Closing the Screen Door to New Invasions

Reuben P. Keller[1] & Michael R. Springborn[2]

[1] Institute of Environmental Sustainability, Loyola University Chicago, 1032 W. Sheridan Rd., Chicago, IL 60660, USA
[2] Department of Environmental Science and Policy, University of California, 2104 Wickson Hall, One Shields Ave. Davis, CA 95616, USA

Keywords
Bioeconomics; international trade; invasive species; policy; risk assessment.

Correspondence
Reuben P. Keller, Institute of Environmental Sustainability, Loyola University Chicago, 1032 W. Sheridan Rd., Chicago, IL 60660, USA.
Tel: (+1)773-508-2952; fax: (+1)773-508-2983.
E-mail: rkeller1@luc.edu

Received
31 May 2013
Accepted
25 September 2013

Both authors contributed equally

Editor
Javier Simonetti

doi: 10.1111/conl.12071

Abstract

International trade in nonnative species generates economic benefits but also introduces many harmful invasive species. Recent advances in nonnative species screening tools enable useful predictions of invasiveness which can be combined with estimates of impacts to effectively manage the trade-off between the benefits and costs of this trade. Despite this, most countries maintain an essentially "open door" policy where almost all nonnative species are allowed for introduction until they prove problematic. This approach implicitly favors minimizing one particular type of assessment error—mistakenly excluding safe species, or "false positives." However, a comprehensive approach to management of species trade should involve balancing the trade-off between false positives and "false negatives" (mistakenly accepting invasive species). Barriers to implementing risk assessment tools include the perception that because assessment tools are imperfect they are not suitable for decision-making. However, recent economic research shows that, relative to an open door approach, "shutting the screen door" with imperfect but informative screening tools, to allow flow of only those species of acceptable invasion risk, increases the net benefits of trade. Given that these tools are relatively straightforward to apply, we argue that policy-makers should no longer allow the perfect to be the enemy of the good.

Introduction

The importation of nonnative species generates both tangible benefits and substantial economic and environmental damage. The ornamental plant and pet industries, for example, move tens of thousands of species around the globe, creating benefits for exporters, importers, retailers, and consumers who value the novel species. However, some of these imported species either become invasive or serve as vectors for parasites or pathogens. The Burmese python (*Python molurus*), for example, was imported and sold at pet stores in the U.S. over a period of decades. It is now established as a top predator in Florida (Figure 1a), where it has been linked to declines of over 90% in some native mammal populations (Dorcas *et al.* 2012). The signal crayfish (*Pacifastacus leniusculus*; Figure 1b) was intentionally imported across Europe during the 1970s for aquarium and aquaculture trades, but has now escaped and threatens native crayfish through the concurrent introduction of crayfish plague, a disease to which the North American signal crayfish is resistant, and direct competition for resources (Hentonnen & Huner 1999). As a final example, the aquatic plant water hyacinth (*Eichornia crassipes*; Figure 1c) has been traded widely as an ornamental plant. Although it is recognized as a devastating invader in many ecosystems it continues to be widely available, and new invasions are regularly recorded (Adebayo *et al.* 2011). Thus, despite the benefits to trade from these and many other live imports, there is little doubt that for a subset of species the costs far outweigh any benefits. This makes it wise to reconsider the trades that intentionally import live nonnative organisms.

Despite the well-known risks from intentional species import, in much of the world policies to address the introduction of nonnative species allow importation of the vast majority of species and accept too much risk relative to the reward (Lodge *et al.* 2006). The U.S. provides a good example. The Lacey Act and the Plant Protection Act are,

Figure 1 Three invaders that entered through an open door (Policy). (a) Burmese python (*Python molurus*), (b) signal crayfish (*Pacifastacus leniusculus*), and (c) Water hyacinth (*Eichornia crassipes*) are three examples of nonnative species that have been intentionally introduced through trade, become established, and caused severe environmental and economic harm. See main text for more details.

respectively, the main federal legislative tools for managing the importation of potentially invasive plants and animals. Each has been brought to bear on just a small fraction of species that pose an invasion risk, and often only after these species were already established (Lodge *et al.* 2006; Fowler *et al.* 2007). For example, Burmese python (*Python molurus*) has been established and spreading in Florida for at least a decade, but was only banned from import under the Lacey Act in early 2012. This approach to the importation of nonnative species, practiced in the United States and most other countries, is effectively an "open door" policy where almost all species are allowed for introduction until they prove problematic. In this article, we describe methods for screening invasive species prior to their introduction that can be used to support policies for preventing future invaders. We then discuss recent economic work that enables risk assessors to develop and apply these screening tools in an economically rigorous way so that maximum benefits are created. We finish by detailing some of the challenges that policymakers face in applying these new screening methods.

