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Research Article

Methods for Prioritizing Invasive Plants in Protected Areas: A Systematic Review

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ABSTRACT

Invasive species are recognized as one of the biggest threats to biodiversity and dealing with them is a daunting challenge for protected area managers. Prioritization based on multiple criteria has been traditionally recommended as essential for the effective management of invasive species. A systematic literature review was undertaken to assess to what extent the scientific literature provides guidelines for implementing priority systems as part of management strategies for invasive plants in protected areas. We detected only 27 studies published up to 2019 reporting some kind of prioritization. Most of them were limited to a list of species built from a combination of biological information extracted from literature and data on the extent and effects of their presence in the area. Our review also revealed that risk analysis has been commonly confounded with prioritization tools. Despite the generalized recognition of the impact of invasive plants on biodiversity, managers of protected areas lack readily applicable support from scientific literature to set up prioritization schemes.

Index terms: biological invasion; conservation; management; prioritization

INTRODUCTION

Protected areas (PA) are established and managed with the conservation of biodiversity features, either species, communities, habitats, or ecosystem processes and services, as a major objective (Barrett and Barrett 1997; Carwardine et al. 2009; Jepson et al. 2017). Due to their specific objectives, functions and environmental settings, the demands and approaches of management in PA are different from those faced by other kinds of organizations and land uses (Worboys and Winkler 2006). Invasive alien plants (IAP) represent a serious risk to native species and other biodiversity assets (Richardson et al. 1989; Downey et al. 2010), are considered the second biggest threat for biodiversity (Wilcove et al. 1998), and are a top management priority in PAs (De Poorter and De Poorter 2007: p. 15).

The ability of managers to respond to IAP in PAs still presents big challenges. After all, to accurately predict which ecosystem will be invaded and by which plants is almost impossible (Rejmánek 2000; Masters and Sheley 2001). Many alien species have little or no detected effect on a new environment (Blackburn et al. 2014), the outcomes may be perceived as negative or positive from the perspectives of different stakeholders (Graves and Shapiro 2003; Chiba 2010; Schlaepfer et al. 2011), the management methods in PAs are usually restrained compared to areas not engaged in conservation (Hobbs and Humphries 1995; Odom et al. 2005), human and financial resources are usually limited (Davis 2003; Davies and Sheley 2007), and PAs usually have broad extension and poor access, and there is a risk of collateral damage to conservation assets (Denslow 2007).

Given the large and increasing number of invasive species, the diversity of vectors and pathways of introduction and spread, and the unique challenges of management in PAs, managers face the challenge of choosing where to focus their efforts carefully (Davis 2003) under scenarios of high uncertainty. Prioritization does appear now as an essential tool to manage IAP at all stages of the invasion process (Heikkilä 2011; McGeoch et al. 2016). Prioritization is "the process of ranking species, pathways or sites for purposes of determining their environmental impact and set the priority of actions to adequately and efficiently prevent or reduce the impact of invasive alien plants" (McGeoch et al. 2016). Formal prioritization processes are expected to do better than individual judgment or other alternatives (Heikkilä 2011) because they are transparent, can be replicated, and they contemplate multiple factors, provide quantitative instruments to assist decision-making when there are several and conflicting objectives that are measured in different units, work through information and grouping the problems, and can be adapted and easily updated (Dooley et al. 2005; Skurka Darin et al. 2011; McGeoch et al. 2016). Recognizing the importance of prioritization and in an effort to encourage its use, in October 2010 the Convention on Biological Diversity (CBD-UNEP) adopted as aim number 9 of its Strategic Plan for Biodiversity 2011-2020 (Aichi Biodiversity Targets) that "by the year 2020 invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment" (https://www.cbd.int/sp/targets/2011), although there were no instructions given on how to accomplish this goal.

A multitude of prioritization approaches and schemes have been designed to date, although very little is known about their application in PAs (Heikkilä 2011) and there are still several shortcomings and limitations to be overcome. Prioritization can be applied at any stage of the invasion, focusing on decreasing the entry and establishment (exclusion), detecting the invasion as early as possible, or controlling it (Carrasco et al. 2010). Prioritization can as well be applied to any management approach, either focusing on invasive species or invaded sites (MIPAG 2012). Most of the prioritization schemes available rank invasive species based on some criteria of weed risk weight (Pheloung et al. 1999; Carrasco et al. 2010; D'hondt et al. 2015; McGeoch et al. 2016; Dodd et al. 2017), but management feasibility is rarely taken into account (Dodd et al. 2017), and it is unclear how embracing and practical they are when compared to usually proposed criteria. Moreover, to be practical and accessible, a scheme must be translated into frameworks, guidelines, or protocols. These are considered an essential part of human health practice (Pullin et al. 2004; Glasgow and Emmons 2007; Kredo et al. 2016), but are still lacking in conservation practice (Pullin et al. 2004; Pullin and Knight 2009; Laurance et al. 2012). Referring to formal methods for setting threatened-species priorities, Joseph et al. (2009) noted that simply ranking a species as highly threatened or valuable in some area does not guarantee success in managing it, as species management also varies in feasibility.

