Decision tools for managing biological invasions: Existing biases and future needs

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Review

Decision tools for managing biological invasions: existing biases and future needs

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Abstract The increasing number of invasive species and their effects on wildlife conservation, together with a lack of public resources, make it necessary to prioritize management actions. In practice, management decisions are often reached on the basis of subjective reasoning rather than scientific evidence. To develop a more evidence-based and efficient management of biological invasions, decision tools (e.g. multi-criteria frameworks) that help managers prioritize actions most efficiently are key. In this paper we review to what degree such decision tools are currently available. We used a literature search to identify relevant studies. Our analysis indicates that available studies are largely biased towards risk analysis and that only a few authors have proposed cost-benefit or multi-criteria frameworks for decision making. Until now, these frameworks have only been applied at limited regional scales but they could be applied more widely. Our review also shows critical biases in the geographical focus, habitats, and taxonomic groups of available studies. Most studies have focused on Europe, North America or Australia; other continents have largely been ignored. The majority of studies have focused on terrestrial plants; other habitats and taxonomic groups have been poorly covered. Most studies have focused on a single invasive species but practical management tools should consider a wide variety of invaders. We conclude with suggestions for developing improved decision tools.

Keywords Biological invasions, cost-benefit, cost-efficiency, decision-making tools, management

Introduction

In the last decade researchers have repeatedly stressed the need to optimize decision-making processes and prioritize investment in biodiversity conservation (Balmford et al., 2003; Stewart & Possingham, 2005; Murdoch et al., 2007). The management of biological invasions requires the development of decision tools that help managers prioritize actions most efficiently, for example by considering bio-economic costs and benefits (De Wit et al., 2001; Perrings, 2001; Pimentel, 2002; Born et al., 2005; Buhle et al., 2005; Hayes et al., 2005; Olaussen & Skonhoft, 2008). This is a complex process involving a range of disciplines (e.g. ecology, sociology, engineering, politics) and that needs to consider the economic resources and human skills available. The need for decision tools to manage biological invasions is justified by the current global scenario, which is characterized by (1) the continuous increase in the number of invasive species, mainly due to globalization, increased mobility, and destruction of natural habitats, (2) the environmental, social and economic consequences of biological invasions (Munda, 2004; Naidoo et al., 2006), and (3) the limited economic and human resources in the public institutions responsible for nature conservation or management.

There is thus a demand for simple tools that guide managers and politicians to optimize their investments based on objective and measurable criteria. Particularly helpful decision tools include cost-benefit or multi-criteria analyses (e.g. Tillman, 2000; Gamper et al., 2006; Gamper & Turcanu, 2007). In simple terms, cost-benefit analyses compare estimated costs of one or more management actions against estimated benefits. Such analyses typically first develop cost-benefit models, which are then parameterized with data or estimates for a single non-native species and geographical area. Costs and benefits are measured in monetary values. Multi-criteria analyses do not necessarily consider monetary values and can consider other quantitative or qualitative measures of inputs (costs) and outputs (benefits) of management actions. Such analyses consider concerns about multiple conflicting criteria for a decision-making process (Gamper et al., 2006). It is beyond the scope of this paper to compare cost-benefit with multi-criteria analyses in detail (see Gamper et al., 2006 and Gamper & Turcanu, 2007 and references therein). It is clear, however, that both tools are more helpful for decision makers than more limited approaches such as analyses that focus only on the potential risks caused by invaders. It is also clear that analyses considering multiple invasive species simultaneously are more helpful than approaches limited to only a single invader, as ecosystems are typically invaded by more than one species (Carrasco et al., 2010).

Here we analyse the availability of practical, readily usable and integrated decision tools to manage biological

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invasions. We performed a literature search to analyse the availability of cost-benefit and multi-criteria analyses, and investigated how frequently published studies consider multiple invasive species simultaneously. We also investigated potential biases of existing studies regarding their focal geographical areas, habitats and non-native species. Finally, we analyse which of the factors that can be helpful for decision-making processes were considered in the available studies.

Methods

We searched the ISI Web of Science in January 2011 to obtain a sample of relevant publications on decision-making tools for managing biological invasions. We used a combination of search terms related to biological invasion (aliens, invasive species, invader) and terms related to management and efficiency (management, cost, efficiency, benefit, tool, protocol, allocation, prioritization, priority, software, bio-economics). We did not limit the search to papers published during a fixed period. We assumed that papers published in peer-reviewed journals are accessible to managers and technicians with scientific skills, either as abstracts, from institutional subscriptions, or by requests to authors. We also considered that a search of international peer-reviewed journals should give more reliable results than a literature search that also included other types of publications (the Web of Science is one of the largest and most widely used databases within the technical and scientific community working on biodiversity conservation).