Risk Assessment for Imported Organisms

The problems from intentionally introduced species becoming invasive could theoretically be solved if it was possible to perfectly identify invaders and

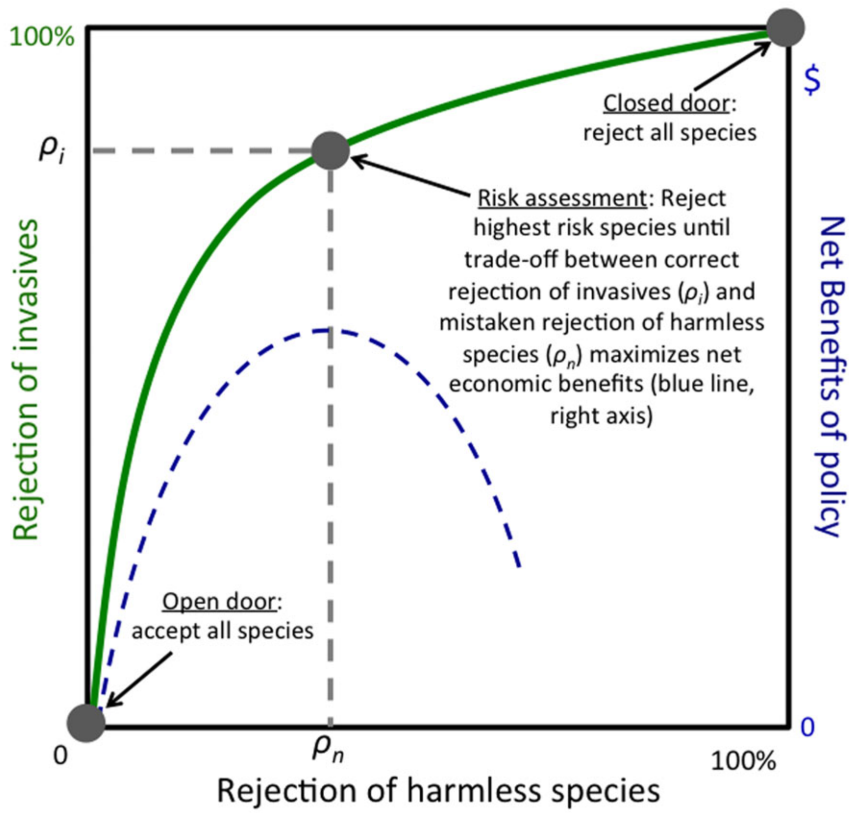

Figure 2 Three policy options for regulating the import of nonnative species. Nations have three options (denoted by the dots) for managing the import of nonnative species: accept all species regardless of invasion potential (= "open door"), reject all species (= "closed door"), or apply risk assessment and accept only species predicted to be of sufficiently low risk (i.e., reject those with an unacceptably high risk of invading). Because risk assessment predictions are not 100% correct, there is a trade-off between the benefits from correct rejection of invasive species (left vertical axis) and mistaken rejection of harmless species (horizontal axis). The solid green line represents the options for applying risk assessment, from more restrictive (top right of graph) to less restrictive (bottom left). Recent advances make it possible to calculate the net economic benefits from applying risk assessment (dashed blue curve, right vertical axis) relative to the common "open door" policy. Several studies have shown considerable benefits from applying risk assessment. The net economic benefit curve intersects the origin because this value is defined here relative to an open door status quo. It is maximized at ρ_n and declines thereafter.

parasite/pathogen carriers prior to their importation. These species could be kept out of trade, while those that caused negligible negative impacts could be allowed. Historically, there has been little policy progress toward such an approach, and this has been due in part to the fact that predictions of invasiveness are not perfect. Yet every policy—including the "open door" policy of doing nothing—is a choice that inevitably results in some error. At one extreme, an open door policy means that all harmless species are accepted. It also unfortunately means that all invasive species are allowed to enter, as shown in the bottom left of Figure 2. At the other extreme (top right of Figure 2), a "closed door" policy means that all species, even noninvaders, are rejected. Many countries practice the open door policy, but we are not aware of any that practice the closed door approach.

