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Common deficiencies of actions for managing invasive alien species: a decision-support checklist

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Abstract

Despite the increasing number of invasive species, protocols devoted to assess the feasibility (i.e., probability of success or failure) of management actions in the field are scarce, yet success depends on a broad scope of issues beyond the biology of species and the ecosystem to be managed. In this paper we make a retrospective analysis of 90 actions and management proposals developed in Andalusia (southern Spain) in 2004 to 2018. Actions included 59 terrestrial and aquatic taxa. We identified items that in case of deficiency were responsible for either the rejection of action proposals (n = 44) or failure of implemented actions for which the goal was not achieved (n = 22). The most frequent deficiencies included the absence of funding during the necessary time to achieve the goals, the risk of reinvasion and an insufficient removal rate to achieve the specific objective. Based on the deficiencies found, we built a comprehensive, broad-scope compliance checklist to assist decision-makers to identify deficiencies before action. In addition, implemented actions for which the goal was achieved (n = 24) were used for validating the checklist. The checklist contains 40 items related to IAS features, administrative features, methodology effectiveness, efficiency and impacts of the action, and invaded ecosystem features. The checklist is valid across all taxa and habitats. The use of this checklist will help reduce the degree of arbitrariness and subjectivity of actions aimed at managing IAS, and a more efficient use of resources.

Keywords

control, decision-making, eradication, failure, feasibility, invasion, management, success

Introduction

The large number of invasive alien species (IAS) in natural areas contrasts with the scarce resources available for their management (Andreu et al. 2009). The increasing number of problems related to biological invasions has led to a growing need to of evidence-based support to policy-makers in order to enhance their decisions about IAS management (Andersen et al. 2004). However, actions may hide mistakes, weak points, inadequacies, gaps of knowledge, or methodological limitations (hereinafter referred to as 'deficiencies') that go unnoticed during their preparation (Maguire 2004; Campbell et al. 2018). These planning deficiencies may include inadequate budget (e.g., underestimation of operational costs), insufficient duration of the financing, or removal methods that are not adapted to the IAS biology and life cycle (i.e., methods that do not consider the 'weak points' of the IAS; Bohren 2017). These deficiencies may compromise the achievement of the main goal or the specific objectives. Besides, when no evidence-based and standardised protocol is used to guide decision-making, decisions may be taken on arbitrary or biased judgements or guesstimates of stakeholders, planners or the general public rather than on comprehensive scientific and technical evidence (Bardsley and Edwards-Jones 2006; Sharp et al. 2011). These deficiencies may cause a series of 'cascade effects' resulting in: (i) a poor definition of main objectives, actions and resource constraints (Game et al. 2013), (ii) the application of different and erratic strategies between neighbour countries, regions and even municipalities (Keller et al. 2011; Monceau et al. 2014); (iii) short-lasting actions that have a high probability of failure (Blossey 1999); (iv) an inefficient use of resources, both monetary and non-monetary, something that is especially relevant given the paucity of available funds (Pluess et al. 2012); (v) overlooking certain introduction pathways and the dynamics of propagule pressure (Simberloff 2006; Brasier 2008); (vi) disregarding action side effects such as the enhancement of other potentially invasive species or major ecosystem disturbances (Águas et al. 2014; Buckley and Han 2014).

The importance of analysing the feasibility of management actions has been recognised in international policy frameworks such as the Biological Convention on Biological Diversity (COP 6 Decision VI/23 on Alien species that threaten ecosystems, habitats or species: guiding principles for the prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species) and the Regulation (EU) 1143/2014 of the European Parliament and of the Council of 22 October 2014. This recognition has led to the formulation of general recommendations to evaluate global feasibility of a given action. Most published criteria to affect the feasibility of actions focus on particular eradication experiences (Simberloff 2003; Pacific Invasives Initiative 2011) or analyse the effect of a few variables such as detectability, search effort and duration of the eradication program (Cacho et al. 2006). However, to our knowledge, no comprehensive checklist applicable across taxonomic groups, habitat types, or specific management aims (prevention, eradication, containment, or control) is available.

In this paper, we list general items related to the feasibility of actions based on a retrospective analysis of 90 real IAS management cases applied to 59 species that were proposed or implemented by the Regional Environmental administration in Andalusia (southern Spain) during 14 years (2004–2018). Specifically, (1) we gathered items responsible for action failure (in unsuccessful actions) and for rejection of action proposals; (2) we assessed the most frequent items related to action failure; and (3) we compared the number of items with deficiency among successful and unsuccessful actions and not-implemented proposals as a basis to validate the usefulness of these items to distinguish between feasible and unfeasible actions. As a result, (4) we built a comprehensive and easy-to-use general checklist (Table 1) to assist decision makers to detect deficiencies that might lead to action failure.

