International Policy Options for Reducing the Environmental Impacts of Invasive Species

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International Policy Options for Reducing the Environmental Impacts of Invasive Species

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Preventing the spread of nonnative invasive species is an international public good. Some categories of invasive species—such as diseases of humans and livestock—are addressed by international agreements that coordinate efforts to reduce their spread. In contrast, invasive species that primarily cause environmental impacts are managed almost exclusively at the national level. Control of environmental invaders is internationally undersupplied because the efforts of nations that do invest to prevent their spread are undercut by nations that do not. Addressing this problem will require international cooperation. We identify the international approach to controlling human diseases as a model that could provide institutions and mechanisms to map the spread of environmental invaders and assess the risks they impose. This would allow individual nations to manage potential vectors of invasion. Because such a system is unlikely to be implemented in the near future, we make recommendations for intermediate steps, including the widespread adoption of existing risk assessments and importation standards.

Keywords: Convention on Biological Diversity, sanitary and phytosanitary agreement, World Health Organization, World Trade Organization, invasive species

International trade increases human welfare but also leads to the introduction and establishment of nonnative invasive species, such as human and livestock diseases, pests and diseases of crops, and species that cause environmental harm. The increasingly global nature of trade means that efforts to prevent the spread of invasive species should be internationally coordinated. To this end, there are already relatively advanced international programs in place for identifying and managing the spread of human diseases, and the 178 member nations of the World Organisation for Animal Health (OIE) have agreed to report outbreaks of animal diseases, mostly diseases of livestock, to a central database. These programs allow nations to track invasive species threats and to use the shared information to impose import restrictions. Species known to be diseases and pests of crops are often the focus of quarantine inspections at national borders, but this varies by country and there is little international coordination. In contrast, nonnative invasive species that do not directly affect human health or agriculture are generally perceived to primarily pose risks of environmental harm. Few international agreements exist to control the spread of these species, and at an international scale, they are traded with much less inspection and fewer efforts to prevent their spread. This essay addresses the potential for wiser management of these species, which we refer to as *environmental invaders*.

Despite the lack of international efforts to prevent their spread, environmental invaders have enormous environmental, economic, cultural, and human-health impacts (Pejchar and Mooney 2008, Sala et al. 2000). These include reductions in the populations of desirable native species as a result of predation, competition, parasitism, and disease. An example of this is the invasion of European waterways by North American crayfish, which both compete directly with native crayfish for resources and carry the crayfish plague disease (*Aphanomyces astaci*) that has devastated European crayfish populations (Gherardi and Holdich 1999). Economic impacts can arise in a variety of ways, including the costs of herbicides and pesticides to control nonnative invaders in national parks and the costs of cleaning industrial facilities that become infested with invaders (e.g., zebra mussel [*Dreissena polymorpha*] infestations of power plants in the Laurentian Great Lakes require the facilities to close down while workers clean pipes; Leung et al. 2002). Cultural and human-health impacts can also arise in many ways, but a good example comes from cases in which invasive species become so prolific that farmers abandon agricultural land, leading to the loss of traditional farmland and agricultural practices and potentially to human-health impacts from reduced food supplies. This has occurred in Mexico, where it is no longer feasible in some areas to control the invasive bracken fern (*Pteridium aquilinum*; Schneider and Geoghegan 2006).

The introduction of environmental invaders is an externality of trade (Perrings et al. 2002, 2005). That is, the impacts of these species are not incorporated into the costs

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of doing trade, and those who trade the species have no economic incentive to reduce the invasion risks inherent in their business. For example, the global horticultural trade is responsible for many thousands of invasions of harmful plants and plant diseases around the world (Reichard and White 2001, Dehnen-Schmutz et al. 2007). However, the environmental costs imposed by this trade are not borne by either exporters or importers. Instead, these costs are spread widely among society as government agencies spend taxpayer dollars on inspection, interception, eradication, containment, and compensation.