There is now a clear alternative to open and closed door policies. Species-level risk assessment tools have been developed to support a rigorous and transparent determination of which proposed species are likely to impose greater risks than rewards (Keller & Drake 2009). At their core, these are predictive ecological models of invasion threat based on attributes of the nonnative species. These attributes can include climatic match between the current range of the species and the region to which it is proposed for import, information about the species' previous invasions, and basic biological data such as fecundity, habitat requirements, and feeding relationships (for reviews of this work, see Kolar & Lodge 2001; Hayes & Barry 2008; Keller & Drake 2009).

While ecological risk assessment can take many forms, it generally involves "analyzing data, assumptions, and uncertainties" to assess the impacts and likelihood of adverse ecological outcomes (CENRNST 1999). The process serves various ends including identifying top risks, assessing implications of various management choices, identification of environmental values of interest, and crucial knowledge gaps (SETAC 1997). Though risk assessment and management are coordinated but separate in some environmental applications, in the context of screening imported species for the likelihood that they will be invasive it is common to integrate assessment, consideration of socioeconomic impacts, and policy implications (CENRNST 1999).

The most common approach for developing a risk assessment tool for a given taxonomic group (e.g., fishes, mammals, plants) in a given ecosystem is to first assemble a list of the species previously introduced. Previous introductions are used because the outcomes (e.g., established or failed to establish) for those species are known. Next, attribute data for these species are collected and analyzed to find patterns that are related to the known outcomes from the introduction (Keller & Drake 2009). For example, Kolar and Lodge (2002) gathered biological trait and invasion history data for all nonnative fish species introduced to the Laurentian Great Lakes. Their analyses revealed that species were more likely to become established if they had relatively high growth rates, relatively broad salinity and temperature tolerances, and a prior history of invasiveness. These relationships were used to create a risk assessment for predicting the likely outcome from future species introductions. Following a similar process, Richardson & Rejmánek (2004) gathered data for conifer introductions across the globe. They found that invasive conifer species have small seed mass, short juvenile period, and produce large seed crops relatively frequently. Again, these results can be used in a risk assessment to determine the likely outcomes from introducing species in the future. As well as these examples, a host of recent research has focused on testing and enhancing models of the invasion threat for both plants (e.g., Caley *et al.* 2006; Koop *et al.* 2011; Lieli & Springborn 2013) and animals (e.g., Bomford 2008; Springborn *et al.* 2011). As a result, high performance risk assessment tools are now available for many taxonomic groups in many regions. New tools can be created and validated following straightforward methods, and in many cases existing tools can be modified for use in new regions (e.g., Gordon *et al.* 2011).

Finding the balance between extremes

Once a risk assessment tool is developed, the challenge is to identify the appropriate risk threshold beyond which a proposed species is rejected for importation. Varying this threshold from high (more species allowed) to low (fewer species allowed) reveals a set of alternatives between the open and closed door policy options (the solid green line in Figure 2). Perfect prediction of invasiveness would lead to an outcome in the top left corner of Figure 2 where all invasives are rejected and there is no exclusion of harmless species. While the complexity of the invasion process precludes perfect prediction, recent advances in species level risk assessment tools have driven progress in that direction, effectively stretching the trade-off curve toward the upper left corner.

Identifying the ideal position along the trade-off curve, that is, the threshold that strikes a balance between the benefits of rejecting invasives and the costs of mistakenly rejecting harmless species, has proven difficult. Locating this point requires knowledge of the *benefits* that accrue from the importation of a species, and the *costs* caused by those species. There are four potential outcomes from assessing any species: if the species is invasive it can be correctly (*true positive*) or incorrectly (*false negative*) classified as such; and if a species is not invasive it can be correctly (*true negative*) or incorrectly (*false positive*) classified. To identify the ideal decision threshold requires estimates of the proportion of imported species that will become invasive, the costs and benefits that accrue from each of the four outcomes just listed, and the frequency with which each outcome occurs. Early risk assessment tools often assumed that the ideal threshold is given by the point at which both types of error are equally likely, that is, where the false positive rate is equal to the false negative rate. However, this simple heuristic is not ideal since the best balance between false positives and false negatives depends on their relative costs, which in turn requires knowledge of the benefits to trade from importing species and the damages from species that cause harm.