Methods

Description of actions on IAS management

We analysed 90 field management actions and proposals of IAS received or implemented by the Regional Environmental Administration of Andalusia in 2004 to 2018 (Suppl. material 1: Table S1). Andalusia (87,268 km^2) is the southernmost administrative region in Spain. The region has a population of ca 8.4 million inhabitants (Instituto Nacional de Estadística 2018) and harbours a wide variety of inland, coastal and marine habitats including 340 protected areas accounting for 49% of the total administrative area (CMAOT 2017). From east to west, Andalusia is characterised by an extensive coast (945 km, along both the Mediterranean Sea and the Atlantic Ocean) and several mountainous ranges with a maximum altitude in Sierra Nevada National Park (Mulhacén Peak: 3,481 m a.s.l.). The dominant climate is Mediterranean, with dry, hot summers, but arid, cold steppe conditions occur in the south-east (Kottek et al. 2006).

The actions encompassed a variety of taxonomic groups, life forms, and habitats (Fig. 1). Plant taxa represented 50% of the action plans analysed (45 out of 90), most of them (37) were terrestrial plants, whereas animals included 24 vertebrate and 21 invertebrate taxa. Regarding the habitat type, action plans included both aquatic and terrestrial habitats with dominance of inland waters and coastal habitats (Fig. 1). Some of the actions involved the same species in different localities with varying characteristics or different elimination methods. Therefore, the total number of actions analysed (N = 90) was higher than the total number of taxa managed (59 taxa: 28 plants and 31 animals).

Action proposals and implemented actions aimed at eradication, control or containment of IAS in the field were made by collectives (NGO, professional associations), managers, scientists, or public institutions. Part of the proposals were selected and implemented as the result of coordinated decisions made by regional decision-makers, local authorities, specialised technicians, and rangers and based on documented and expert knowledge.

Table 1. Checklist for identifying deficiencies of actions for management of invasive alien species (IAS) in the field aimed to biodiversity conservation. The items must be answered in the framework of the action plan area. For assessments, the proposed methodology is defined by the elimination technique (biological, mechanical, chemical), the time or season of application, the number of applications, the final concentration (in case of a biocide), the frequency of monitoring and rounds of control, and methodological adaptations to minimise the impact and to promote ecosystem recovery.

Block 1: Basic prerequisites and definition of the main conservation goal and specific objective
1. The target species is alien
2. The alien species causes (or will cause) significant negative impacts (damage) on biodiversity
3. The main conservation goal of the action plan is [select one option]: a) Ecological restoration: to return the ecosystem to a 'reference' state b) Ecological enhancement or rehabilitation: to increase the quality or quantity of some characteristic or functions of the action plan area c) Ecological reallocation, reassignment or replacement: to replace the ecosystem by a different one d) Protection: to preserve (maintain or recover) the abundance of certain native species or habitats e) Mitigation: to compensate the permitted loss of species or ecosystems f) Others not related with biodiversity conservation (e.g., to keep or recover uses or to protect human health); or the goal is unknown/uncertain
4. The specific objective against the IAS is [select one option]: a) Prevention: to avoid or minimise the risk of introduction b) Eradication: all individuals and propagules must be permanently removed c) Containment: to minimise the risk of spread d) Population control: to maintain population size below a desired threshold e) Other management or conservation actions not involving the IAS but other elements of the ecosystem, or the goal is unknown
5. The size of invasion impedes the application of any effective method nowadays
6. The removal rate and the frequency of post-treatment reviews and rounds of control are coherent to the specific objective (item #4): (a) eradication: removal rate exceeds recruitment and dispersal rate and all individuals can be removed; (b) containment: removal rate stops colonization rate; (c) control: removal rate allows reducing the population size below the desired threshold
7. The action plan is legal and meets all administrative requirements (permits of landowner, authorisations of responsible institutions, authorization to use chemical compound, etc.)
8. The methodology proposed is selective against the target IAS and does not provoke irreversible or long-lasting impacts in the ecosystem, site characteristics, economic activities and values (e.g., religious, cultural, recreational, etc.)
9. The methodology proposed can have an impact on human health
10. The expected environmental impacts provoked by the methodology exceed those caused by the IAS
11. There are other processes (e.g., habitat loss, pollution, resources overexploitation, etc.) not included in the action plan that are responsible for a greater negative impact than the target IAS
12. Hazards for workers can be avoided or minimised with personal protective equipment. In case of a possible accident, potential risks for workers are acceptable
Block 2: Ias and invasive population features
13. The possible benefits and functions of the IAS (refuge, feeding, nesting sites, dispersal, uses, etc.) have been assessed
14. In the case that more than one IAS is present in the action plan area, the target IAS is the main threat for biodiversity conservation
15. Indicators related to the IAS will be measured and are coherent to the specific objective (item #4): (a) prevention and eradication: the absence of the IAS can be confirmed; (b) containment: the absence of the IAS can be confirmed in the preserved area; (c) control: a population threshold has been selected
16. The IAS spatial distribution is known
17. The IAS reproductive cycle is known