Two factors have hampered efforts to slow the international spread of environmental invaders. First, although nations generally act defensively to control invasive species, the benefits arising from that control are almost always shared broadly among those at risk of being invaded, not just among those who pay for the control (Perrings et al. 2002). For example, if a country spends resources to ensure a disease-free horticultural industry, all nations to which it exports benefit from a reduced likelihood that they will be invaded. In the absence of cooperation, however, individual countries will protect their own borders but are less likely to commit resources to preventing the export of invaders. Because the invasion risk to which a country is exposed depends on the actions of its neighbors and trading partners, this means that countries face higher risks than they would if there were greater cooperation. Second, controlling the spread of an invasive species is a "weakest-link" public good (Perrings et al. 2002). Although the risks posed by any nation will depend on a complex set of climatic, biogeophysical, and social factors, including the type of trade they engage in and its volume, the overall global risk will be strongly determined by the nations or trades that operate the least-effective programs to control species transport. Because removal of an invasive pest from trade requires all those involved to contribute, and because little is gained by providing more than the country making the smallest contribution, there is an incentive to adopt a matching strategy—to converge on the weakest link. This is because unilateral action cannot prevent the pest from continuously spreading through trade (Touza and Perrings 2011).

Nevertheless, even though enhancing cooperative efforts should be the ultimate goal of a collective strategy to manage the problem of environmental invasions, there is much that can be done independently. In this article, we identify alternative strategies at the national and international levels for reducing the spread of environmental invaders with or without cooperation. We begin by reviewing existing unilateral defensive efforts to reduce exposure and by identifying programs that have been successful and could be implemented more widely without the need for additional international policy. We then consider the options for effective coordinated international management, building on existing commitments by countries under the Convention on Biological Diversity (CBD) and on the international success achieved in managing human diseases. Finally, we discuss the options for achieving at least some of the gains that could be had from coordinated action without the need for renegotiation of any multilateral agreement. Figure 1 summarizes our recommendations.

a) Species in native range

1) Assess risks posed by species, and where (globally) it would have impacts
2) Determine which vectors could transport species
3) Publicize risks, especially to trading partners in regions where species could become invasive
4) Manage high-risk vectors to limit the potential for species transport
5) Modify trades or trade practices as necessary to reduce risks of species spread

b) Species in vector

1) Monitor vectors for high-risk species (e.g., quarantine inspections)
2) Manage vectors to reduce chance of species transport (e.g., ballast water exchange)
3) Survey likely sites of introduction (e.g., high-traffic ports) for species

c) Species introduced or established beyond their native range

1) Eradicate populations where it is feasible
2) Limit the spread of invasive species
3) Notify international community of species range expansion
4) Reassess the risk of a species, inform the international community of any results, and modify trade practices as is necessary in order to reduce the risk of further spread
5) Repeat the previous steps as necessary if the species continues to spread

Figure 1. Potential intervention points in the international transport of environmental invaders. The lettered panels show a modified version of the invasion sequence. The numbered lists show actions that could be followed by the international community to reduce the chance for species spread. Not all countries will have the capacity to follow all of the steps in the lettered panels. In these cases, the international public good would best be served through technical, institutional, and financial assistance from developed to less-developed nations. See the text for more detail.

National efforts to manage the spread of environmental invaders

Under the World Trade Organization (WTO) and its constituent agreements, particularly the General Agreement on Tariffs and Trade (GATT) and the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS), individual countries have the right to take actions in restraint of trade if those actions are needed in order to protect food safety and animal or plant health. In contrast to those that deal with human diseases, these agreements authorize only national defensive measures. That is, individual nations have direct responsibility for managing risks to themselves posed by the many vectors of nonnative species introduction (table 1) but are not permitted under the GATT and the SPS agreement to cooperate in the collective control of pest or pathogen transmission through trade restrictions. The standard-setting bodies for the SPS agreement—the International Plant Protection Convention (IPPC), the OIE, and Codex Alimentarius—do cooperate in setting sanitary and phytosanitary standards and reporting requirements for member countries. This has led to the harmonization of rules on classes of traded commodities involving known risks. The OIE has also coordinated veterinary campaigns against particular pathogens within member countries and has achieved success in the eradication of rinderpest, one of the most damaging of all animal pathogens (Normile 2008). But only in the case of novel human diseases does there exist an agreement to take collective action in restraint of trade as a precautionary measure.

Table 1. A selection of transport vectors and subvectors that move environmental invaders outside their native ranges.