Recent progress in developing risk assessment tools and better estimates of the costs and benefits of invasives and harmless species are now available to support more robust calculations of where the ideal threshold lies. The benefits of species imports were first (crudely) estimated using import revenues as a proxy (Keller *et al.* 2007). This approach ignores two import economic concepts. First, revenue is an incomplete measure of the welfare generated by an activity, such as the well being or utility from trade in a species. A more rigorous estimate is given by the *net* benefits or "surplus" generated. In this case, surplus from trade is the difference between the maximum someone is willing to pay for an import less the price paid for it. Second, the lost welfare from rejecting a species for importation depends on the availability of substitutes. Intuitively, the loss from rejecting a species will be much greater if it is the sole species available, relative to the case in which the species is one of many related alternatives. Methods for estimating value which account for the change in net benefits and the availability of substitutes have recently been demonstrated and can now be used to develop risk assessment thresholds (Springborn *et al.* 2011; Schmidt *et al.* 2012).

Invasion damages are more difficult to characterize, prompting a reliance on existing estimates from the literature with well-noted imperfections (e.g., Pimentel *et al.* 2005). However, work is ongoing to develop ever more sophisticated analyses of the distribution of possible impacts from invasion (e.g., Aukema *et al.* 2011), which should improve the quality of this decision model input over time. While data often exists to assess direct impacts (e.g., government expenditures, household expenditures, and property value losses), fewer data are available to estimate indirect costs such as declines in nonmarket ecosystem services (Aukema *et al.* 2011). Methods for valuing losses in such nonmarket goods do exist but typically require the careful execution of new assessments (see e.g., Champ *et al*. 2003 for a primer).

Once the benefit and cost data have been gathered they can be used to calculate the net benefits of applying the risk assessment tool at each potential decision threshold. This is demonstrated by the dashed blue curve in Figure 2, and allows the ideal level of screening stringency to be determined based on maximizing net returns. In this way, the combination of a risk assessment tool based on ecological data with economic information about the costs and benefits of imported species can be used to determine whether a policy of risk assessment, as opposed to an open or closed door policy, produces net benefits (e.g., Keller *et al.* 2007; Springborn *et al.* 2011; Schmidt *et al.* 2012).

Illustrating the substantial payoff of risk assessment

Two recent applications of the framework described above include Springborn *et al.* (2011) for animal trade and Schmidt *et al.* (2012) for plant trade. The central data sets and results from these applications are listed in Table 1. Springborn *et al.* (2011) created a risk assessment tool based on biological traits and invasion history for live reptile and amphibian imports to the United States. Import data characterizing the demand for these species in trade were then used to locate the ideal risk threshold for allowing or prohibiting imports. Figure 3, recreated from Springborn *et al.* (2011), illustrates the integration of the predictive model of establishment threat with the decision model to determine a threshold of acceptable risk. Reptile and amphibian species in the model training data set, which includes both established (top) and non-established (bottom) species are ordered along the horizontal axis by their estimated establishment threat from the risk assessment model. Species for which the benefits of trade outweigh the risks of establishment lie to the left of the threshold (vertical line) and are ideally accepted. Species to the right of the threshold carry a level of establishment risk that exceeds their trade benefits and are ideally excluded. Results show that the estimated net benefits (*ENB*) of applying this risk assessment tool at the ideal threshold are \$54,000–\$141,000 per species assessed (Table 1). That is, it would be rational to spend up to this amount to assess each new reptile and amphibian species proposed for import to the United States, and to manage imports based on the assessment results. The second example used similar methods to look at plant imports to the United States and calculated the *ENB* at \$80,000–\$140,000 per species assessed (Schmidt *et al.* 2012).

While Australia and New Zealand have employed risk assessment tools for over a decade to restrict high risk animals and plants from importation, most countries continue to operate with an effectively open door. Because some degree of prediction error is inevitable, the perception lingers that risk assessments will not enhance societal welfare. The proverbial danger here is allowing perfect (prediction) to be the enemy of good. For the example of U.S. reptile and amphibian imports discussed above, even though classification imperfectly identifies establishing species (true positive rate of 87–92%) and safe species (true negative rate of 60–76%) the estimated net benefits *per species* assessed are still substantial. The same is true for the plant import trade (Table 1).