A quantitative assessment of studies can identify evidence-based guidance for improving the correct application of prioritization management of IAP in PAs. Systematic reviews and meta-analysis are the best levels of scientific evidence since they base their findings on systematic protocols of search and interpretation of research background, more comprehensive and less biased than other forms of review (Pullin and Stewart 2006; Cook et al. 2013; Doerr et al. 2015). In addition, the use of systematic reviews in the area of ecology and management is still scarce despite works demonstrating the importance of using this tool in conservation to increase the efficiency of the techniques used (Fazey et al. 2004; Sutherland et al. 2004; Cook et al. 2013). In an attempt to gain insight into translating invasive plant prioritization research for application in PA, we asked one broad question: What tools, approaches and criteria have been most used for the prioritization of plant invasions in PAs? We used published assessments of invasive plant prioritization in PAs to address this question and systematically analyzed invasive plant prioritization over all invasion stages, multiple species, and PAs.

METHODS

We built a protocol search based on PRISMA's criteria (Moher et al. 2009).

Criteria for Considering Studies for This Review

We included empirical or theoretical studies that (1) applied or proposed criteria for prioritization of invasive plants, (2) were explicit about the criteria and how to combine them, (3) were promptly applicable for prioritization or to be included in a prioritization scheme, and (4) were applicable in protected areas.

Search Methods for the Identification of Studies

We framed the question using a set of keywords grouped in five topics of interest: **1-Protected area**: ("*Protected area**" *OR park* OR* "*protected landscape**" *OR* "*nature reserve**" *OR* "*wilderness protection**" *OR* "*wilderness area**" *OR* "*resource protected area**" *OR reserve* OR* "*natural area**" *OR* "*conservation area**" *OR heritage* OR* "*ramsar site**" *OR* "*natural monument**" *OR* "*protection site**" *OR* "*conservation site**" *OR* "*nature monument**" *OR* "*historic site**" *OR* "*historical site**"); **2-Invasive**: (*weed* OR pest* OR invasive* OR* "*non-native**" *OR* "*non indigenous**" *OR alien* OR invader* OR imported* OR introduced* OR naturalized* OR colonizer**); **3-Plant**: (*weed* OR plant* OR tree* OR vegetation* OR habitat**); **4-Intervention**: ("*rapid response**" *OR* "*early warning**" *OR* "*early detection**" *OR prevention* OR intervention* OR control* OR management* OR maintenance* OR* "*alien clearing**" *OR extirpation* OR eradication* OR modeling* OR monitoring* OR assessment* OR evaluation* OR screening**); **5-Outcome**: *(protocol* OR analysis* OR risk* OR* "*systematic conservation planning**" *OR* "*expert judgement**" *OR prioritization* OR* "*decision making**" *OR scheme* OR strategy* OR* "*action plan**" *OR guide* OR rationale* OR method**). We first ran a search for each keyword group and then combined them using the connector **AND**.

We excluded experimental studies not conducted at real management scale and studies not focused on the conservation of biodiversity by filtering the retrieved database adding exclusion words using the expression **NOT** (*Urban* OR Bird* OR Pesticide* OR Crop* OR* "*Green House**" *OR Herbicide* OR Agriculture* OR Nutrient* OR Medicine* OR Mineral* OR Insect* OR Engineer**). We excluded studies in urban settings because we are interested in evaluating IAP management in natural, wild settings. Urban settings are peculiar in disturbance regimes, novelty of resources and conditions, and strength of human pressures, and green areas have different objectives from those of PAs.

We further refined the first combination to specific scientific areas of interest: *environmental sciences ecology* OR *plant sciences* OR zoology OR *biodiversity conservation* OR *forestry*; and *agriculture & biological science and environmental science*, for Web of Science and Scopus, respectively. We carried out the structured search in the databases Scopus and Web of Science. We also developed a loosely structured search on Google academic (scholar.google.com) combining a few keywords of the topics 1, 2, and 5. We also searched the web pages of relevant organizations in order to find additional published and gray literature (Table 1).

Only studies written in English were considered. The search was done without restriction on time and included all studies before 20 September 2021.

Selection of Studies and Data Extraction: All citations identified were entered into an electronic database and duplicates were deleted. The search produced more than 6000 unique references. After removing the duplicates, the remaining titles and abstracts were systematically screened. Initially, one investigator screened the titles and abstracts of potentially

Table 1.—Organizations we searched for reports and publications providing guidance for the prioritization of management of invasive alien plants in protected areas.