Vector	Subvector
Trade in ornamental plants	Intentional transport of desirable plants
	Unintentional transport of plant diseases, parasites, or seeds in soil
Pet trade	Intentional transport of animals
	Unintentional transport of diseases, parasites, or whole organisms
Live food	Intentional transport of live food organisms
	Unintentional introduction of diseases
Intentional release for hunting or food	Fishes (e.g., trout) and mammals (e.g., rabbits) released to provide new opportunities for angling and hunting
International aid programs	Intentional transport of organisms to establish new farming opportunities
Biological control	Intentional release of organisms to control pest species
Shipping (all unintentional)	Organisms in ballast tanks
	Insects living in wood of packing crates
	Fouling organisms attached to ship hulls
Air travel (unintentional)	Organisms entrained outside planes (wheel wells, engines)
	Plant seeds transported in mud on shoes
Canals (unintentional)	Species spread through canals to reach new watersheds

Environmental invaders can be transported to a country through intentional or unintentional vectors. Regardless of the vector, it is widely accepted that the most cost-effective way to reduce total impacts from nonnative invasive species is to prevent their arrival and establishment (see figure 1a, 1b; IUCN 2000, Leung et al. 2002, Lodge et al. 2006, Keller et al. 2007, 2009). That is, preventing the arrival of an invasive species will generally lead to less harm than addressing the species after it enters a country. Nations can choose from a range of options to prevent a species' arrival, including restrictions on trade in species of concern, requirements on exporters to ensure that invaders do not leave their shores or do not survive transit, and the operations of quarantine and inspection facilities at the point of entry (Lodge et al. 2006).

Importantly, policies focused on prevention have more opportunities to shift the burden of responsibility to the industries that profit from risky trade in live organisms (Perrings et al. 2005). As an example of a prevention program, most plant shipments to the United States must be accompanied by a phytosanitary certificate to show that they were produced at a facility following high standards for the control of plant diseases and parasites. This system puts the costs of obtaining certificates and those of producing relatively safe plants onto exporters. In contrast, established plant pest species can generally be controlled only through expensive techniques such as manually pulling plants or the use of herbicides and pesticides. Because it is almost never possible to determine the party responsible for an invasion, these costs have never (to the best of our knowledge) been passed on to importers or consumers who benefited from imports.

Intentionally introduced species, including pets, crops, and garden plants (table 1), provide many economic and social benefits. They also often become environmental invaders or act as vectors for environmental invaders (Jeschke and Strayer 2005). Efforts to reduce imports of environmental invaders generally consist of individual-species risk assessments so that resources can be focused on those species posing the highest risk. Because the proportion of traded species that become invasive is generally low (Smith et al. 1999), this approach leaves most species—those with low risk of invasion—unaffected. The approach has been shown to yield financial benefits for importing countries (Keller et al. 2007), whereas fewer invasions confers environmental, social, and agricultural benefits. The most prominent risk-assessment procedure currently available is the Australian Weed Risk Assessment (WRA; Pheloung 1995). Australian government scientists developed this tool in the early 1990s, and in 1997, it was introduced as a mandatory screening tool for all new plant species proposed for introduction to Australia. Species assessed as posing a high risk are not allowed to be imported. The WRA has been demonstrated to have good accuracy in Australia, New Zealand, Florida, Hawaii, and the Czech Republic (Gordon et al. 2008). It has been adopted in a modified form by New Zealand.

In contrast to intentional introductions, species transported unintentionally have some probability of becoming invasive but are not expected to provide benefits. This means that efforts to prevent their arrival can aim to simply remove all organisms from transport. Although this is conceptually simple, the number and magnitude of unintentional vectors makes preventing introductions an enormous challenge. For example, the global maritime fleet includes more than 99,000 large vessels and moves most international trade (IMO 2009). Each arriving ship presents risks of introducing new nonnative species entrained in its ballast water, attached to its hull, and in the cargo it offloads (table 1; Keller et al. 2011). It is unlikely that any nation could commit sufficient resources to ensure that all arriving ships are free of invasive species.

