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Control of Invasive Plants: Ecological and Socioeconomic Criteria for the Decision Making Process

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Abstract

Biological invasions have contributed to biodiversity loss, ecosystem degradation, and impairment of ecosystem services worldwide, requiring actions towards their prevention and control. Since human and monetary resources are both limited in most countries, priorities must be settled in the real world of biological invasion prevention and control. To support the decision making process regarding plant species already introduced, we propose a classification key, based upon biogeographical and ecological attributes of the target plant population. The key shall be applied to a particular biogeographical region, based on the premise that a species never invades two distinct ecosystems in the same way. The key categorizes the species according to the potential threats offered to the native biodiversity and ecosystem services in that region. Management strategies are recommended on the basis of both the species performance as invader and its economic importance in the region. We highlight the importance of ecological studies to categorize a species by the threats it offers to a specific ecological region, in order to avoid the waste of efforts and resources with non-risky species. Eradication experiments are equally important to find ecologically, technically and economically viable solutions for the problems derived from biological invasions.

Key words: Biological Invasions, Species Categorization, Management, Invasion Status, Impact Evaluation.

Introduction

The phenomenon of biological invasion comprises the human-mediated introduction of an alien species outside its native range, and its fate in the new range, including survival, establishment, reproduction, dispersal, spread, proliferation, interaction with native species, and influences on the invaded ecosystems (Richardson *et al.* 2011). In some cases, biological invasions can cause severe biodiversity losses and impairment of ecosystem services by modifying the structure of native communities, and often by changing soil properties, hydrological processes, biogeochemical pools, and fluxes of materials and energy (Armstrong 1995; D'Antonio *et al.* 1999; Ehrenfeld 2010; Le Maitre *et al.* 1996; McKinney & Lockwood 1999; Pysek & Richardson 2010; Rosenzweig 2001; Simberloff & Rejmánek 2011). The harmful effects of biological invasions have been widely recognized, and multi-scale programs are in place in many parts of the world to reduce current and future impacts (Pysek & Richardson 2010). Prevention and control actions are necessary to avoid or to reverse the negative effects of biological invasions. For the decision making process, that requires, at first, the identification of those species on which the actions shall be focused.

The terms that should be used to accurately express the different aspects and levels of biological invasions are still controversial (Colautti & MacIsaac 2004; Daehler 2001; Davis & Thompson 2000, 2001; Pysek *et al.* 2004; Rejmánek 1995; Rejmánek *et al.* 2002, 2013; Richardson *et al.* 2000, 2011). A general concept has been widely accepted: invasive exotic species (IES) are those that colonize and expand into an ecosystem they have not previously naturally inhabited (Richardson *et al.* 2000; Williamson 1996; Pysek *et al.* 1995, 2004). However, this concept includes from 'benign invaders' up to 'transformers', a term proposed by Wells *et al.* (1986) and adopted by Richardson *et al.* (2000, 2011). The most controversial issue is the impact of the alien species over the new environment. For most ecologists, an invader not necessarily causes impact in the new range (Richardson *et al.* 2000, 2011; Daehler 2001; Pysek *et al.* 2004; Rejmánek *et al.* 2002, 2013). For some other ecologists and, particularly, for those dealing with

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practical issues related to biological invasions (Cronk & Fuller 1995; IUCN 2000; CBD 2000; Davis & Thompson 2000), an invader must have an undesirable impact on its new environment, whether economic, health, or ecological. From the point of view of managers and policy makers, the most important issue is: which species deserve attention and which should be controlled first? The answer to this question requires differentiation among alien species causing impact or not, and, preferably, a hierarchical classification on the basis of extension and severity of impact they cause on the invaded ecosystem. In order to differentiate the invasion status of a plant population, some basic features must be considered, such as: whether the invaded ecosystem is natural or seminatural or the invasive plant is found exclusively in disturbed areas (Pysek *et al.* 2004). The lack of consensus regarding the operational categorization of an 'invasive species' is a constraint for the decision making process (Colautti & MacIsaac 2004; Simberloff *et al.* 2005; Khuroo *et al.* 2008).