For all papers returned by the search we checked if they were within the scope of our analysis and if they were original research papers (either empirical or theoretical) rather than review articles; the latter were excluded to avoid double-counting as they might refer to original articles already included in our analysis. We identified 43 relevant original research papers. Other papers that are relevant but were not returned by the literature search (e.g. Hobbs & Humphries, 1995; Goodwin et al., 1999; Sobrino et al., 2002; Leung et al., 2002; Gassó et al., 2009a,b; Liu et al., 2011) were excluded from our analysis, as we aimed for an approach that can be repeated by other researchers. It was not our goal to compile an exhaustive list of all relevant publications but rather to analyse a relevant sample.

We categorized the 43 studies into one or more of the following six categories, which represent different types of decision-making tools for managing biological invasions (further information on most of these approaches can be found in Clout & Williams, 2009): (1) cost-benefit and multi-criteria analyses (theoretical cost-benefit models that were not sufficiently parameterized for actual non-native species and regions were not included), (2) studies of quarantine or border inspection, (3) risk analyses (i.e. studies assessing the risk of invasion, or potential impact of invasion, by one or more non-native species not yet present in the focal habitat), (4) studies of eradication, containment or control (i.e. studies focusing on tools to manage non-native species that are already present in the focal habitat), (5) internet applications and other software decision-making tools for managing biological invasions, and (6) studies of other tools (i.e. studies not matching any of the other five categories).

For each study we noted the geographical focus (using a continental scale), focal habitat(s) (terrestrial, freshwater, marine), taxonomic group(s) of focal non-native species (plants, vertebrates, invertebrates, microorganisms), and the number of focal non-native species. This information was not applicable for some theoretical studies. We also noted which of the following five factors (often considered as key for decision-making tools to manage biological invasions; Clout & Williams, 2009) each study considered: (1) the features of the non-native species (e.g. its biological traits as predictors of its invasiveness, its propagule pressure, its competitive abilities or its impacts), (2) habitat features (e.g. climate, geography or chemistry; studies predicting the risk of invasion based on species distribution models fall into this category; see Jeschke & Strayer, 2008), (3) predicted or expected effects (outputs) of management action(s) (e.g. the socio-economic benefits of reducing invader impacts but also the negative consequences of management action), (4) the efforts (inputs) required to perform management action(s) (e.g. monetary costs), and (5) the legal, social, technical or scientific difficulties that may hamper management action(s) (e.g. regulations or administrative procedures, land ownership issues, social perception of charismatic invasive species, or lack of scientific/technical data).

Results

The majority of studies on decision-making tools for biological invasions focus on risk analysis (Fig. 1). Some studies fall into multiple categories. For example, because cost-benefit and multi-criteria frameworks consider costs and benefits of management actions, they often include a risk analysis in their framework to assess benefits of management actions; three of the five cost-benefit and multi-criteria analyses were also categorized as risk analyses.

We detected biases in the geographical, habitat and invasive species foci (Fig. 2). Of the 39 studies that could be assigned a geographical focus (the other four studies were theoretical), the majority were in Europe, North America or Australia/Oceania. Only a few studies had other focal continents, and none were located in Asia. Most studies focused on invasive species in terrestrial habitats, a few focused on freshwater habitats, and there was only one study on marine habitats (Acosta et al., 2010). With respect