Each vector of unintentional species transport requires a different management approach. This approach needs to be based on the trade moving the species, the mode of transport, and the available technology. For example, the approaches necessary to limit the movement of fouling organisms of recreational boats are very different from those required to prevent the spread of invasive mollusks on water-garden plants or of forest pests in wooden packaging material. One relatively successful approach to limiting the spread of unintentional invaders is the US phytosanitary certificate system mentioned previously. This program aims to prevent the arrival of diseases, parasites, and plants that unintentionally accompany a traded species. It does this by requiring certain standards of plant and soil hygiene at facilities that grow plants for export to the United States. It is consistent with the United States' obligations as a signatory to the WTO's SPS agreement (Hedley 2004).

Although the number of risk-assessment tools and vector-management strategies continues to increase, they still provide protection against only a small proportion of the vectors that introduce invasive species. We offer two suggestions for improving this situation within the current international policy framework. First, some existing risk-assessment tools have been shown to perform well in a range of countries (e.g., Gordon et al. 2008), and other nations could adopt those tools. This was done by New Zealand when it adopted a modified version of the Australian WRA. In many cases, it may be possible for nations to relatively cheaply adopt tools developed elsewhere. Second, established national standards for treating vectors of unintentional introduction could be adopted by other countries. For example, the US Phytosanitary Certificate program could probably be adopted by other importing countries because many export facilities are already set up to achieve its standards. Further developing and applying these tools and standards would serve a double purpose by directly protecting those countries that adopt the procedures and by providing indirect protection to other nations that would subsequently be less likely to receive invaders from their trading partners.

Although there are potential advances to be made in national defensive policies, these can never provide the level of protection that would arise from increased international cooperation (see figure 1c). Most vectors could be more efficiently rendered free of invasive species in their country of origin. This would, for example, reduce the demand on quarantine facilities at ports of entry. Such coordination is currently unlikely for at least three reasons. First and foremost, there are no international agreements or bodies that are mandated to implement such a coordinated approach. Second, the "free-rider" issue means that the financially rational approach for many countries is to take the benefits from trading with countries that implement higher standards but not to pay the costs to implement those standards in their own operations. Finally, many countries lack the resources, institutions, or political will to implement such policies. Without programs to transfer resources and expertise to these countries, they will remain weak links and will continue to pose a risk to all other nations.

International policy and management for invasive species

Environmental invaders are an externality of global trade, the rules of which are largely governed by the WTO and the increasing number of regional trade agreements (RTAs). A major goal of each of these agreements is to eliminate barriers to free trade, but as countries become more open to imports, they also increase the risk of arrival of new invasive species (Dalmazzone 2000, Vilà and Pujadas 2001, Ricciardi 2006). Nations can mitigate this risk by inspecting and intercepting products or vectors deemed likely to introduce new invasive species. This can lead to trade disputes, however, because any action imposing explicit or implicit tariffs on imports can be seen as a form of protectionism and may therefore be in violation of the terms of the GATT, the legal instrument of the WTO. Under WTO rules, a country is only allowed to restrict the import of products in order to prevent the introduction of a potentially harmful species if it can provide scientific evidence that the restrictions are justified (Perrings et al. 2010a). The sheer number of environmental invaders and their vectors (see table 1) and the costs of scientifically justifying each restriction mean that this provision is not used very often. The scientific justification requirement is also a barrier to low-income nations lacking strong scientific resources and institutions (UNEP 1999).

Despite the lack of restrictions on global trade to limit the risks from environmental invaders, there is clear justification for this approach in the CBD, which gives its 193 party nations "the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction" (Article 18). This statement implies that these nations are committed to take actions that limit the export of invasive species. Parties to the CBD are also committed to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" (Article 8(h); see the CBD Web site at *www.cbd.int/invasive* for further details, including additional guidance documents for achieving CBD goals).

Pursuing the two CBD principles described above in combination would serve the international public good by removing species from vectors of transport at the source and by limiting the population size of environmental invaders so that the risk of international spread across land and aquatic borders is reduced. Despite this, most nations work to control only a subset of their established environmental invaders, and only a few countries have advanced programs to prevent invaders' arrival (e.g., the Australian WRA). The CBD commitment to prevent the export of environmental invaders has generally been ignored. This means that all nations must continue to rely on defensive measures, which, as was described above, are an inefficient way to reduce the impacts from environmental invaders.