18. The IAS regeneration rate (expressed as year recruitment, growth rate, biomass production, etc.) has been or will be gathered at the action plan area or in comparable areas	
19. IAS abundance and demography (e.g. estimate or census of the size of the population, cohorts/size classes, sex ratio, etc.) has been or will be gathered	
20. The ecological niche of the IAS (biotic, abiotic and movement requirements) is known at the action plan area or in comparable areas	
Block 3: Administrative features	
21. The institution (agency, ministry, section, or department) that will conduct the action plan has the necessary competences	
22. The budget includes all the tasks necessary to undertake the action (staff, machinery, materials, transports, fuel, external analyses, contracts, characterization of ecosystem, etc.)	
23. Availability of funds is guaranteed during the necessary time frame to achieve the specific IAS management objective	
24. Availability of specialized staff is guaranteed during the time frame needed to achieve the specific IAS management objective	
25. There is a lack of consensus of involved administrations/departments on the decision to execute the action plan or the methodology to be used	
26. All or part of the invading population is on private property and: (i) there is no will or permission from the owner to work on their property; (ii) there is no legislation that obliges the owner to facilitate access to undertake the removal of the target IAS	
Block 4: Methodology effectiveness, efficiency and impacts	
27. In the short or the medium term, the area will surely be re-invaded from connected areas/ vectors and the positive effects of the action plan will disappear. Consider the possibility of (i) accidental introductions by not managed pathways (e.g., ballast water), (ii) recolonisation from non-treated areas that could act as propagule sources; or (iii) deliberate introduction. Answer 'unknown/uncertain' in case the IAS distribution is unknown (item #16)	
28. The action plan area is entirely accessible for workers. No refuges or IAS individuals remain inaccessible	
29. Field and environmental conditions are adequate for the treatment to reach the entire target IAS population (e.g., proper diffusion of a biocide)	
30. The best time (season, moment of the day) to act has been chosen in order to maximize efficiency (total catch, yield, biomass per unit effort)	
31. Previously published reports or experimental evidence (including previous experience by planners and field workers) show that the methodology proposed is effective in similar cases	
32. Previously published or experimental evidence shows that the methodology proposed is not effective in similar cases	
33. The methodology is adapted to the expected population changes (e.g., size classes, sex ratio, abundance, changes in spatial distribution, etc.) and to the presence of resistance structures (e.g. seed bank, spores, cysts), hidden or hibernating individuals	
34. The plan includes field supervision to ensure that people involved in the action plan will strictly adhere to methodological instructions and will not change them without previous notice	
Block 5: Native ecosystem features and social perception	
35. The presence and abundance of native species with conservation value (e.g., endangered, protected, or locally rare species) is known and will not be negatively influenced by the action plan	
36. The presence of habitats of special conservation value has been or will be gathered	
37. Ecological processes of special importance in the action plan area has been or will be gathered	
38. Results of the action plan will be monitored using indicators. Indicators design and sampling frequency will be adapted to the conservation goal and the ecosystem treated	
39. Indicators will be compared between invaded, non-invaded, treated, and reference areas	
40. Social opposition is expected. Take special care if opposition may involve physical/verbal violence, complaints, or smear campaigns (e.g., against the staff or the leading institution)	