Organization	Website
USGS	https://gapanalysis.usgs.gov/padus/
IUCN	https://www.iucn.org/theme/species/our-work/invasive-species
Instituto Hórus	http://www.institutohorus.org.br
European Environment Agency	https://www.eea.europa.eu/themes/biodiversity/europe-protected-areas/europe-protected-areas-1
Australian Department of the Environment and Energy	http://www.environment.gov.au/land/nrs/about-nrs/australias-protected-areas

relevant studies for eligibility. When the information was not sufficient to determine if the article was eligible for inclusion, the article's full text was obtained for further evaluation and the inclusion was discussed with a second investigator until consensus was reached. Relevant title publications were then appraised using the full text.

We read the retrieved publications to extract information to answer the following questions:

- Was a formal protocol presented?
- What categories of criteria were used?
- What kind of data source was used?
- Was the approach based on invasive species or invaded sites?
- At what spatial scale was the prioritization applied?
- Did the approach involve modeling, remote sensing, mapping?
- Was the approach adaptive?
- What has been applied in conservation area (more studies found means that they are applying prioritization)?
- Which stage of invasion did they focus on (prevention, early detection or control)?
- Which outcome did they have?

We summarized the results (Table 2), listing the publications included and depicting the information about the above questions that was explicitly considered in each prioritization proposal.

RESULTS

Our search returned 27 studies published since the beginning of the database up to 2021 that reported IAP's management prioritization in protected areas context (Figure 1; Table 2). The oldest study was from 1999, while the newest was from 2016. One third of the studies were applied in USA, 22% in Africa, and 7% in Australia.

Most studies (52%) were conducted using literature as the source of data, 30% combined data from field and literature, and only a few (11%) used some kind of remote data or were based on field surveys (7%; Figure 2).

Impact was the most commonly used criterion (52%), vulnerability/risk was used in 37% of the studies, and management feasibility was considered in just 4% (Figure 3). Only two of the studies used more than one criterion, one combining vulnerability/risk and feasibility, and the other combining impact and costs. Criteria evaluating the costs or feasibility of management were rarely used. Under the vulnerability/risk criteria, 30% of the studies used the plant's ability to colonize an area as a sub-criterion, followed by plant attributes and history of invasion (20% each). Other sub-criteria considered a list with all aliens present in the area to then choose the priority species, invasion risk, and the species' invasive behavior in the area, with each of them used in 10% of studies. The main sub-criteria used as measures of impact were the prevalence of the species (30%), followed by an invasive plant ranking (20%), and by previous invasive behavior elsewhere, local impact (at the PA), a list of exotic species composition, and an estimation of areas most invaded locally, with 10% each of usage. To assess the impact, the main criteria used were the extension of the invasion and the species' distribution. Ten percent of the studies did not clarify the criteria used to measure the impact.

Sixty-seven per cent of the studies used only data from presence of species, 26% used presence/absence, and few used abundance (7%) (Figure 4). More than 50% of the studies focused on prevention by searching for potential areas where the species could eventually occur, 22% concentrated on controlling species already established, 22% focused on early detection, and only 4% proposed protocols for eradication (Figure 5). Most of the studies (52%) focused on invasive species prioritization, while 48% focused on invaded sites (Figure 6). More than 70% of the studies were conducted at a local scale, 15% focused on multiple scales, and 11% of the considered a regional scale (Figure 7). Finally, only nine studies (28%) presented an explicit prioritization scheme. The majority did not provide any guidance that could be replicated in other areas.

DISCUSSION

Our review suggests a scarcity of readily applicable schemes designed to prioritize the management of invasive alien plants in protected areas, despite their importance as a main threat to biodiversity. Although prioritization is recognized as a key component to assist conservationists in choosing the best target to allocate resources, our study found that this kind of tool is infrequently available (Downey et al. 2010). The retrieved publications share in common the tendency to focus on prevention of invasions at local scales using literature as the source of data and considering explicit criteria for evaluation but failing to provide an explicit prioritization protocol. The major shortcomings we found are the lack of consideration of costs and feasibility, the lack of methods based on real, field-based data about the invasion status and effects, and the lack of concern about the relative importance of different conservation targets. The shortage and narrowness of publications related to the application of IAP prioritization in PAs may be conditioned by the scarcity of data about invasive species in PAs. Our review probably underestimated the efforts in place aimed at prioritizing IAP in PAs that are not well communicated or that are not readily available at the search engines used.

Two major approaches are alternatively used for prioritization, focusing either on invasive species or on invaded sites (McGeoch et al. 2016). While the first tends to accent attributes

Table 2.—Summary of studies that provided guidance for the prioritization of management of invasive alien plants in protected areas that met the criteria of inclusion. "Yes" means that the criteria were present, and "No" means that the criteria were not provided.

