, and demographic, economic, and institutional conditions. Aside from monitoring trends and providing risk assessments and recommendations for action, the organization should be able to coordinate responses to invasive species threats, particularly in poorer countries. Pending the formation of a World Environment Organization commanding sufficient resources to fill this role, there seems to be little alternative to the sponsors of the Global Environmental Forum (GEF), the United Nations Environmental Programme (UNEP), the United Nations Development Programme (UNDP), and the World Bank. Because the global benefits are directly related to the incremental costs of biodiversity protection authorized by the CBD and implemented by the GEF, it would be a logical and consistent development of the role of that institution. The GEF should be urged to consider the establishment of a resource with the capability to protect both global and regional interests from the threat of biological invasions by strengthening the weakest links in the chain.

Responses to this article can be read online at:
http://www.consecol.org/vol6/iss1/art1/responses/index.html.

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