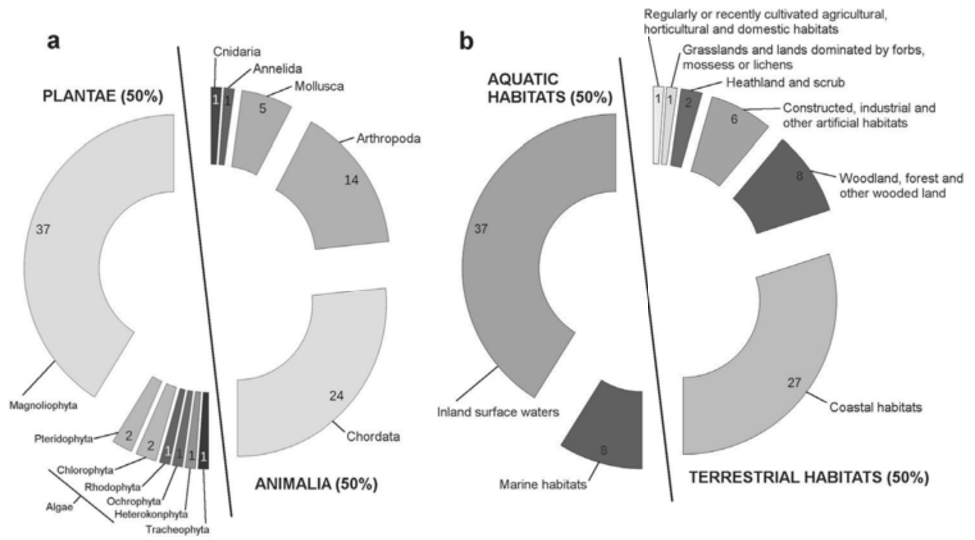

Figure 1. a Taxonomic groups represented in 90 action plans evaluated in this study. The taxonomic classification is based on BOLD (Barcode of Life Data system), a cloud-based data storage and analysis platform developed at the Centre for Biodiversity Genomics in Canada (http://www.boldsystems.org) **b** major habitat types represented in these action plans, following the EUNIS classification. Numbers inside the pie chart indicate the number of actions for each.

Monitoring of goal achievement

We visited managed localities annually to check if initially defined goals were accomplished. Eradication was considered achieved when no new individual was detected for five years. Control was considered achieved when the IAS abundance (e.g. plant mean coverage or captures per unit effort) decreased at least 90% after the action and maintained at least at 75% of the initial abundance for a minimum of 3 years. Containment was reached when the treated area was not reinvaded after the action. Accordingly, each action was classified into the following categories: (i) implemented actions that did not achieve the goals or specific objectives initially defined (n = 22) (hereinafter 'unsuccessful actions'), (ii) implemented actions that achieved the goals or specific objectives initially defined (n = 24) (hereinafter 'successful actions'), or (iii) proposals for management actions that were not implemented (n = 45) (hereinafter, 'not-implemented proposals').

Items related to feasibility and checklist design

After the execution of the action, we gathered information on the causes responsible for not-implemented proposals and for unsuccessful actions based on discussions with the different participants responsible for the execution of the action. With all the information, we generated a raw list of items associated with rejection or failure of each action.

Then, the raw list of items was refined (e.g., redundancies removed) and transformed into an easy-to-understand checklist of 40 items organised in five blocks, namely 'basic prerequisites' (items #1–12), 'IAS and invasive population features' (items #13–20), 'administrative features' (#21–26), 'methodology effectiveness, efficiency and impacts' (#27–34), and 'native ecosystem features and social perception' (items #35–40) (Table 1). This checklist was applicable to any action or proposal independent of its specific objective (prevention, eradication, containment, or control), the taxonomic group or the habitat type. To validate the extent to which the checklist serves to discern between feasible and unfeasible actions, the checklist was systematically used to assess all the not-implemented proposals (n = 44) and unsuccessful actions (n = 22) previously used for the raw list preparation and also successful actions (n = 24). For assessments, the proposed methodology was defined by the elimination technique (biological, mechanical, chemical), the time or season of application, the number of applications, the final concentration (in case of a biocide), the frequency of monitoring and rounds of control, and methodological adaptations to minimise the impact and to promote ecosystem recovery. In the case of not-implemented proposals, we only evaluated the prerequisites (first 12 items in Table 1) except for one case that did not show any deficiency in these prerequisites. Finally, we built up a database including the action, whether the goal was achieved or not and deficient items for each action.

Statistical analysis

First, we assessed the relative importance of each checklist item for determining the failure of unsuccessful actions or rejection of not-implemented proposals by calculating the frequency of deficiency of each item (number of times that item i showed a deficiency * 100 / total number of actions of category j), being j either not-implemented proposals (j = 44) or unsuccessful actions (j = 22). Second, to evaluate to what extent the checklist discerns between feasible (successful, j = 24 in the previous equation) and unfeasible (unsuccessful) actions, both the frequency of deficiency of each item and the amount of items with deficiency were compared between successful and unsuccessful actions. We compared the total number of items with deficiency, considering both the number of prerequisites (items #1–12) and the rest of items (items #13–40) separately and all together. Since the data did not follow a normal distribution, pairwise Mann-Whitney U tests (Zar 1996) were used. Significant differences were considered when $p < 0.05$. The software Past® version 3.15 (Hammer 2001) was used.