In spite of the uncertainties on definition and categorization of invasive species, official lists of invasive species have been elaborated and published to support public policies towards the prevention and control of biological invasions. In Brazil, official lists of invasive species have been discussed at the leading states like São Paulo, Paraná and Rio de Janeiro. Zenni & Ziller (2011) presented a pioneer long list of 117 plant species reported as invasive in Brazil. Considering the precaution principle, the initiative of creating a dataset with the occurrence of invasive species is positive. However, as this list lacks criteria, it groups together both the invasive species threatening the native biodiversity and ecosystem functioning (the *transformers*), and non-risky exotic species that occupy only disturbed areas or do not proliferate. In Brazil, the occurrence of *transformer* species has been registered, such as *Pinus elliotti* L. (Zanchetta & Diniz 2006; Almeida *et al.* 2010; Abreu & Durigan 2011), *Urochloa decumbens* (Stapf) R.D.Webster (Pivello *et al.* 1999) and *Melinis minutiflora* P.Beauv. (Hoffmann *et al.* 2004) in the Cerrado; *Archontophoenix cunninghamiana* H. Wendl. & Drude (Dislich *et al.* 2002) and *Artocarpus heterophyllus* Lam. (Abreu & Rodrigues 2010) in the Tropical and Subtropical Rain Forest; *Prosopis juliflora* (Sw.) DC. in the Caatinga (Tropical Drought-Deciduous Forest and Woodland, Pegado *et al.* (2006)); and *Eragrostis plana* Nees in Temperate Grasslands (Medeiros & Focht 2007). High priority should be given in public policies for these species, in the mentioned ecological regions. On the other hand, there are some examples of unlikely invasions, such as C4 African grasses invading the rain forest or the flesh fruit trees *Artocarpus heterophyllus* and *Mangifera indica* L. invading the Cerrado. Nevertheless, they were included in the list from Zenni & Ziller (2011), as well as *Cupressus lusitanica* Mill., *Sterculia foetida* L., and *Eucalyptus robusta* Sm. – which are not really invasive anywhere in Brazil; and *Centella asiatica* (L.) Urb. – which has a pantropical distribution. For the absence of robust criteria to differentiate the species by their threat, the lists do not help much in the decision making process. Claiming for improvement of information on invasive plants in the botanical lists, Moro *et al.* (2012) proposed the classification of species as *exotic*, *naturalized*, *weed*, *ruderal* or *invasive*, based on their population size and reproductive success. They suggest that exotic species should be easily categorized by botanists in taxonomic, floristic or phytosociological studies. However, based on these criteria, species like *Ricinus communis* L. or *Leucaena leucocephala* (Lam.) de Wit, which spread only over roadsides in most regions of Brazil, do not differ from the '*transformers*', being all labeled as 'invasives'. This hampers the action prioritization. We agree that the omission of exotic species in botanical studies and regional surveys is negative, and they should always be reported, as proposed by Pysek *et al.* (2004). However, there is a great risk of labeling all non native species occurring outside their native ranges as simply 'invaders', without the differentiation that gives support for management decisions.

In addition to the problem of all species in the lists grouped in a single category – '*invasive*', the national lists ignore that political boundaries are not an ideal framework for the categorization of plant invasion (Pysek *et al.* 2004). Invasiveness of an alien species varies among ecosystems, being correlated to ecological range, and invasibility of an ecosystem is variable among species according to their biological attributes (Alpert *et al.* 2000; Lodge 1993; Rejmánek *et al.* 2013). Many alien species can be invasive in some regions and have few or no negative impacts in other regions, even within the same country (Williamson 1996; Simberloff & Rejmánek 2011). Biological invasions represent a biogeographical rather than a taxonomic phenomenon, and, thus, the invasion status should refer to each individual population and not to all populations of a certain species (Colautti & MacIsaac 2004). Before including alien species in official lists of dangerous species and expending resources in their eradication or control, clear criteria are necessary in order to differentiate those species requiring management actions in each biogeographical region. Careful prioritization is necessary to optimize the allocation of resources (Hiebert 1997; Moody & Mack 1988; Rouget *et al.* 2002; Rejmánek *et al.* 2013).