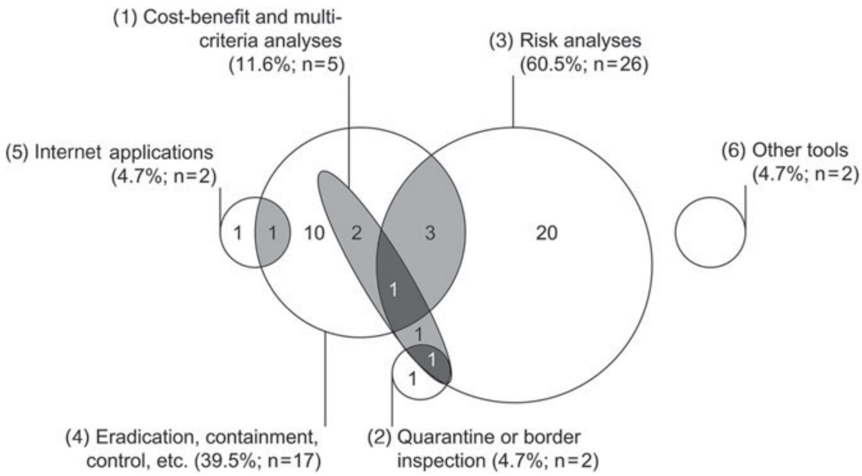

FIG. 1 Venn diagram illustrating the number and percentage of a total of 43 studies using six decision tools (see text for further details) for managing biological invasions. The percentages sum to > 100% because some studies fall into multiple categories. The literature sources are (1) cost-benefit and multi-criteria analyses (Keller et al., 2008; Ameden et al., 2009; Roura-Pascual et al., 2009; Carrasco et al., 2010; Liu et al., 2010); (2) quarantine or border inspection (Ameden et al., 2009; Moore et al., 2010); (3) risk analyses (Cook et al., 2007; Leung & Mandrak, 2007; Burns, 2008; Evangelista et al., 2008; Keller et al., 2008; López-Darias et al., 2008; Ameden et al., 2009; Copp et al., 2009; Dawson et al., 2009; Drake & Bossenbroek, 2009; Reino et al., 2009; Vall-llosera & Sol, 2009; Yemshanov et al., 2009; Acosta et al., 2010; Andreu & Vilà, 2010; Carrasco et al., 2010; Crosti et al., 2010; Fuentes et al., 2010; Miller et al., 2010; Muturi et al., 2010; Paini et al., 2010; Smolik et al., 2010; Strubbe et al., 2010; Thum & Lennon, 2010; Tricarico et al., 2010; Wu et al., 2010); (4) eradication, containment and control (Cacho et al., 2008; Firn et al., 2008; Olson & Roy, 2008; Sebert-Cuvillier et al., 2008; Hauser & McCarthy, 2009; Marvin et al., 2009; Roura-Pascual et al., 2009; Rout et al., 2009; Burgman et al., 2010; Carrasco et al., 2010; Christy et al., 2010; Fuentes et al., 2010; Liu et al., 2010; Muturi et al., 2010; Sanchirico et al., 2010; Sandham et al., 2010; Strubbe et al., 2010); (5) Internet applications (Marvin et al., 2009; Xia et al., 2009); (6) other tools (Kataria, 2007; Makowski & Mittinty, 2010).

to taxonomic groups, most studies investigated plants, followed by invertebrates and vertebrates, and only one focused on microorganisms (Carrasco et al., 2010, analysed three non-native species, including one microorganism). Finally, the majority (67.6%) of studies only investigated a single non-native species, and few looked simultaneously at multiple non-native species. Thus, a typical study on management tools for invasive species focuses on a single terrestrial plant species that is potentially invading, or has already invaded, Europe, North America or Australia.

Our results also show large differences in the factors considered in each study (Table 1). Features of the focal habitat (e.g. climate, geography or chemistry) and biological traits of the focal non-native species were the main factors considered. Only two studies (Roura-Pascual et al., 2009; Liu et al., 2010) considered legal, social, technical or scientific difficulties that could hamper or delay management actions, 10 considered inputs required to perform management actions, and 11 considered the predicted or expected effects of management actions. Considering only the 23 studies on risk analysis that were not also classified as cost-benefit or multi-criteria analyses, none of them considered predicted effects, inputs required or difficulties related to management actions. By their nature, risk analyses typically include species-ranking approaches (e.g. weed risk assessments) or predictions of which regions are more likely to be invaded (e.g. based on climate matching) but specific management actions, with their inherent difficulties, costs and effects, are rarely considered. Of the 26 risk analyses, five (19.2%) focused only on features of the focal non-native species, 10 (38.5%) focused only on features of the focal habitat, and 11 (42.3%) focused on features of both non-native species and habitats.

Despite the need for effective tools to optimize the management of biological invasions, there are few comprehensive cost-benefit or multi-criteria analyses available. We identified five such analyses in our sample of studies (Keller et al., 2008; Ameden et al., 2009; Roura-Pascual et al., 2009; Carrasco et al., 2010; Liu et al., 2010). The complexity of these analyses is reflected by their coverage of the key factors for decision-making tools (Table 1). Each of the five analyses included at least three factors but only one analysis (Roura-Pascual et al., 2009) included all five factors (i.e. features of the non-native species, features of the habitat, predicted effects, inputs required, and difficulties of management actions). Using the South African fynbos as an example, Roura-Pascual et al. (2009) offer a procedure for complex decision-making for plant invasion management. They employed the Analytic Hierarchy Process to prioritize management actions based on both species and stand attributes, while considering that environmental and management contexts (funding

TABLE 1 Specific factors considered by the 43 studies analysed, with the percentage (and number) of studies considering each factor (a blank cell indicates that no study of this category considered this factor).