Results

Forty items were found to induce rejection or failure of actions (Table 1). All the non-implemented proposals shared deficiencies in 12 items which were nearly absent in implemented successful and unsuccessful actions (Fig. 2). These 12 deficiencies were

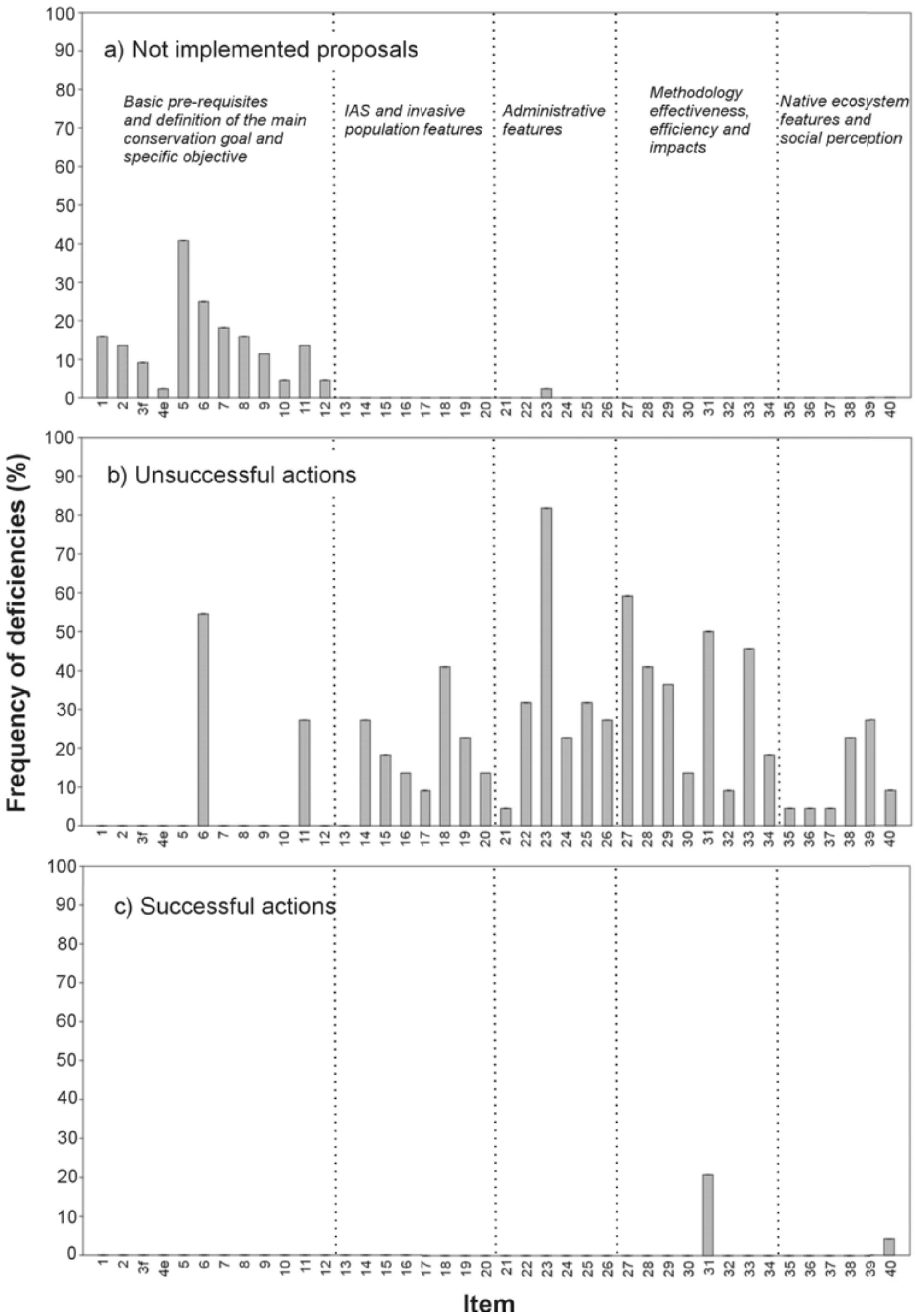

Figure 2. Percentage of deficiencies for the different checklist items (see Suppl. material 1: Table S1) in **a** not-implemented (*n* = 44) **b** unsuccessful (*n* = 22), and **c** successful (*n* = 24) actions aimed at managing IAS in Andalusia in 2004–2018. See Table 1 for a description of each item.

related to basic aspects of the action and therefore, were considered as pre-requisites (items #1–12, Table 1). These prerequisites include whether the target species is alien and invasive (i.e. causes a significant negative damage on biodiversity; Bartz and Kowarik 2019), the type of main conservation goal and IAS management specific objective (eradication, containment, or control), the absence of any effective methodology (usually in large scale invasions), legality, impacts on native ecosystem caused by the action implementation, incoherence between the methodology application, and the specific objective, risks for humans or workers.