Two promising exceptions to this lack of international agreement are the International Standards For Phytosanitary Measures no. 15 (ISPM 15; FAO 2009) standard for treatment of wood and wood packaging and the International Maritime Organization's (IMO) International Convention for the Control and Management of Ships' Ballast Water and Sediments. The former was developed in response to the large number of forest pests that have been inadvertently spread in untreated wood (FAO 2009) and requires signatory nations to treat wood packaging material (e.g., wooden pallets) prior to their export to lower the probability that it contains pests. The IMO's agreement, completed in 2004, sets standards for allowable densities of live organisms in the ballast water discharged from ships. Although this agreement has the potential to greatly reduce the spread of environmental invaders, it is not yet in effect because too few countries have ratified it. Although we believe that each of these agreements represent steps in the right direction, we note that neither requires nations to report invasions to their trading partners, nor do they require efforts to control invasions when they occur. Because the ISPM 15 standard is less than a decade old and because the IMO agreement has not yet come into effect, there are not yet data available to assess the extent to which they decrease invasive species transport.

Strengthening the international capacity to prevent environmental invaders

Improved international programs to prevent the spread of environmental invaders could be based on the relative success achieved at controlling the spread of invasive human diseases. The 2005 International Health Regulations (IHR) administered by the World Health Organization (WHO) mandate cooperative international action to address the human-health risks posed by trade- and travel-related disease introductions. A central tenet of the IHR, embodied in Articles 6 and 7, is that member countries are required to notify the WHO of any event that may have implications for international health. More particularly, Article 9 requires notification of any international public health risk due to the movement of people, disease vectors, or contaminated goods (WHO 2008). The WHO is then mandated to take precautionary action on behalf of the international community to mitigate the risks posed by the disease (Perrings et al. 2010b).

The potential for this approach to limit harm from invasive species is well demonstrated by the SARS (severe acute respiratory syndrome) epidemic of 2002–2003. The first international spread of the disease occurred soon after 21 February 2002, when 12 guests at a Hong Kong hotel became infected. These people traveled to Singapore, Vietnam, Canada, the United States, and Ireland, causing outbreaks in all of these places except Ireland. This spread occurred just months after the disease is presumed to have made the jump from animals to humans and before the infectious agent had been identified (Mahmoud and Lemon 2004). Although the disease ultimately spread to a large number of countries, it was rapidly identified, and the WHO coordinated an effective international response. Fewer than 10,000 people became infected before the disease was contained (Mahmoud and Lemon 2004).

Similar systems, established for the international management of environmental invaders, would be justified by the enormous costs that these species currently cause. On one hand, like infectious human diseases, many diseases of plants and animals are undesirable across their whole range and warrant a similarly coordinated approach. On the other hand, many environmental invaders that are pest species when introduced elsewhere are desirable in their native ranges. Management strategies for such species should obviously not include local eradication but should include measures to prevent their export. In the following paragraphs, we make four recommendations for how this could be achieved (see also figure 1):

First, harmonization of the IHR and the SPS agreement should incorporate standards for reporting outbreaks of animal and plant pathogens into the SPS agreement and a requirement to take collective action to deal with those outbreaks in the same way that parties to the IHR are required to report human disease outbreaks and to take collective action to control the movement of infectious agents (Perrings et al. 2010c). This is necessary if the international community is to take collective action on the control of trade-dispersed pests and pathogens (i.e., to internalize the externalities of global trade). Given the very tight relation between human and animal pathogens (most emerging infectious diseases are *zoonoses*, animal diseases that cross over into the human population; Daszak et al. 2000), there is an additional advantage in harmonizing the two agreements from a human-health perspective. This option does involve renegotiation of an international instrument of the WTO, however, and is only a potential solution in the longer term. In the shorter term, there may be some scope for using the provisions of the standard setting bodies—the

IPPC, the OIE, and Codex Alimentarius—and especially the determination of equivalence of measures to strengthen sanitary and phytosanitary measures for a range of known pests and pathogens. These bodies are bound by the same sovereignty restrictions that inhibit international coordination of control efforts under the SPS agreement but offer an alternative way to strengthen protection against specific bilateral trade risks.