					1 - Data Source			
#	Author	Year	Title	Region	Field	Remote	Literature	Questionnaire
1	C.C. Young and J.L. Haack	2009	A rapid, invasive plant survey method for national park units with a cultural resource focus	EUA	Yes		Yes	
2	D.G. Despain, T. Weaver, and R.J. Aspinall	2001	A rule-based model for mapping potential exotic plant distribution	EUA			Yes	
3	R.F. Fernandes, J.R. Vicente, D. Georges, P. Alves, W. Thuiller, and J. P. Honrado	2014	A novel downscaling approach to predict plant invasions and improve local conservation actions	EU		Yes		
4	J. Hortal, P.A.V. Borges, A. Jimenez-Valverde, E.B. de Azevedo, and L. Silva	2010	Assessing the areas under risk of invasion within islands through potential distribution modelling: The case of *Pittosporum undulatum* in São Miguel, Azores	EU			Yes	
5	C.C. Jones, S.A. Acker, and C.B. Halpern	2009	Combining local- and large-scale models to predict the distributions of invasive plant species	EUA			Yes	
6	J.R. Vicente, D. Alagador, C. Guerra, J.M. Alonso, C. Kueffer, A.S. Vaz, R.F. Fernandes, J.A. Cabral, M.B. Araújo, and J.P. Honrado	2016	Cost-effective monitoring of biological invasions under global change: A model-based framework	Portugal			Yes	Yes
7	C. Hui, L.C. Foxcroft, D.M. Richardson, and S. MacFadyen	2011	Defining optimal sampling effort for large-scale monitoring of invasive alien plants: A Bayesian method for estimating abundance and distribution	RSA	Yes		Yes	
8	T.J. Stohlgren, P. Ma, S. Kumar, M. Rocca, J.T. Morisette, C.S. Jarnevich, and N. Benson	2010	Ensemble habitat mapping of invasive plant species	EUA	Yes		Yes	
9	R. Zhang, J. Liu, L. Mo, and Z. Zhang	2014	Environmental and human factors in influencing invasive plant species in Songshan National Nature Reserve	China	Yes			
10	D. Spear, L.C. Foxcroft, H. Bezuidenhout, and M.A. McGeoch	2012	Human population density explains alien species richness in protected areas	RSA			Yes	
11	L. Jefferson, K. Havens, and J. Ault	2004	Implementing invasive screening procedures: The Chicago Botanic Garden model	EUA			Yes	
12	T.R. Lookingbill, E.S. Minor, N. Bukach, J.R. Ferrari, and L.A. Wainger	2014	Incorporating risk of reinvasion to prioritize sites for invasive species management	EUA	Yes		Yes	
13	A. Pauchard and P.B. Alaback	2004	Influence of elevation, land use, and landscape context on patterns of alien plant invasions along roadsides in protected areas of south-central Chile	Chile	Yes			
14	R. Otfinowski, N.C. Kenkel, P. Dixon, and J.F. Wilmshurst	2008	Integrating climate and trait models to predict the invasiveness of exotic plants in Canada's Riding Mountain National Park	Canada			Yes	
15	M. Masocha and A.K. Skidmore	2010	Integrating conventional classifiers with a GIS expert system to increase the accuracy of invasive species mapping	Zimbabwe		Yes		
16	G.P. Asner, D.E. Knapp, T. Kennedy-Bowdoin, M.O. Jones, R.E. Martin, J. Boardman, and R.F. Hughes	2007	Invasive species detection in Hawaiian rainforests using airborne imaging spectroscopy and LiDAR	EUA		Yes		
17	A. Barros and C. Marina Pickering	2013	Non-native plant invasion in relation to tourism use of Aconcagua Park, Argentina, the highest protected area in the Southern Hemisphere	Argentina			Yes	
18	K.M. Giljohann, C.E. Hauser, N.S.G. Williams, and J.L. Moore	2011	Optimizing invasive species control across space: Willow invasion management in the Australian Alps	Australia	Yes		Yes	
19	L.C. Foxcroft, D.M. Richardson, M. Rouget, and S. MacFadyen	2008	Patterns of alien plant distribution at multiple spatial scales in a large national park: Implications for ecology, management and monitoring	RSA			Yes	
20	D.I.S. Odom, O.J. Cacho, J.A. Sinden, and G.R. Griffith	2002	Policies for the management of weeds in natural ecosystems: The case of Scotch broom (*Cytisus scoparius* L.) in an Australian national park	Australia			Yes	
21	T. Dirnbock, J. Greimler, P. Lopez S., and T.F. Stuessy	2003	Predicting future threats to the native vegetation of Robinson Crusoe Island, Juan Fernandez Archipelago, Chile	Chile	Yes		Yes	
22	M. Simpson and B. Prots	2012	Predicting the distribution of invasive plants in the Ukrainian Carpathians under climatic change and intensification of anthropogenic disturbances: Implications for biodiversity conservation	Ukraine			Yes	
23	G.D. Iacona, F.D. Price, and P.R. Armsworth	2014	Predicting the invadedness of protected areas	EUA			Yes	
24	L.C. Foxcroft, M. Rouget, and D.M. Richardson	2006	Risk assessment of riparian plant invasions into protected areas	RSA			Yes	
25	W. Dawson, D.F.R.P. Burslem, and P.E. Hulme	2009	The suitability of weed risk assessment as a conservation tool to identify invasive plant threats in East African rainforests	Tanzania			Yes	
26	S.M. Zalba, M.I. Sonaglioni, C.A. Compagnoni, and C.J. Belenguer	1999	Using a habitat model to assess the risk of invasion by an exotic plant	Argentina			Yes	
27	R. Pouteau, J.-Y. Meyer, and S. Larrue	2015	Using range filling rather than prevalence of invasive plant species for management prioritisation: The case of *Spathodea campanulata* in the Society Islands (South Pacific)	French Polynesia	Yes	Yes		

