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PERSPECTIVES AND PARADIGMS

Biological invasions in developing and developed countries: does one model fit all?

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Abstract There is a strong bias concerning the regions of the globe where research on biological invasions is conducted, with notably lower representation of developing countries. However, in developing countries, effective management strategies to control invasions could be more beneficial in conserving global biodiversity since these countries tend to have larger, highly diverse natural habitats. Lower levels of development are seen as an obstacle to tackling biological invasions, but little thought is given to the advantages of developing countries in dealing with invasive species. We analyzed differences between developed and developing countries regarding the problem of invasive species and their historical and current patterns of international trade, disturbance levels and land use, research and monitoring, control and mitigation, and social awareness. Developed nations have some advantages, especially in levels of social awareness and means for controlling and studying exotics, but developing nations also enjoy important advantages given their lower levels of international trade and the availability of low-cost labor. Also, there is evidence that the process of economic development, which results in more efficient ways to transform landscapes and increases international trade, is strongly associated with increasing rates of biological invasion. Differences in data quality and availability between developed and developing countries make comparative analyses of biological invasions a difficult task. Thus, these differences creates a challenge in forming global strategies to deal with invasions. There have been calls for creating international plans to deal with invasive species, but we believe that it is important first to acknowledge the challenges and understand both the advantages and disadvantages of developing countries.

Keywords Anthropogenic disturbance · Control of invasions · Development · International trade · Management

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Introduction

There is a clear dissociation between geographic areas where most of the research on invasive species is conducted and the areas of the globe where conservation efforts are most needed and biological invasions can have the largest impact on biodiversity. While research on invasive species is primarily

concentrated in developed countries (Pyšek et al. 2008), the highest proportion of natural ecosystems and the greater number of biodiversity hotspots are located in developing countries (Myers et al. 2000; Smith et al. 2003b). In general, ecological research centers and scientists are mostly located in developed countries, influencing the amount of research on the causes and effects of biological invasions and also influencing management strategies to control this growing problem. Pyšek et al. (2008) found a strong bias in the regions of the globe where research is being done, with notably lower representation of developed countries. Paradoxically, developing countries are the ones where effective management strategies to control invasions could be more beneficial from a global perspective since they tend to have larger, highly diverse areas of natural habitats (Myers et al. 2000).

Socio-economic factors are key to understanding processes contributing to biological invasions (Levine and D'Antonio 2003; Lin et al. 2007; Taylor and Irwin 2004; Williamson 2006). This is why it is important to recognize that developing and developed countries may face different challenges when dealing with invasive species, and that research and management should recognize these differences. Thus, the aim of this paper is to discuss differences between invasion processes in developed and developing countries, with emphasis on their causes, potential consequences, and how to control and mitigate invasions. We hypothesize that historical, societal, political and economic differences influence the way that invasive alien species affect the environment and how the society perceives and controls invasives. Specifically, we argue that developing countries when dealing with biological invasions will face disadvantages compared to developed countries, ultimately constrained by their limited budgets. However, at the same time developing countries might enjoy certain advantages such as their lower levels of international trade and subsequent lower rates of introduction, and the availability of low-cost labor (Table 1). We will focus on five themes where we think there are important differences between developed and developing countries regarding the problem of invasive species and their control: (1) historical and current patterns of international trade, (2) disturbance levels and land use, (3) research and monitoring, (4) control and mitigation, and (5) social awareness. For the purpose of this paper we used the United Nations list of developed and developing countries (United Nations 2006).

Development and invasions: advantages and disadvantages of being poor

Historical and current patterns of international trade

International trade is a major component in explaining current levels of biological invasions worldwide (Meyerson and Mooney 2007). Therefore, the balance of trading between developed and developing countries should, at least partially, explain differences in patterns of invasions across countries. The high rates of worldwide commerce and importations characteristic of developed countries should increase the chances of being invaded by exotic species (Levine and D'Antonio 2003). For example, the pet and horticulture industries are a large problem for wealthy countries (e.g., Padilla and Williams 2004), but are probably less important in developing countries due to their lower buying power (although there are invasions related to these type of imports, e.g., Matthews and Brand (2005)). Developing nations tend to rely more on locally available natural resources and many of them export raw materials based on naturally occurring species (e.g., tropical forests) increasing the chances for exporting invasions into more developed economies. However, many developing countries also rely heavily on industrial agricultural, aquaculture, and forestry cultivars based on exotics and sometimes invasive species (e.g., Matthews and Brand 2004, 2005; Richardson et al. 2008).