Category (no. of studies)	Features of non-native species; e.g. biological traits, % (no.)	Features of habitat; e.g. climate, geography, chemistry, % (no.)	Effects of management; e.g. benefits by reduced invader impacts, % (no.)	Costs & other required efforts for management, % (no.)	Difficulties that may hamper or delay management, % (no.)
1, Cost-benefit & multi-criteria analyses (5)	40.0 (2)	60.0 (3)	100.0 (5)	100.0 (5)	40.0 (2)
2, Quarantine or border inspection (2)	50.0 (1)	50.0 (1)	100.0 (2)	100.0 (2)	
3, Risk analyses (26)	61.5 (16)	80.8 (21)	11.5 (3)*	11.5 (3)*	
4, Eradication, containment, control (17)	41.2 (7)	64.7 (11)	41.2 (7)	35.3 (6)	11.8 (2)
5, Internet applications (2)					
6, Other tools (2)	50.0 (1)		50.0 (1)	50.0 (1)	
All studies (43)	51.2 (22)	67.4 (29)	25.6 (11)	23.3 (10)	4.7 (2)

*These three studies are cost-benefit or multi-criteria analyses that include risk analysis

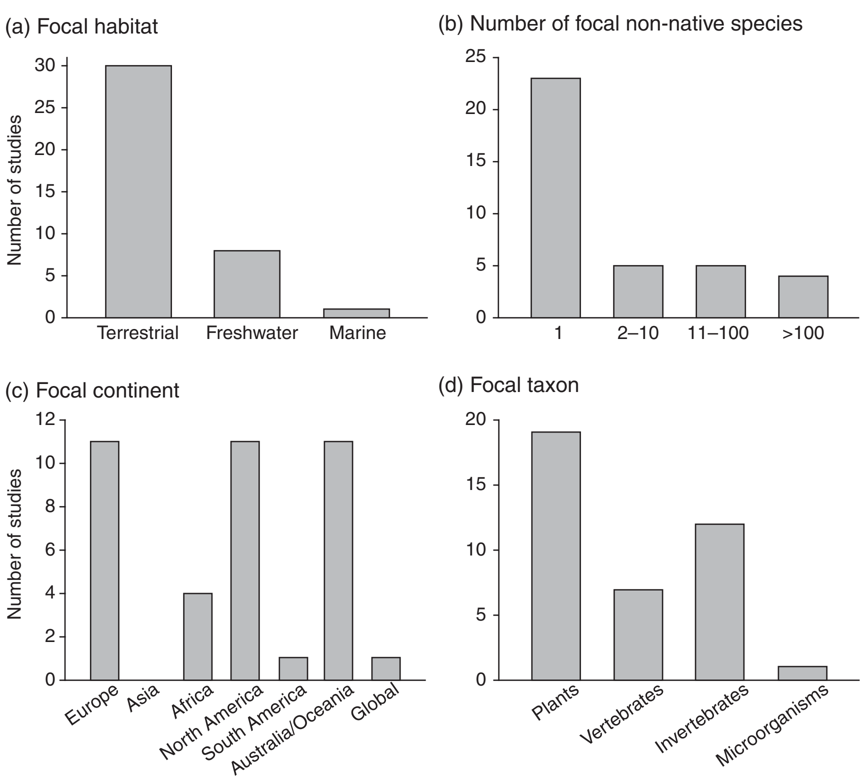

FIG. 2 Differences among studies in terms of (a) focal habitat, (b) number of focal non-native species, (c) geographical focus (on a continental scale), and (d) taxonomic group of focal non-native species. The studies are those listed in Fig. 1 but some theoretical studies could not be assigned to categories, which is why the number of studies does not sum to 43.

availability and permanence, management and institutional capacity, social or landowners' motivations) may also influence the final implementation.

Discussion

Current procedures used in decision making

Our analysis has revealed biases in current decision-making procedures for the management of biological invasions. Most published studies focus on certain decision-making tools such as risk analysis but largely ignore others. In particular, comprehensive cost-benefit or multi-criteria analyses are currently rare in the literature. This lack of a comprehensive methodology is mirrored by a lack in simultaneous consideration of multiple invasive species. We concur with Carrasco et al. (2010) that 'it is necessary to develop more comprehensive models that integrate the management of multiple NIS [non-indigenous species]' (p. 1304). Carrasco et al. did not base their criticism on quantitative evidence but our analysis now provides this evidence. The biases we found are not particularly surprising as they largely reflect general biases in research on biological invasions (Pyšek et al., 2008; Jeschke et al., 2012). They are nonetheless critical because, for example, not a single study included in our analysis focused on the largest continent, Asia. Africa and South America are both under represented in studies, which is not only problematic for the continents themselves but also for other continents, because invasive species established on one continent are likely to spread to others.