The most common deficient prerequisite in not-implemented proposals was the absence of an effective methodology to be applied at the full scale, because the invaded area was very large (over 100 ha, data not shown) (item #5, 41% of cases analysed). Examples of such proposals are the control of the brown algae *Rugulopteryx okamurae* in the Strait of Gibraltar (area invaded >1000 ha), the eradication of the zebra mussel (*Dreissena polymorpha*) and European catfish (*Silurus glanis*) in a reservoir of 2,500 ha, the eradication of *Caulerpa cylindracea* in the sea bed of Almería (area invaded >100 ha, including depths > 30 m), and the control of the cord grass (*Spartina densiflora*) in Huelva salt marshes (area invaded of ca 1000 ha) (Suppl. material 1: Table S1).

In unsuccessful actions, the most items with deficiency belonged to the blocks 'Methodology effectiveness, efficiency and impacts' (median frequency of items with deficiency = 38.6%) and 'Administrative features' (median frequency = 29.5%) (Fig. 2).

Not-implemented proposals showed a higher number of prerequisites with deficiency (p = 0.0010, DF = 65, 1, Mann-Whitney U test) than unsuccessful actions (Figs 2, 3). The number of items with deficiency was significantly higher (p < 0.001, DF = 45, 1, Mann-Whitney U test) in unsuccessful actions than in successful actions within a block and across the overall checklist (Fig. 3). Unexpectedly, unsuccessful actions showed deficiency in two prerequisites related to an inconsistency between removal rate and objective needs (item #6, 54.5%) (e.g., eradication of *Arundo donax* on a river bank; eradication of *Eriocheir sinensis* in the Guadalquivir estuary) and the existence of other processes responsible for a greater negative impact than the target IAS whose management was not included in the action (item #11, 25%) (e.g., Eradication of *Pelodiscus sinensis* in the Guadalquivir estuary; control of *Galenia pubescens* in coastal areas from Málaga).

In sum, up to 29 items (out of 40) showed deficiency in unsuccessful actions (76% of items, median frequency = 7.5%), whereas only two items (5.1%, median frequency = 0.0%) showed deficiency in successful actions (Fig. 2).

The top 5 items that showed the highest frequency of occurrence in unsuccessful actions (Fig. 2) were: (1) the absence of funding during the necessary time to achieve the goals (item # 23, 82% of cases analysed); (2) the risk of reinvasion (item #27, 59% of cases analysed); (3) an insufficient removal rate to achieve the specific objective (item #6, 54% of cases analysed); (4) the absence of evidence reporting that the methodology applied is effective (item #31, 50% of cases analysed); and (5) the lack of adaptation of methodology to the expected population changes (item #33, 45% of cases analysed).

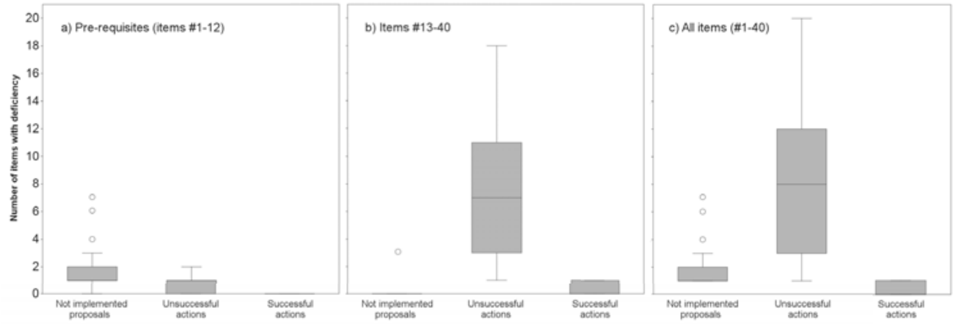

Figure 3. Number of items with deficiency in each action type. The block of prerequisites (**a**) was analysed separately from the rest of checklist items (**b**). In **c** the number of deficiencies is shown for all checklist items.

Discussion

Importance of unsuccessful actions for improving IAS management practices

Mistakes or unexpected outcomes constitute the basis for individual, professional, and organisational learning (Clark 2002), and their analysis may provide useful information to improve management practice. Management failures may be considered fiascos prone to be swept under the carpet. However, excepting for negligence or wilful ineptitude, failures may be simply mismatches between expectations and outcomes or the result of contingencies, uncertainties, or limitations of existing knowledge (Argyris and Schön 1978; Simberloff 2003). In this study, the analysis of not-implemented proposals and unsuccessful actions served as the basis for defining what items were related to feasibility of IAS management actions. These items included basic prerequisites and different topics related to the IAS biology, the administrative requirements, the methodology used to remove the IAS and the characteristics of the native ecosystem. This checklist is the basis to avoid the same mistakes in future actions.