In the last few centuries, colonization by world powers (many of the current developed nations such as Spain and England) and massive human immigration to developing countries resulted in the arrival of many alien species (Mack 2003). Some of these species are now recognized as invasive. In addition, developing countries economies have relied partially in importing raw materials for their production processes, increasing the risk of exotics arriving in packing material, ballast water and containers (Matthews and Brand 2005). Some authors have already recognized that wealth and trade are positively associated with occurrence of exotics species (Levine and D'Antonio 2003; Taylor and Irwin 2004).

Table 1 Major factors that differentiate developed and developing countries related to the management of invasive species

Factors affecting the establishment and control of exotics	Developed nations	Developing nations	Possible implications (see text for more detail and references)
Presence of a stable scientific community	+	−	In developing nations, lack of biologists with a solid background in science that can propose, evaluate, and conduct programs to deal with invasive species could decrease their chances of success. Also, lack of the understating of ecosystems and the biology of species could be problematic for developing countries relative to developed countries
Possibility of large scale volunteer work	+	−	In developing countries it could be harder to plan programs depending mainly on volunteers than in developed countries
Inexpensive labor to control exotics	−	+	In developed countries in could be impossible to plan large scales programs that depend on inexpensive labor, like the Working for Water program, which is successful program in a developing country
Volume of imports and exports	+	−	Large volume of imports and exports increases the chances of invasion and they are larger in developed nations than developing nations
Level of education	+	−	It may be harder to educate people on developing countries in the problems of invasive species, since access to education is more limited
Dependence on natural resources	−	+	People in developing countries depend more directly on natural resources (e.g., for food), so they may be more sensitive to changes in resources do to bio-invasions, and therefore have more will to control invasions
Public awareness of the problematic of invasives	+	−	In developing nations it could be harder to find volunteers or public support for management programs. Also, unintentional introductions may be triggered by lack of awareness
Availability of basic scientific data of the local ecosystems	+	−	In developing nations, lack of baseline data could decrease chances of successful programs
Presence of well established Animal/species rights societies	+	−	In developed countries some control or eradication programs may fail or be harder to conduct due to the activities of these groups that could act as obstacles for such plans

The "+" and "−" sings show which countries have more (+) or less (−) on the given factor

For example, a recent study in China demonstrates development directly associated with the number of exotic species (Lin et al. 2007), showing that the increase in number of invasive species is related to economic development in China since 1970. Also, in a comparison between developed and developing countries in the Mediterranean region of Europe and Africa, Vilà and Pujadas (2001) found that level of imports and the level of human developments were the only variables associated with the density of exotic plant species. As countries become more industrialized, the chances of large scale human immigration and importation of new cultivars increases, raising the probability of biological invasions.

Differences in the introduction of alien species not only relate to the abundance of such species but also with the variety of species introduced. For example, California, although it has a similar climatic range to central Chile, shows a much richer alien flora with a more diverse array of origins than its southern hemisphere counterpart (Jiménez et al. 2008). Similarly, the San Francisco Bay area in California is among the most invaded marine ecosystems (Cohen and Carlton 1998). Both on land and at sea, the well-known importance of California as a center for international trade has lead to massive introduction and establishment of alien species.