A third problem related to biological invasions is the unclear differentiation between risk assessment and impact evaluation. Risk assessment aims to prevent invasion by avoiding the introduction of harmful species to a new environment. Risk assessment protocols are often based upon the species attributes in their native ranges to predict if they can behave as invasive in the new range (e.g. Pheloung *et al.* 1999 in New Zealand; Tye (2001) in the Galapagos Islands; Werren (2001), in Australia). When dealing with already introduced species, it is a matter of impact evaluation. Some initiatives to assess and categorize invasive species based on their performance in the new range (impact) have been presented (e.g. Hiebert & Stubbendieck (1993) in the USA; Colautti & MacIsaac (2004); Khuroo *et al.* (2008) in India; Thomas *et al.* (2012) in Brazil). All these initiatives,

as well as the present study, aim to prioritize management actions when the exotic species are already established in the new environment. This is particularly important for management plans of individual protected areas, but it is also relevant for decisions on the conservation and management of biodiversity on broader scales. Here, we propose a dichotomous key to classify plant species already established, on the basis of species population ecology, and discuss management implications related to invasion status and economic importance of the species, in addition to the ecological relevance of the invaded environment.

A Protocol to Assess the Invasive Performance of a Plant Species in a Particular Biogeographical Region

The first challenge to classify the species by their threat to natural ecosystems is to identify the attributes of the species or population that really matter. Considering what science has already explained about plant invasions, we suggest the attributes and categories listed in Table 1. These biological attributes (Table 1) were used to assemble a dichotomous key (Table 2), which allows the user to choose between successive pairs of alternative descriptions, until coming to the category that matches the species population under consideration.

We acknowledge that species categorized as *ruderals* are included among the invaders by most ecologists (Richardson *et al.* 2000; Williamson 1996; Pysek *et al.* 1995, 2004; Rejmánek *et al.* 2013). However, considering that the level of threat posed by alien species on the native biodiversity is much higher when they invade natural ecosystems than when they spread over disturbed areas, we decided to keep these two groups of species in distinct categories, adopting the term 'ruderal' for the last. This clear distinction and objective denomination is necessary for managers, since management interventions and the priority level of actions shall be remarkably distinct between these two groups of species.

Additional Points to Consider When Prioritizing the Control of Biological Invasions

In addition to the classification of the invasive species population based upon the criteria suggested here (Table 1), some other ecological and, particularly, technical and socioeconomic aspects must be considered by decision makers. Such elements are essential to set priorities, and to evaluate the convenience and liability for invasion control:

1) What is the ecological importance of the invaded site?

Losses caused by invasion are in decreasing order if the invaded site is a protected area, a remnant of native vegetation, a riparian zone, roadsides, or a degraded area. The less disturbed the ecosystem, the higher the priority for interventions aiming to reduce biodiversity losses. Occupation of degraded areas by exotic species can, in some cases, be positive, by recovering ecosystem services where the natives can hardly establish.

2) How fast can the invasive population expand?

Considering species for which eradication is recommended and possible, those that spread more rapidly shall be controlled first.

3) How important is the invasive species for the regional economy?

If the species has no social or economic importance, there are no constraints for its management or even eradication. If the species has economic or cultural relevance, control actions have to consider the social impact, besides the environmental aspects.

4) Can the invasive be replaced by a non invasive species that play the same function?

For those species that are important for people and are irreplaceable, eradication must be seen with restrictions. In these cases, actions must be directed towards the control of

Table 1. Attributes and categories to classify a plant species as invasive based on the threat it offers in a particular biogeographical region.