Feasibility analysis as a prior step to prioritization

The feasibility analysis of IAS management actions has received little attention compared to risk (Dana et al. 2014) and priority analysis (Nielsen and Fei 2015; Kerr et al. 2016; Courtois et al. 2018). While feasibility analysis is based on criteria related to the outcome of management actions, priorities setting seeks to identify where, how, on what, and when we should act first (Wilson et al. 2009). A step-by-step assessment of feasibility and priority-setting as the one we present in this paper can help to differentiate those unfeasible actions from those that, being feasible, are not prioritized, for example, due to a transitory lack of resources (Simberloff 2003). Accordingly, decision-making in biological invasion management should be considered as a three-step process: invasion risk analysis (e.g., Vilà et al. 2018; Copp et al. 2005; D'hondt et al. 2015), feasibility analysis, and, finally, priority-setting (Fig. 4).

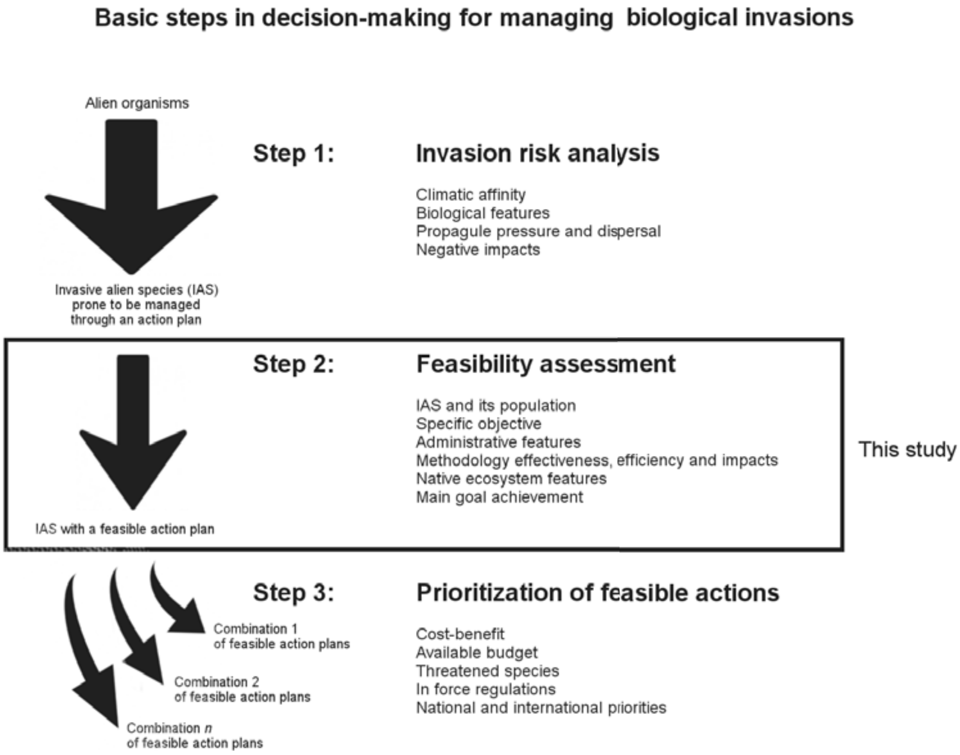

Figure 4. Basic steps in decision-making for managing biological invasions. The checklist proposed in this study focuses on step 2.

Common deficiencies of IAS management actions

The consideration of up to 40 sources of deficiencies highlights the underlying complexity associated with the decision making for IAS management. The relatively high number of items may be the consequence of the number and heterogeneity of actions and proposals assessed but also of specific circumstances of management at the regional scale (e.g., administrative features).

The application of methodologies that are not consistent with the IAS management objective is a prerequisite that was commonly overlooked in unsuccessful actions (up to 54.5% of cases analysed), probably because the initial objective was too ambitious (e.g., eradication of invasive crayfish in rivers; Dana et al. 2010) or simply because the impact thresholds was rarely defined in control actions (Panetta and Gooden 2017). Consequently, it is difficult to establish the necessary removal rate or even to conclude whether the action was a success or a failure.

The absence of funding during the time frame to accomplish the management goals showed the highest occurrence in unsuccessful actions. This is a consequence of the current approach of conservation in the area of study, where IAS conservation actions are financed by biennial programmes whose long term durability is not guaranteed. Funding is a critical factor (Simberloff 2003) but may be a temporary obstacle as the planner or decision-maker can often search for different funding sources to implement feasible actions. Therefore, we decided not to include this item as a prerequisite to avoid stopping the feasibility assessment of an action at early stages.