Disturbance levels and land use

Developing and developed countries face different realities in the alteration of their natural ecosystems, and since disturbance is recognized as a major driver of biological invasions, this pattern should influence probabilities of invasion. Many developed nations have suffered a great loss of biodiversity and

replacement of their native species. For example, Europe suffered drastic losses in forest cover owing to the industrial revolution (Jeanrenaud 2001). Therefore, disturbed ecosystems dominate the European landscape, increasing the chances for ruderal invasive plants to establish (e.g., Pyšek et al. 2005). In other developed regions deforestation in the nineteenth and early twenty centuries were also widespread. For example, in the United States by 1920, 660,000 km^2 of forest were cut, which is one of the biggest deforestation episodes ever (Williams 2002). Similar events have also occurred also in Australia, were 400,000 km^2 of forest were cut by early twentieth century (Williams 2002). Of course, there are exceptions, especially in some parts of Asia, where humans have dominated the landscapes for millennia but in many cases this has not led to modern development (Ellis and Ramankutty 2008). In these countries, where natural environments are scarce and introductions of species have been a consistent process at least for centuries, invasion scenarios are hard to quantify and diverge from the overall trend discussed here.

In general, developing countries have not suffered as much loss of natural areas as developed countries, and many developing countries, like Brazil, still have pristine areas with enormous biodiversity despite current trends of rainforest destruction (Fearnside 2005). Similarly, in central Africa there are still large extensions of primary rainforest (second only to the Amazonian basin), a circumstance that may change due to sharp population growth and a mounting Asian interest in African timber (Koenig 2008). This potentially lower invasibility caused by reduced levels of anthropogenic disturbance may rapidly change as natural resource exploitation and associated transportation networks increase the availability of disturbed habitats (Pauchard and Alaback 2004). Current development is creating large scales disturbances in developing countries, were pressures for extracting natural resources are high. This has lead to high rates of deforestation in developing areas, specially after 1950 in tropical forests (Gash 2002; Williams 2002).

Research and monitoring

One clear advantage of wealthy nations in dealing with invasive species is the presence of well established scientific communities, which produce basic and applied information on their native species and ecosystems, educate biologists, and which also influence governmental policies (e.g., Inderjit et al. 2006; Lawton 2007; Plessis and Primack 2001). This is not the case in developing nations, where the most basic information on biological invasions, such as a complete list of naturalized alien species may be lacking. An additional problem is that even if there is an emergent scientific community, there is little influence on policy-making.

In a search conducted on the ISI web of science from 4,379 articles, published from 2003 to 2007 using Simberloff and Von Holle search terms (i.e., "species AND inva* OR introduced OR alien OR exotic OR non-native OR non-indigenous") (Simberloff and Von Holle 1999) but restricted to published papers in the subject areas of ecology and biodiversity conservation, we found that only 15.8% of all the papers related to exotic species had authors from developing countries, and only 6.5% had authors solely from developing countries. There is variance in the level of research among developed and developing countries, but developed countries tend to have much stronger research programs (Table 2). This is not surprising, Robert May conducted a study to determine how countries invest their money in science and development. May mentioned that 12 countries are responsible for 80% of the investment in science and development, based on scientific publications. Of these only China and India are on the list, this is due to their large population size. Their investment per citizen is very low compared to developed nations (May 1997, 1998). Although Web of Science does not include all the literature on the topic (e.g., excluding grey literature) and has a bias against literature that is not in English (Fazey et al. 2005; Seglen 1997), it provides a reasonable representation of the global scientific studies on invasive biota. It has been suggested that a large part of the literature in developing countries on conservation biology is in the form of "grey" literature, but researchers in these countries tend to publish in international journals and they are encouraged to do so, by in some cases influencing promotion and salary increases (Fazey et al. 2005).