Attributes	Categories
Origin	• taxa that evolved in the region, or reached it from another area where they are native without human interference (native) • taxa which owe their presence in the region to contemporary human activity (non native)
Natural regeneration potential	• taxa that occur only temporarily in the area, and are not able to persist for a long time without human assistance • form sustainable populations without human interference, but do not necessarily spread
Habitat type	• do not establish in natural (undisturbed) ecosystems, spreading preferable over disturbed areas • form sustainable populations without human interference and spread over natural (undisturbed) ecosystems
Dominance	• do not inhibit native species regeneration and growth • change the composition or structure of the native plant community, inhibiting or suppressing the regeneration of native species

Table 2. Dichotomous key to classify plant species by their invasion status in a particular biogeographical region. Nomenclature adopted in this paper is in **bold**. Other denominations given for each category were considered as synonymous, based on their use in the relevant literature (e.g. Daehler 2003; Groves 1992; Mack 1996; Owen *et al.* 1996; Adair & Groves 1998; Pysek *et al.* 2004; Rejmánek *et al.* 2002, 2005, 2013; Woitke & Dietz 2002; Richardson *et al.* 2000, 2011).

1a	Native species (includes cosmopolites)	2			
	2a	Does not form pure stands at the level of inhibiting regeneration of other native plant species	**Wild species** Non agressive native species		
	2b	Forms pure stands or dominates the community at the level of inhibiting regeneration of other native plant species, especially in degraded sites	**Dominant wild species** Agressive native species Competitive wild species Dominant native species Native weed "Native invader"		
1b	Alien (non indigenous, non native, exotic)	3			
	3a	occurs only temporarily, not leaving persistent descendants without human assisted input of diaspore	**Casual alien Species** Transient alien species		
	3b	forms sustainable populations without human help (naturalized plants)	4		
		4a	Does not establish in undisturbed natural ecosystems, spreading only in degraded or anthropized areas (ruderals)	5	
			5a	Does not form pure stands, not inhibiting regeneration of native plant species	**Non dominant ruderal** Non aggressive weed Minor weed Non competitive weed
			5b	Forms pure stands or dominates the community, inhibiting regeneration of native plant species	**Dominant ruderal** Aggressive weed Competitive weed Environmental weed Pest plant
		4b	Establishes in undisturbed natural ecosystems	6	
			6a	Does not spread nor change the composition or structure of the native plant community	**Non dominant invader** Non aggressive invader Non competitive invader Naturalized
			6b	Spreads and changes the composition or structure of the native plant community, suppressing the regeneration of native species	**Dominant invader** Aggressive invader Competitive invader Environmental weed Super invader Transformer Pest plant

the invasive population, instead of eradication of the species. If replacement by a noninvasive is possible, eradication of the invader can be the goal, if technically possible.

5) Is the eradication technically feasible?

In some cases, eradication is technically impossible. Even if the species is a dominant invader, the only viable recommendation in such cases is avoiding population expansion over new habitats.

6) Is ecological restoration possible after eradication?

Environmental changes caused by invasive species can be irreversible in some situations and, thus, the native vegetation cannot be recovered. The success of restoration after eradication has been frequently hampered by re-invasion or establishment of a novel invader (Kettenring & Adams 2011).

Management Recommendations

Prevention of biological invasions is the first strategy to be adopted, by avoiding the introduction of harmful species, which is much less costly than post-entry control (Finnoff *et al.* 2007). However, when dealing with already invaded areas, extirpation and control form the cornerstones of the practices recommended to restore invaded ecosystems. Depending on the category of the species in the region, from those provided by the classification key, management strategies recommended can vary in type and extent of intervention, as follows:

1) Management intervention:
   a) Management not required;
   b) Invasion avoidance (isolation of native ecosystems);
   c) Population control (thinning);
   d) Extirpation of the invasive population;
   e) Disincentives for cultivation;
   f) Cultivation permitted under strict rules;
   g) Cultivation of the species prohibited.
2) Areas where interventions shall be applied:
   a) The interior of legally protected areas (parks and reserves);
   b) Other remnants of natural ecosystems;
   c) Buffer zones of protected areas;
   d) Areas under ecological restoration;
   e) The entire biogeographical region (beyond natural ecosystems).

Management recommendations are presented for every category from the classification key (Table 3).

Table 3. General management recommendations for populations of plant species on the basis of their status as invasive (diagnosed according to the criteria from Table 2).