While the estimates of net benefits above take into account the lost welfare from restricting imports, implementation costs for conducting assessment and enforcing exclusions should also be considered. To assess the typical cost of conducting a basic risk assessment, Jenkins (2013) surveyed practitioners in several different countries (e.g., Australia, New Zealand, and the United Kingdom) and found that the cost per risk assessment ranged most commonly between \$1,600 and \$12,000 (U.S. dollars). Once species have been identified for exclusion, this decision will need to be enforced at the border. The costs of implementing such a border security program will depend on the existing portfolio of rules and enforcement programs. Most developed countries already enforce regulations that prevent the import of some animal and plant species, and quarantine programs are in place to prevent the import of some pathogens. Since the exclusion of species on these lists is already enforced, many of the resources for inspection are already in place. For these countries, risk assessment is expected to generate minor costs for assessment (\$1,600–\$12,000) and minimal

Table 1 Examples of existing and potential applications of invasive species risk assessment to the United States

Source	Taxon	Training data	Trade data	Numerical results
Springborn *et al.* (2011)	Reptiles and amphibians	Biological and invasion history trait data report (Bomford 2008)	Law Enforcement Management Information System (LEMIS) database from the U.S. Fish and Wildlife Service (USFWS)	*ENB* ($K): $54–$141; *TPR*: 0.87–0.92; *TNR*: 0.60–0.76
Schmidt *et al.* (2012)	Plants	Plants National Database from the U.S. Department of Agriculture	Global Agricultural Trade System online database from the U.S. Department of Commerce 2010	*ENB* ($K): $80–$140; *TPR*: 0.59–0.94; *TNR*: 0.44–0.77
Potential application	Birds	Bird trait and invasion database (Sol *et al.* 2012)	LEMIS database from the USFWS (see above)	

Notes: Numerical estimates include estimated net benefits of applying risk assessment relative to an open door policy (*ENB*), the true positive rate (*TPR*), and the true negative rate (*TNR*) for the risk assessment tools developed. See text for full description of these metrics, and original papers for full descriptions of methods.

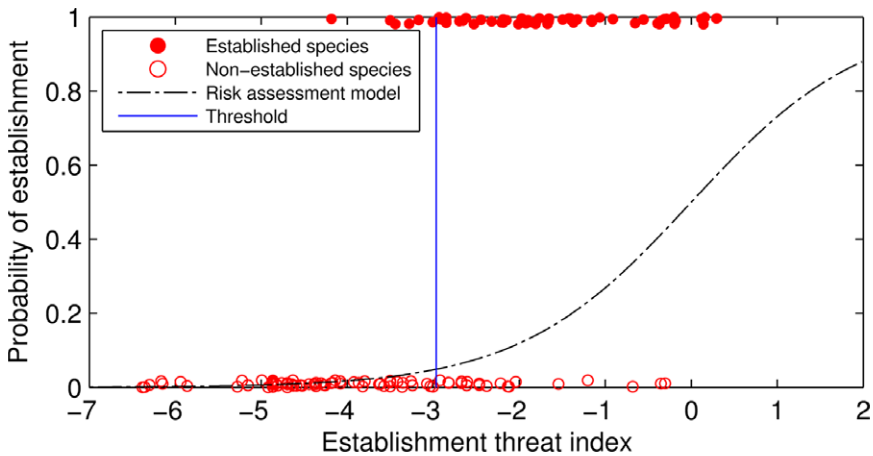

Figure 3 Combined risk assessment and import decision model for the U.S. trade in live reptiles and amphibians (redrawn from Springborn *et al.* 2011). Each circle represents a species introduced to the U.S. that either became established (filled circle, plotted at Pr[*establishment*] = 1) or failed to establish (open circle, plotted at Pr[*establishment*] = 0; symbols are jittered slightly for differentiation). The logistic risk assessment model, estimated from these training data, was developed by mapping species attributes to the probability of establishment (via a linear combination of the predictive variables—the establishment threat index—converted to a probability measure using the logit link function; see Springborn *et al.* 2011 for full details). The vertical line indicates the optimal decision threshold given the benefits of a species in trade and the expected costs of an established species. Species proposed for import in the future could be assessed with the risk assessment model, and those found to have a score greater than the decision threshold should be excluded while those to the left of the threshold are accepted.

costs for inspection and enforcement. We consider that these administrative costs are highly unlikely to exceed the *ENB* of moving from an effectively open door policy to one of risk assessment (see Table 1).