Table 2.—Extended.

2 - Criteria				3 - Data Type				4 - Focus				5 - Approach		6 - Scale				
Vulnerability/ Risk	Impact	Cost	Feasibility	Density	Frequency	Presence	Absence	Prevention	Early detection	Control	Eradication	Species based	Site based	Local	Regional	Multiple	Uncertain	7-Prioritization Protocol
	Yes					Yes				Yes			Yes	Yes				No
Yes						Yes		Yes					Yes	Yes				No
	Yes					Yes		Yes					Yes		Yes			No
Yes						Yes		Yes					Yes	Yes				No
Yes						Yes	Yes	Yes					Yes			Yes		yes
	Yes			Yes		Yes		Yes					Yes			Yes		Yes
	Yes					Yes	Yes			Yes		Yes		Yes				No
	Yes					Yes				Yes			Yes		Yes			No
	Yes					Yes				Yes		Yes		Yes				No
	Yes					Yes			Yes			Yes		Yes				No
Yes						Yes		Yes				Yes		Yes				Yes
	Yes					Yes				Yes		Yes		Yes				No
Yes				Yes	Yes	Yes			Yes				Yes		Yes			No
Yes						Yes		Yes				Yes		Yes				Yes
			Yes			Yes	Yes		Yes			Yes		Yes				No
	Yes					Yes			Yes			Yes				Yes		No
	Yes					Yes	Yes		Yes			Yes		Yes				No
Yes			Yes			Yes		Yes					Yes	Yes				Yes
	Yes					Yes			Yes			Yes		Yes				No
	Yes	Yes				Yes				Yes			Yes	Yes				Yes
	Yes				Yes	Yes		Yes				Yes		Yes				No
Yes						Yes		Yes				Yes		Yes				No
	Yes					Yes		Yes					Yes			Yes		No
	Yes				Yes			Yes				Yes		Yes				Yes
Yes						Yes		Yes				Yes		Yes				Yes
Yes					Yes			Yes					Yes	Yes				No
Yes						Yes					Yes		Yes	Yes				Yes