Second, if countries are to use the options currently open to them under the SPS agreement, they need to know where potentially invasive species are established, they need to know the risks posed by those species, and they need to know the extent to which they are exposed to those risks through trade and travel networks. A global monitoring and evaluation system could ensure that the provisions of the Agreement were used in a systematic way. This would essentially be a global repository of information about where invaders are established, combined with risk assessments for the threat they pose to different global regions. The reporting requirements of the IPPC and the OIE provide valuable data on outbreaks of plant and animal pests and diseases. In addition, several databases already collect data about the range, ecology, and risks of invasive species, but they are all either limited geographically or they do not provide explicit risk analyses (e.g., Delivering Alien Invasive Species Inventories for Europe, Global Invasive Species Database). The information from these databases, however, could support efforts by existing institutions that do have international monitoring functions. Three are potentially relevant: (1) the Group on Earth Observations and its Biodiversity Observation Network (Scholes et al. 2008), (2) the longer-established Global Ocean Observing System (Glenn et al. 2000), and (3) the recently authorized Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Larigauderie and Mooney 2010, Perrings et al. 2011). Although it is not currently within their mandate, one or more of these institutions could take the role of monitoring the range of invasive species and assessing the risks they pose in different regions of the world. This would support trade-related actions under the SPS agreement aimed at limiting the further spread of high-risk species.

Third, there are over 400 RTAs either already in force or of whose existence the WTO has been notified. Because many RTAs cover contiguous or neighboring countries that are bioclimatically similar and because they are designed to encourage the free flow of goods and services among member states, they can also accelerate the movement of potentially harmful species between member states (Perrings 2007). Many have environmental committees. Although a number of these committees are ineffective, there are at least some with the capacity to identify and address the costs imposed by the trade-related dispersal of pests and pathogens within the regional trade area. A number of RTAs also have committees to implement the SPS provisions of the agreements. In some cases, these provisions link obligations for harmonization and equivalence, and in others, they support mutual recognition agreements under which the assessments by exporters are automatically accepted by importers. It is the role of environmental committees to identify actions to mitigate the associated risks. Guidelines on this function, supported by information on emerging international threats, and enhanced coordination between environmental and SPS committees, would enable the RTA environmental committees to be more effective.

Fourth, although the world trade network is very tightly linked, there are nodes that are of particular importance for the redistribution of species. For example, Amsterdam has historically been especially important in the distribution of horticultural species, and this trade is widely recognized as a principal source of many of the pests and pathogens that have been most damaging both to the commercial production of foods, fuels, and fibers and to plant communities outside of agroecosystems. Other cities play a similar role for the trade in live animals or birds. There are also common transit points for shipping traffic—the Panama and Suez Canals, for instance—that provide inspection opportunities. Globally funded inspection efforts at such nodes would provide significant international benefits and would support an early-warning system on emerging threats. These inspection efforts could be guided by risk assessments such as those described elsewhere in this article and especially in the discussion of RTAs above.

Conclusions

The international capacity to prevent the movement and impacts of nonnative invasive species has fallen far behind the ability of trade and travel to move organisms. Previously separate ecosystems are now connected through trade and travel routes, and nonnative species are being introduced and becoming established at increasing rates. One subset of these species—environmental invaders—have been largely ignored by international treaties but are recognized as a serious global economic burden and as a strong driver of biodiversity loss, and they are known to pose an increasing threat to humans through the emergence and spread of zoonotic diseases. Reducing the impacts of these species will require agreements that allow for internationally coordinated action. The current approach to human diseases, through the IHR and WHO, provides a model for environmental invaders management. Most importantly, bringing the SPS agreement into conformity with the IHR would give nations information about the location and threats of invaders and a mechanism for a coordinated response to restrict their spread.

Because the strengthening of the SPS agreement would need to be negotiated internationally, it is not realistic to expect that it will happen in the near future. Other measures can be pursued in the meantime. First, within the current framework of national defensive measures, there is the potential for greater adoption of national policies and practices that have been developed and have proven successful.

This includes risk-assessment tools (e.g., Australian WRA) and import standards. Second, within current efforts to develop global observation systems, there is scope for the coordinated monitoring of trade-related movements of environmental invaders. Third, within the environmental committees of many RTAs, there is scope for communicating the risks associated with environmental invasive species. Although these approaches will not achieve the benefits that could arise from true international coordination, they would provide additional protection from environmental invaders and would reduce the overall impacts from this category of invasive species.

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