The majority of studies on decision tools for managing biological invasions are risk analyses. Because of a number of advantages (e.g. ease of use, possibility of calibration and adaptation), the combination of questions on scenarios and numerical score ratings has been used repeatedly in the design of biological risk analyses (e.g. Pheloung et al., 1999; Copp et al., 2009; Gassó et al., 2009a; Tricarico et al., 2010). This methodological approach has proven useful for guiding management prioritization (Roura-Pascual et al., 2009). It requires environmental managers or stakeholders to choose from pre-defined ordered categories that are then translated to a set of ordered scores; e.g. high-risk invaders are those with a high resulting score (e.g. Copp et al., 2009; Tricarico et al., 2010).

The general approach (not specifically directed at biological invasions) proposed by Joseph et al. (2009) may be helpful for the design of improved decision-making tools, specifically when different management options need to be compared. Joseph et al. (2009) analysed how to optimize resources invested in the management of threatened taxa. By using score ranks and weights they developed a procedure that takes into account not only ecological aspects but also those related to the management of threatened species. Their analysis is based on the Noah's Ark framework, an approach to conservation that considers costs and benefits of management actions for threatened species, thereby also estimating the value of these species (Metrick & Weitzman, 1998; Hartmann & Steel, 2006). Joseph et al. (2009) extended this framework by including the likelihood that management actions will succeed and thus developed a project prioritization protocol to optimize resource allocation among management projects in New Zealand. The protocol takes advantage of accessible information and previous experience, which is important because environmental managers generally have to rely on qualitative, scattered information (Ramsey & Norbury, 2009; Dana et al., 2011). In fact, comprehensive biological and ecosystem data are rarely available for many species, lessening the opportunity for using most published studies for management (e.g. Cacho et al., 2008; Dana et al., 2010). The use of semi-quantitative systems for prioritization has also included multidisciplinary aspects related to either biological conservation (e.g. Lahdelma et al., 2000; Ramsey & Norbury, 2009; Roura-Pascual et al., 2009; Liu et al., 2010; Miller et al., 2010) or resource planning and use (Munda, 1995; Bender & Simonovic, 2000; Mazari-Hiriart et al., 2006; Srdjevic & Medeiros, 2008; Wang et al., 2008).

Costs and benefits of managing biological invasions: biases and opportunities

Risk analyses and knowledge about characteristics of invasive species (invader traits) and potentially invaded habitats are essential for designing decision tools but they are not sufficient. Our results revealed that most published studies on the topic lack several factors that may be key for integrated decision-making processes. Besides biological and ecological complexities the management of biological invasions will benefit if variables that influence the feasibility of management actions and the probability that they succeed are considered more regularly. These variables may include the estimated time needed for management action, the resources required and the duration of available resources (economic, time, human resources), interactions with stakeholders (conflicts or synergies) and legal or political opportunities or constraints (Finnoff et al., 2005; Drechsler & Wätzold, 2007; Clout & Williams, 2009; Hulme et al., 2009; Joseph et al., 2009; Wainger et al., 2010; Epanchin-Niell & Hastings, 2010; Dana et al., 2011). Managers and scientists should be aware of funding availabilities, technical constraints, political or institutional opportunities, and even widespread reluctance to consider preventative measures against biological invasions (Andreu et al., 2009). We also recommend that tools for prioritizing management actions more often apply a multi-criteria framework that includes biological, ecological, and monetary factors as well as variables related to feasibility and predicted efficiency (Munda et al., 1995; Gamper et al., 2006; Gamper & Turcanu, 2007; Joseph et al., 2009; Roura-Pascual et al., 2009). Without the help of analytical tools management decisions will continue to be heavily subjective and based on insufficient information (Liu et al., 2010).

One reason for the current lack of comprehensive decision-making tools may be insufficient communication between managers, politicians and scientists (Andreu et al., 2009), which in turn is partly caused by difficulties in finding common ground. It would thus be useful to create effective and dynamic communication platforms for these sectors (Hulme, 2011).

Conclusions

Although studies published in the peer-reviewed scientific literature have recognized the need to improve management of biological invasions, more effort is required to develop integrated decision tools. Immediate consequences of the lack of such tools include a potentially biased selection of management actions, a lower success of actions taken, or inefficiency in the use of public resources (Finnof et al., 2007; Andreu et al., 2009). Despite the advancements achieved, the practical use of existing decision tools has often been limited, as they typically ignore economic, social, technical, institutional or political factors related to conservation and management practices. We call for more attention to these factors when developing decision-making tools for biological invasions.

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