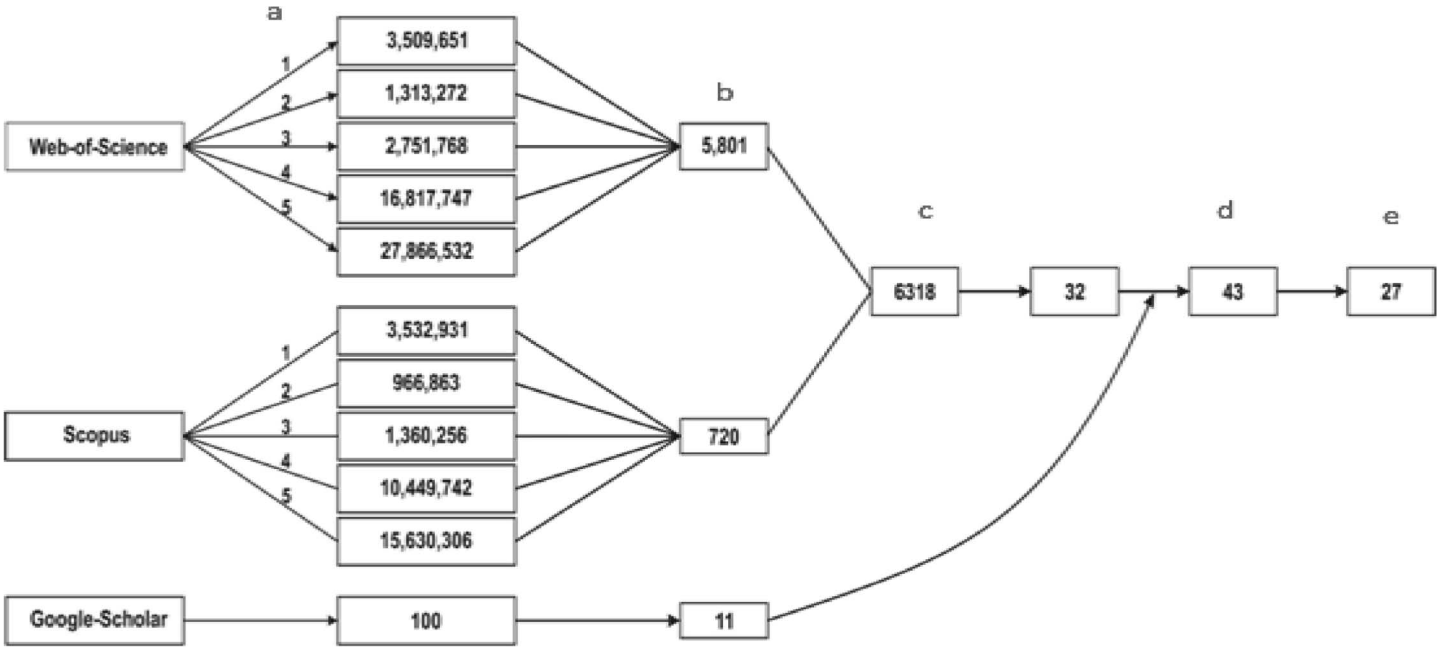

Figure 1.—Systematic review flow chart of studies providing guidance for the prioritization of management of invasive alien plants in protected areas: (a) set of keywords; (b) combination of all set of keywords, duplicates removed, and refined to areas of interest; (c) combination of the two groups, duplicates removed and remaining screened by the title; (d) data from Google Scholar added, duplicates removed and remaining screened by abstract and all the text; (e) studies that met the inclusion criteria.

and antecedents of the exotic species as invaders, the second focuses on local variations in habitat vulnerability and conservation value. Sometimes the selection between these options is limited by knowledge about variations in the conservation value of local environments or their vulnerability, which prevents the use of prioritization systems based on the spatial approach. Thus, for example, the dispersal dynamics of invasive species or the effects of local conditions on their successful establishment are frequently ignored, which seriously limits the possibilities of comparing the vulnerability to invasion between different sectors or environments of a PA. Available or preferred methods of control to be applied also influence the choice of prioritization options. Biocontrol, for instance, is necessarily a species-based tool, while ecosystem management techniques, like prescribed fire, depend on characteristics of the species but are mostly site-based tools. Beyond these considerations, the approach based on local variations in the value of conservation and vulnerability seems to be the least frequent (Giljohann et al. 2011). This approach has advantages from at least two points of view: on the one hand, in that it is directly related to the goals of management in terms of biodiversity conservation, and on the other, because in a scenario of incomplete knowledge on species interactions, control based on a particular species can result in increases in abundance and impact of other companion invaders or can even affect native species (Zavaleta et al. 2001; Ballari et al. 2016).

Cost, feasibility, effectiveness, success and benefit are rarely considered in the papers evaluated in this survey, and when this happens, they are usually mixed, confounded, and vaguely treated. Costs change in time and space; therefore, including costs can be done explicitly only in a very specific model, or it can be treated very vaguely in a broader model. Feasibility is usually used as an alternative to formal cost analysis (Hiebert

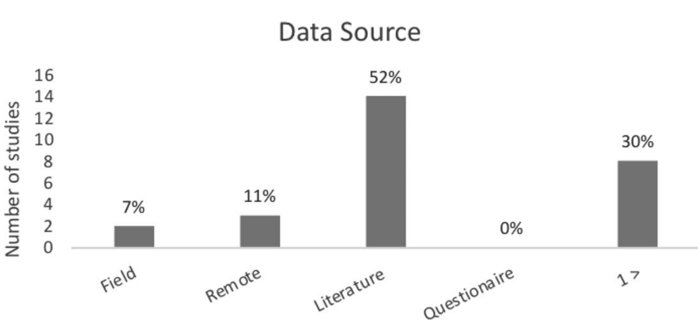

Figure 2.—Main source of data used in the retrieved literature to generate a list of invasive plants in protected areas. “1 >” means that the study used more than one data source.

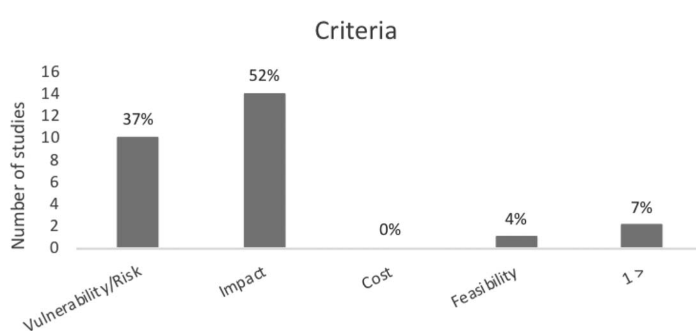

Figure 3.—Criteria used in the retrieved literature to choose a group of invasive alien plant species among all existent in protected areas and to rank them. “1 >” refers to studies that used more than one criterion to rank the species.