It is difficult to estimate which proportion of the research should be expected from developing countries, but if we consider that most of the countries in the globe are not yet developed, 15.8% seems to be a worrisome small percentage. Having a small

Table 2 Number of articles published in different countries and associated states from 2003 to 2008 and the number of article per million habitants. We selected these countries based on Dalmazzone (2000). See text for details on the search procedures

Developing nations			Developed nations		
Country	Number of articles	Articles/population (in millions of habitants)	Country	Number of articles	Articles/population (in millions of habitants)
China	104	0.08	Australia	572	26.36
Mexico	139	1.27	Canada	474	14.11
India	29	0.02	Finland	63	11.89
Brazil	96	0.5	France	381	5.86
Belize	0	0	Greenland	2	0.04
Chile	74	4.4	New Zealand	253	58.84
Cuba	5	0.45	Norway	49	10.21
Djibouti	0	0	Puerto Rico	22	5.64
Egypt	3	0.04	Continental USA	2,754	9.05
Namibia	2	0.95	Italy	96	1.6
Panama	23	6.76	Germany	242	2.95
Peru	8	0.27			
Poland	32	0.84			
Rwanda	3	0.3			
Swaziland	1	0.91			
Uganda	13	0.4			

proportion of researchers in developing countries is a problem for analyzing potential impacts of exotics as well as organizing management strategies given the idiosyncrasy of invasions. For example, developed countries have larger proportions of exotics plant species than developing countries (Fig. 1). However, it is difficult to assess whether these differences are real or if they are an artifact of the lack of information on the subject from developing countries. This issue may hamper any comparative study between developed and developing nations and can lead to biased results (Pyšek et al. 2008; Westphal et al. 2008). The scarcity of invasive species scientific reports in developing countries is probably associated with the low funding for ecological research compared to other disciplines perceived as more urgent (e.g., medicine, engineering).

Control and mitigation

Developed countries have advantages in how they can control their imports and their territory. These countries have more resources and economic incentives to secure their borders. For example, developed countries have more funds for sophisticated control techniques than developing countries. Furthermore, in most cases developing countries have not prioritized border control for invasive species, probably caused by a lack of awareness and lack of funding. However, a few developing countries have shown high restrictions to the intentional and accidental import of species (e.g., Chile).

Resources to control spreading or established invasives are also greater in developed countries, but not all is bad news for developing countries. Poor countries have low-cost labor, which is a major advantage that allows the implementation of efficient low-technology control strategies. Major achievements have been produced in developing nations, for example, *Anopheles gambiae*, a vector of malaria, which was eradicated from large extensions of northeastern Brazil, which is evidence that in countries with low resources management of challenging exotics can be achieved (Simberloff 2003). A great example of how a developing country can make important progress in the control of non-indigenous species is the Working for Water program in South Africa. This program was launched to diminish the problems of invasive species and unemployment; it also serves as a way of educating people on different

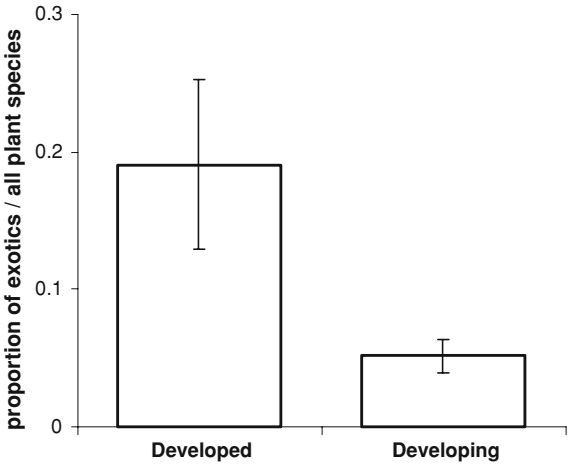

Fig. 1 Proportion of the number of exotic plants versus the numbers of all plant species in developed and developing countries. These data is extracted from Dalmazzone (2000), from which we used her entire list of countries and associated states. Countries and associated states included as developed: Australia, Canada, Finland, France, Greenland, New Zealand, Norway, Puerto Rico, and Continental USA. Countries included as developing: Belize, Chile, Cuba, Djibouti, Egypt, Namibia, Panama, Peru, Poland, Rwanda, Swaziland and Uganda

issues ranging from environmental problems to AIDS. This project has reduced the impact of exotics and employs thousands of previously unemployed men and women (60% of the total working force), thus producing a direct economic benefit for local communities (Magadlela and Mdzeke 2004).