Category		Management recommendation
Wild species		• management not required;
Dominant wild species		• overpopulation control in the interior of legally protected areas (low priority) • population control in areas under ecological restoration (low priority)
Casual alien species		• extirpation from legally protected areas (low priority)
Non dominant ruderal		• extirpation from legally protected areas (low priority)
Dominant ruderal		• extirpation from legally protected areas (intermediate priority) • extirpation from areas under ecological restoration (high priority) • discouragement of cultivation in the buffer zones of protected areas (intermediate priority)
Non Dominant Invader		• extirpation from protected areas (intermediate priority) • disincentives to cultivation in the buffer zone of protected areas (low priority) • Invasion avoidance – isolation of the natural ecosystems (low priority)
Dominant Invader	*Irrelevant for the regional economy*	• extirpation from the whole biogeographical region (high priority) • cultivation prohibited in the whole region (high priority)
	Relevant for the regional economy	• extirpation from legally protected areas (high priority) • extirpation from other natural ecosystems (high priority) • extirpation from areas under ecological restoration (high priority) • Invasion avoidance – isolation of the natural ecosystems (high priority) • disincentives to cultivation (high priority) • cultivation permitted under strict rules (permanent invasion control by those cultivating the species) (high priority)

Invasiveness, Biogeography, Economy and Management

Risk assessment should be reinforced to avoid the spread of exotic species which can potentially perform as invasive in a new environment. This is not related, however, to management decisions. For those species already introduced with populations established in the new range, the performance of the species and the consequences of the invasion need to be evaluated before management decisions.

Since the status of invasion of a species varies greatly among regions, the categorization of plants in the context of biological invasions must be restricted to individualized biogeographical regions, where at least soil and climate conditions are relatively homogeneous. These are environmental factors governing the adaptation of a species to a geographic range and, consequently, to the local invasiveness of the species (Lodge 1993; Kolar & Lodge 2001; Noble 1989; Rejmánek & Richardson 1996) and to the invasibility of the habitats (Crawley 1987; Goodwin *et al.* 1999; Lonsdale 1999; Prieur-Richard & Lavorel 2000; Shea & Chesson 2002; Thuiller *et al.* 2005). Some alien species seem to have few or no negative impacts in certain regions, but behave as dominant invaders in other regions (Williamson 1996; Simberloff & Rejmánek 2011). Management strategies, therefore, can be settled for the biogeographical region as a whole, even when it contains more than one population of the same species, as they will perform similarly under homogeneous soil and climate conditions.

By incorporating the socioeconomic relevance of the species into management decisions, we put the subject under a sustainable development perspective. Permanently controlling the spread of an alien species over natural ecosystems can present a benefit:cost ratio better than extirpation in cases of economically very important species that cannot be immediately replaced in the regional economy. In these cases, the costs of invasion control shall be incorporated to the supply chain.

As observed by Davis (2011, p. 368),

> "[...] the ecological impacts of introduced species are many, and they vary from species to species, and environment to environment. Invasion biologists have only begun to understand the array and extent of these effects."

There is no widely recognized protocol to diagnose invasion impacts, and this has been an obstacle to be surpassed. Although the knowledge on invasive plant species has increased considerably, our ability to predict their impacts, or even measure them by using standardized methods, is still very rudimentary (Rejmánek *et al.* 2013). The simple observation of the species occurrence outside its native range, even reported by scientists, is important as the first step in invasion detection, but is certainly not enough to label a species as invasive or harmful for an entire region or a country as a whole. We need, at first, to apply proper ecological methodology in order to assess the dimensions and consequences of the invasion by different species in distinct ecological regions. Thenceforth, for aggressive invaders, which can displace native species and effectively cause biodiversity losses or changes in ecosystem functioning (the dominant invaders from the dichotomous key, in Table 2), urgent eradication experiments are needed in order to find technically, ecologically and economically feasible eradication practices and restoration techniques.

The framework that we described here can assist the managers and policy makers when defining and prioritizing actions related to alien plant species. For its effectiveness, however, ecologists must be involved in the diagnosis of the invasion status. The categorization of a species as invader demands specific studies on the species population in the invaded environment. We expect that the dichotomous key and the management recommendations proposed here can help improving the selection of which invasive species should be managed at first within each ecoregion and, particularly, which alien species do not require efforts or resources to their eradication or control.

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