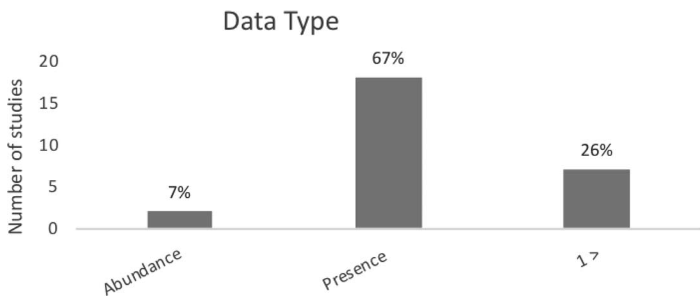

Figure 4.—Information used in the retrieved literature to generate the list of invasive alien plant species for prioritization of management. "1 >" refers to studies that used more than one type of data.

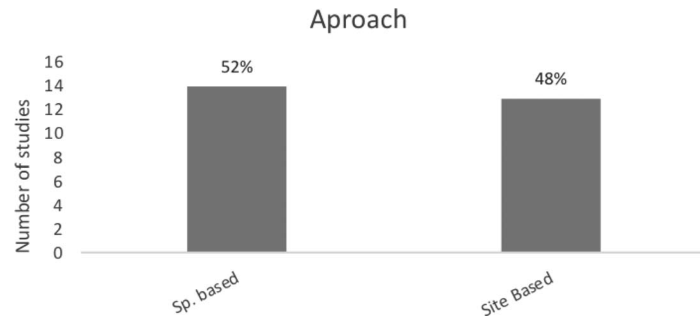

Figure 6.—Approaches used in the retrieved literature when dealing with invasive alien plant prioritization/management in protected areas.

and Stubbendieck 1993; Larson et al. 2011; Carwardine et al. 2012), and accessibility as a proxy of feasibility (Downey et al. 2010). The success of prospecting and control efforts is proportional to the probability of detection of the species or their being managed, so most of the studies that report actions of this type focus on species with simpler detection and control (Underwood et al. 2004; Hauser and McCarthy 2009). Efficacy is therefore a common optimization criterion, according to which optimal resource allocation is associated with moderate surveillance and control efforts (Giljohann et al. 2011). The expected result of IAP management in PA is the conservation of biodiversity assets, not the optimization of control efforts. It is very important that the analyses incorporate independent standards of conservation for the environmental values that are sought to be protected or recovered through management actions.

The preference for literature and presence of species data only can be associated with the absence of a well-structured knowledge about species occurrence and habitat characteristics. Stohlgren et al. (1995) found a significant information gap, as less than 80% of park inventories in the United States presented complete biological information, and when available, it was usually restricted only to species lists. Making these data available could provide help for the application of strategic conservation analysis, like IAP prioritization, but they must be critically used, since they were usually collected for different purposes (Rew et al. 2006).

We found a lower application of prioritization for early detection in comparison to prevention and control. According to Pysek et al. (2013), most management efforts in Europe were focused on eradication control, rather than prevention, and the same was reported by Brancatelli and Zalba (2018), for nature reserves in Latin America. The prevention approach must be used with caution, as many studies can predict a broad group of invasive species based on their characteristics (seed or juvenile/adult attributes), but still fail to restrict this group to the ones that really need attention from managers because they are dependent on many factors related at one particular time (Hobbs and Humphries 1995). Prioritizing invasions in their early stages is particularly challenging based on the high uncertainty about the evolution of the invasion process for different species and in variable environmental scenarios, which can lead to errors in the allocation of efforts and resources (Harremoës et al. 2001), but this limitation could be reduced by comparisons with management cases and experiences elsewhere (McDougall et al. 2011). At any stage, solving the constraint related to the lack of information available about what went right or wrong, and why, would definitely improve the level of success in future attempts.

The preference for studies at the local scale can be explained by the challenges that a large scale represent. Increase in size augments efficiency in the case of map analysis, but management practices grow in costs up to levels that are prohibitive for most of the PAs (MIPAG 2012); local scale is associated with a decrease in the number of species, which can facilitate management (Hauser and McCarthy 2009). A multi scale (local and regional) approach should perform better in many cases, as it can make a permanent link between research and monitoring of invasive plants (Hui et al. 2011).