Social awareness

Awareness of the problem of invasive species is clearly different in developed versus developing countries. Most developed countries have conservation groups that can help to promote awareness and control invasive species, and are capable of providing large number of volunteers for conservation projects (Brandon et al. 2003; Delaney et al. 2008; Leslie et al. 2004). These kinds of organizations are not as widespread in developing nations and the public interest in nature conservation, and therefore in control of biological invasions, may not be sufficient to promote a consistent policy on invasive species. In addition, environmental education is higher in developing countries just as a consequence of higher overall education levels. However, developed nations may suffer other barriers to control invasive species. For example, the presence of other organizations of concerned citizens like animal rights activists that have been shown, in particular cases, to impede or delay the control and management of exotic invasive species (Bertolino and Genovesi 2003; Genovesi 2005; Perry and Perry 2008).

How could we better deal with invasive species?

There have been calls for the creation of a worldwide organization to control exotics (e.g., Inderjit et al. 2006; Perrings et al. 2002). Global strategies are generally planned by developed countries with little input from developing countries. This could be problematic. Developing countries are sometime viewed as poor, disorganized, and corrupt versions of developed countries (e.g., Laurance 2004; Smith et al. 2003a, b), but little thought is given to their comparative advantages in dealing with invasive species.

Problems in developed and developing countries are different and solutions need to reflect those differences. The economic need to control invasion can be greater in countries that depend more on natural resources; and where food security or basic ecosystems services (such as water supply) can be threatened by exotics; or where just the presence of pristine habitats contribute to their income (e.g., to attract tourism). However, experiences of success and failure in developed countries should be considered critically before applying a "one model fits all" approach to the control of invasive species, especially in light of the lack of information and research on developing countries. It might be the case that factors promoting or halting invasions are different in developing and developed nations, and therefore we should avoid the use of proven "recipes" without consideration of local realities.

Biological invasions are a global problem, not a regional one. Probably, every country in the world has exported and received invasive species. Therefore, both exporting and importing countries may be considered responsible for such introductions. Developed countries could take the first step on this issue, toughing their requirements for the importation of potentially invasive taxa and no longer exporting species that are known to be invasive to countries that cannot afford to fund research to determine their chances of invasion. Of course this will have a cost to

developed countries, but this strategy may be more efficient that using funds for the control of invasive species once they have established in the area. This is not an easy task and other considerations may come into play (e.g., equality for development) and there is evidence on how problematic limiting the exportation of goods can be, even among developed nations (e.g., Victor 2000).

Just an example, several developing programs, many of them with funds from developed countries, rely heavily on exotic invasive species. Just to cite two examples, this is the case of the Japanese International cooperation agency that promotes since the 1980s salmon farming in Chile (JICA 2005), and GTZ (an international cooperation enterprise for sustainable development with base in Germany) that had promoted for several years plantations of exotic conifers in Argentina (Chidiak et al. 2003). The goal of these programs is to help rather than to create problems, but international agencies aimed to promote development should consider beforehand the problematic that these species could produce in the long run.

Concluding remarks

Socio-economic factors, such as the differences between developing and developed countries, need to be acknowledged in order to plan successful programs to deal with biological invasions. Developing nations enjoy certain advantages compared to developed nations in dealing with the problems associated with biological invasions. We believe that well-planned development will conserve natural resources and lower the risk of invasion, thereby enhancing the quality of life in developing countries. Developing countries need not follow the environmental trajectory of developed nations (i.e., destroying in some way their natural inheritance to achieve development) (Balmford et al. 2002). In fact, developing countries can learn from past mistakes of developed countries in dealing with invasive species. Today we have information on factors that are directly associated with invasions, such as international trade, propagule pressure or modification of natural habitats. Therefore, political leaders and lawmakers in developing nations must use this information to plan development strategies. Given the economical losses that invasive species produce (Pimentel et al. 2005), this is a crucial decision for the economies of these countries, as well a critical step for their biodiversity conservation. Such an effort of developing countries should be supported (morally, scientifically and economically) by developed countries. Ultimately, the effects of biological invasions in the world biota do not recognize borders.

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