Technical viability, social acceptance, legality, assumable impact, the possibility of restoration or the availability of specialised personnel have been considered as key factors related to feasibility of actions in several reports (Simberloff 2003; Pacific Invasives Initiative 2011; Dana et al. 2016), but the relative importance of each factor has not been previously assessed. IAS biology and life cycle are crucial aspects to define effective removal methods. For instance, annual dicotyledons and grasses may request very different biocides. The relevance of these aspects was considered in items #17, 18, 30, and 33 (Table 1). Besides, our analysis demonstrated that also non-biological aspects such as administrative features linked to the management action have often determined the likelihood of goal achievement. For example, management of IAS populations that are located inside private properties can involve additional difficulties when implementing an action plan. This was the case of *Aedes albopictus* in Málaga (Suppl. material 1: Table S1), which currently colonises a high number of private properties (e.g., saucers under flowerpots, and other small containers). In such cases, it is unfeasible to enter house by house to control potential breeding sites or colonies. Very often, part of the invasive population traverses private properties (e.g., *Colocasia esculenta* in Dos Hermanas, Seville or *Ailanthus altissima* in Aracena, Huelva) (Suppl. material 1: Table S1). In Andalusia, management of IAS in private properties requires of signed agreements between the public administration and landowners are necessary. Thus, the absence of will by any of the parties prevents a feasible, effective management of the invading population. Our work also revealed limitations in the efficacy of the existing approved methodologies, which often may lead to inadmissible impacts or to social rejection. This was the case of chemical control of *Oenothera drummondii* in coastal dunes of Huelva (García-de-Lomas et al. 2016). The analysis supports the need of investing in adequate (in terms of ecological indicators selected and design), adaptive, long-term monitoring (Lindenmayer and Likens 2009). Although directly related to goal achievements, the incorporation of long-term monitoring may involve an added challenge, as it requires extending the duration of the projects beyond possible changes of government. Again, long-term IAS management actions do not fit well with current short-term funding sources (Blossey 1999). The use of the proposed checklist prior to the implementation of IAS management proposals will encourage the definition of a monitoring programme in advance with an array of indicators consistent with a previously defined conservation goal and specific objectives (Lovett et al. 2007).

Validation of the checklist to assess the feasibility of actions

The significant differences found in the number, frequency, and identity of deficient items between successful and unsuccessful actions suggest that the present checklist discerns reasonably well between feasible and unfeasible actions. The use of a checklist prior to implementation of management proposals is of high interest to decrease the number of unsuccessful actions worldwide. The presence of basic prerequisites in some unsuccessful actions supports a systematic assessment of feasibility before action. The basic prerequisites (i.e., 12 simple items) we listed may be seem obvious, however, we decided to include such items in the checklist for three different reasons: (i) the analysis of feasibility starts at the planning stage and pre-requisites are essential to decide whether or not to implement an action proposal; (ii) planning may be done by people from different disciplines or different level of expertise on IAS, therefore, items that may seem obvious for some decision-makers may be overlooked by others; and (iii) the assessment of prerequisites is a quick step in decision-making in comparison with the major implications that the implementation of actions can have. For example, in the present study area up to four native species were confused with IAS, something that it is not rare among practitioners (Bardsley and Edwards-Jones 2006). Other rejected proposals included species whose origins of introduction remain uncertain. Such cases (e.g., *Alopochen aegyptiacus*, *Alpheus ponteridae*) may represent expansions at range edges without an apparent human intervention or in response to climate change (Gutiérrez 2003; Lindström et al. 2013).

In successful actions, the occurrence of deficiencies in two items suggests that certain items may or may not provoke failure depending on different circumstances. The valuation of a greater number of cases from different regions could help to distinguish items that are unambiguously related to non-feasibility (as the basic prerequisites seem to be) from others that may or may not motivate the action failure depending on additional factors (e.g., the planner experience). In this sense, conducting pilot tests or research projects on the use of novel methodologies are needed as a basis for improving the management of IAS.

To our knowledge, the present checklist is the most comprehensive ever done to date, as it includes a broad range of items integrating an interdisciplinary scope, useful to evaluate management of biological invasions in different habitats, involving taxonomic groups, and specific objectives. Therefore, the present checklist could be potentially used to detect weak points of IAS management actions before implementation in different parts of the world.

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Supplementary material 1

Table S1

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Data type: Description of actions aimed at managing IAS that were analysed in this study

Explanation note: For each action, the name of the target IAS, the specific objective, the locality, year of implementation and deficiencies found (according to Table 1) are indicated.

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