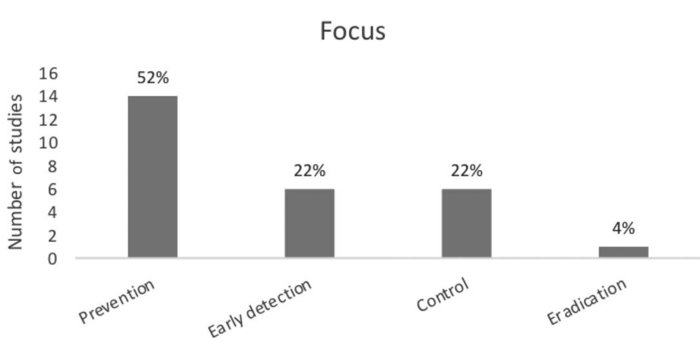

Figure 5.—Stage of management of invasive alien plants in protected areas that the retrieved studies focused on.

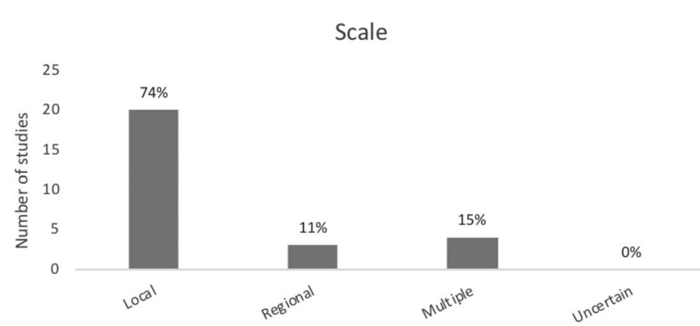

Figure 7.—Scale of the areas used in the retrieved literature about prioritization of invasive alien plant species management in protected areas.

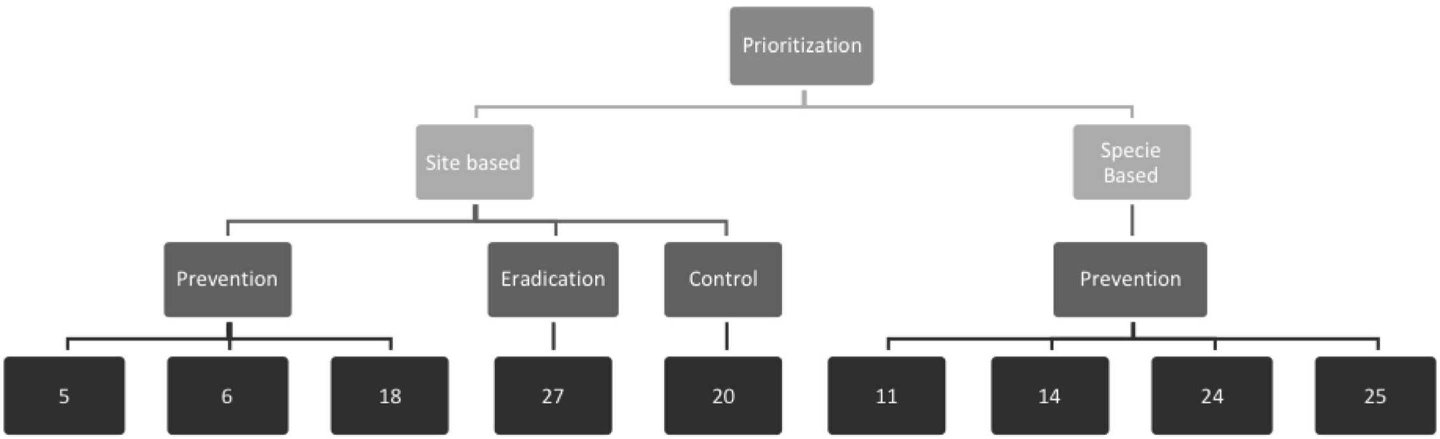

Figure 8.—Approaches and focus used in the retrieved literature for prioritization of invasive alien plant species in protected areas. The numbers in the lowest row of boxes represent position of the studies in Table 2 that in the end produced an improved guideline that could be followed in other conservation areas.

We also detected a lack of studies providing an explicit, reproducible scheme for prioritization. There are many studies that are presented as prioritization systems but that in fact work as risk assessments. Although they are both related, they aim at different purposes—the former focuses on the quantification of the risk, while the later ranks those risks for action (McGeoch et al. 2016). Game et al. (2013) pointed out that we cannot simply generate a list of species as these lists require little critical judgment, and that even when prioritization is used, there are several mistakes made during their application.

Invasive plants can have several impacts, both inside and outside protected areas, but in the specific case of protected areas, their effects on biodiversity are of major concern. We still lack comprehensive protocols to assess the conservation value of habitats and species as criteria of importance to prioritize the management of IAP. The main gaps are related to the lack of linkage with conservation values and the lack of acknowledge of management feasibility, especially with regard to costs. As more prioritization models are created and modified to be applied in conservation areas worldwide, it is crucial that this information becomes available for the majority of conservationists.

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