Further lowering the barrier to implementing risk assessment, recent research shows that some tools can be applied with little modification in many areas of the world. For example, the Australian Weed Risk Assessment has high accuracy in many regions beyond Australia (Gordon *et al.* 2008), and a modified New Zealand Aquatic Plants Risk Assessment has good performance in the United States (Gordon *et al.* 2012). Where existing tools such as these can be modified for use in other settings there will be a relatively low technical barrier to implementing a policy of invasive species risk assessment. Indeed, even when new tools need to be developed the data are now often readily available. For illustration, at the bottom of Table 1 we note that a recently published global data set of introduced and established bird species and their traits (Sol *et al.* 2012) could be combined in a straightforward fashion with import data to construct a risk assessment model for bird imports to any nation or region.

Looking forward: policy initiatives and potential barriers

There have been recent attempts to increase risk assessment in the United States, and this example is illustrative of the challenges faced around the world. While several attempts to update the regulation of live species imports to the United States have failed in the last few decades (Smith *et al.* 2009), a bill was introduced to the House of Representatives in 2012, but not passed, with a degree of bipartisan support. The proposed *Invasive Fish and Wildlife Prevention Act of 2012* (HR 5864, 112 Congress, 2nd Session) aimed to establish "an improved regulatory process for injurious wildlife to prevent the introduction and establishment in the United States of nonnative wildlife and wild animal pathogens and parasites." The Act would direct the Secretary of the Interior to develop a process whereby nonnative animals are assessed "prior to allowance of their importation" using "scientific risk screening systems or predictive models." This is the approach that the new research and results described above support.

The United States is not the only nation with the opportunity to more firmly embrace a policy of risk assessment for intentionally imported nonnative species. Elsewhere, European leaders are considering an overhaul of invasive species programs, with one potential outcome being a program of risk assessment (EC 2013). South Africa (ISSA 2012), and Great Britain (GBNNSS 2011) are also developing or already utilizing some level of risk assessment. In each of these cases there is little doubt that accurate risk assessment tools could be created or are already available. Hence, the main challenge for the future is to create policy that effectively uses those tools to prevent the arrival of future invaders.

Developed nations tend to have higher levels of trade in nonnative species, well-developed scientific institutions that can create and implement risk assessment tools, and stronger programs to identify and exclude invasive species at the border (Nuñez & Pauchard 2010; Keller & Perrings 2011). For these nations there is both a need and capacity for risk assessment policies. In less developed nations, lack of expertise and capacity may make it prohibitive to develop risk assessment tools, establish quarantine facilities, and to train border personnel to identify invasive species. This issue is only partially offset by lower trade in nonnative species. While it is beyond the scope of this article to suggest solutions that can immediately work in all nations, we note that others (e.g., Perrings *et al.* 2002; Keller & Perrings 2011) have suggested that the global nature of the invasive species problem justifies creation of a global facility that would monitor the spread, impacts, and threats of different species across the globe. Such a facility could provide much of the expertise needed for developing countries, would enable *exporting* nations to ensure that species are not sent to places where they pose a high risk of invasion, and would have the potential to be far more efficient because these tools and processes would not be repeated in each nation.

While the *aggregate* net benefits from implementing species screening are substantial, the asymmetric distribution of benefits and costs in live organism trade raises practical concerns. Those directly involved in species importation gain concentrated benefits from the trade, while the losses from invasion are often widely distributed, with much of the burden falling on landowners and tax payers. This is a classic externality problem in which a significant portion of the costs of international species trade are not borne by those directly receiving the benefits (Perrings *et al.* 2005). Furthermore, the diffuse nature of the costs and the concentrated nature of the benefits create a political context in which beneficiaries have greater motivation than damaged parties to influence voluntary standards or regulation. Thus, implementing a policy of species screening would serve the greater good, but may generate far more opposition from the few who are strongly impacted by a restriction on species imports than support from the many who are affected by invasive species.

Although there is policy activity in several countries indicating that risk assessment tools could soon be in greater use, we caution that such preliminary activity has been taking place for a long time without finalization. U.S. programs for restricting the importation of invasive animals illustrate this particularly well. The Lacey Act was passed in 1900, and since this time has allowed (but not required) the type of proactive screening discussed above. It has rarely been used for that purpose, and currently lists only 26 animal taxa, covering some 236 species (USFWS 2013). Thus, while we support current proposals in nations around the world to proactively screen live species trade, continued pressure is needed to ensure that wise application of risk assessment will indeed be implemented.

Acknowledgment

We thank John Drake, David Lodge and Charles Perrings for their suggestions on an earlier draft.

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