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Managing invasive species in cities:

A decision support framework applied to Cape Town

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Abstract

It has been suggested that existing frameworks for guiding management of invasive species in rural areas and protected areas are inadequate for dealing with invasions in urban settings. A framework for selecting appropriate goals for managing invasive species in urban areas was developed by Gaertner et al. in 2016. This framework groups species into three management approaches (control priority, active engagement, and tolerance) depending on their real or perceived benefits and their potential to generate negative impacts.

This study tests the practical application of the framework using the example of Cape Town. We assess the suitability of the framework to support decision-making for managing invasive species in urban ecosystems using a questionnaire-based survey of members of the public, and an e-mail-based survey and a workshop with invasion biology researchers and managers. Specifically, we (1) determine the differences in perceptions regarding the benefits and impacts of invasive species between the public, managers and researchers; (2) investigate how consistently managers and researchers group invasive species into the three management categories; and (3) identify, with the help of managers and researchers, issues linked to the framework and give suggestions to overcome the identified issues.

We found no clear pattern in the perceptions of the public, managers and researchers regarding perceived benefits and negative impacts. Instead, the answers were widely scattered among all groups for most of the species that were considered. However, using the framework leads to a higher consistency among managers in placing the species into management categories, compared to invasive species grouping without guidance of the framework.

We conclude that decision-support frameworks can assist managers in placing invasive species into management categories. However, even more specific guidelines on the use of invasive species management frameworks in urban areas are needed.

Keywords Biological invasions • Management • Stakeholder engagement • South Africa • Urban invasions

Introduction

Invasive non-native species (sensu Richardson et al. 2011; hereafter 'invasive species') are often more prolific in cities than in rural areas (Cadotte et al. 2017). The long history of human activities, disturbance and habitat modification enhances the opportunities for introduction, establishment and spread of invasive species (Kowarik, 2011). Cities serve as transportation hubs for human-mediated movement of commodities that facilitate the intentional or unintentional introduction and dissemination of non-native species through dispersal pathways such as trade and horticulture (Dehnen-Schmutz et al. 2007). For example, non-native animals kept as pets can establish and become invasive (van Wilgen & Richardson, 2012), and alien ornamental plants in gardens can act as sources of non-native propagules for launching invasions in surrounding areas (Alston & Richardson, 2006; Bowers et al., 2006). Within urban regions, non-native species encounter climatic conditions (e.g. due to the urban heat-island effect), disturbance and hydrological regimes, and soil conditions that have been profoundly influenced by human activity and that can promote their establishment and spread (Pickett et al., 2001; Kowarik, 2011; Cilliers et al., 2008; Zisenis, 2015; Lechuga-Lago et al. 2017; Walker et al. 2017).

Although some invasive species are intentionally introduced to provide or restore particular ecosystem services, such as trees for timber production or erosion control, the subsequent spread and proliferation of such species can ultimately have net detrimental effects (e.g. van Wilgen et al., 2008; Vilà et al., 2009). Invasive species in cities may provide ecosystem services, but at the expense of other services or of various elements of biodiversity (Potgieter et al. 2017). They may affect human health, disrupt important ecosystem services such as water filtration, flood attenuation and coastal protection, and displace native species, thereby contributing to the homogenization of habitats within cities (Burton et al., 2005; Kühn & Klotz, 2006; McKinney, 2006; Trentanovi et al., 2013). This can lead to conflicts over whether to manage a species to sustain or optimize the ecosystem services it provides, or to control it to reduce its negative effects. In South Africa, for example, local communities in or near many urban areas use invasive *Acacia* trees for timber, charcoal and firewood, but the same species reduce streamflow, increase fire intensity and reduce biodiversity (Richardson & van Wilgen, 2004). To reduce negative impacts, invasive species management plans have been developed for many cities around the world (e.g., The Brisbane Invasive Species Management Plan in Australia, the Invasive Plant Strategic Management Plan in the City of Calgary in Canada, or the City of Richmond Invasive Species Action Plan in the United States). Despite such efforts, the management of invasive species in cities is still particularly challenging compared to rural areas (Gaertner et al., 2016).

Cities have more numerous and diverse stakeholders who hold more divergent views of particular invasive species than do stakeholders in rural areas. Conflicts over the management of invasive species are therefore more likely to occur in urban environments (e.g., trees, Dickie et al., 2014).

Given the complex conflicts of interest that exist within cites, it has been suggested that existing frameworks for guiding management in rural areas (e.g., van Wilgen & Richardson, 2014) are inadequate for urban invasions (Gaertner et al., 2016). In this context, Gaertner and colleagues (2016) used the city of Cape Town in South Africa as a study system for exploring the challenges and complexities of managing invasive species in cities. A key message of their study is that management approaches need to consider not only species characteristics and available management tools, but also stakeholder views and social consequences of management actions. They proposed a framework (Figure 1) for developing invasive species management actions that explicitly and transparently considers stakeholders' perceptions. This framework considers the potential societal reactions to invasive species control operations in cities, which would become apparent in consultations with affected local stakeholders. It is crucial to anticipate and plan for societal opposition to the control of particular types of invasive species since negligence will either lead to a delay of the control operations and add substantial costs or, even worse, prevent control from preceding altogether. The framework helps to group invasive species in urban areas into three broad management categories based on their perceived benefits and their potential to generate significant negative impacts:

i) “Control priority”, for species with low or no benefits and high potential for negative impacts, requiring either eradication (for species with small and isolated populations), or containment and impact reduction (where local eradication is not possible);

ii) “Active engagement”, for species with both high benefits and negative impacts, for which the appropriate management action depends both on the societal response and the political and social consequences of deciding to control or tolerate the species; and

iii) “Tolerance”, for species with low potential for negative impact that are generally acceptable to society and to conservationists, requiring very little management. The framework proposed by Gaertner et al. (2016) may be useful as an aid for developing invasive species management actions in cities. However, it has yet to be tested to determine its applicability and usefulness in supporting real-world decision making. Several challenges must be considered: The users of the proposed framework (i.e., decision makers, experts, or managers) are expected to be aware of varying perceptions among different stakeholder groups and to make decisions that integrate them. For example, Monterey pine (*Pinus radiata*) occurs in commercial plantations around Cape Town and it is very popular among hikers, cyclists and tree enthusiasts. However, the species is also highly invasive in the region (Richardson & Brown, 1986) and poses a substantial threat to the biodiversity in the adjoining Table Mountain National Park (Richardson et al., 1996). The public and conservationists can thus have divergent perceptions of the benefits and impacts of Monterey pine in Cape Town, and managers face the challenge of integrating such divergent views regarding the species' benefits and impacts. Moreover, management decisions should be consistent regardless of the user of the framework. The framework should make provision for the fact that judgements may vary depending on the context, and the user's experience, knowledge or interests.

The main objective of our study is to assess the suitability of the framework to support decision-making for urban invasive species management. In particular, we (1) determine the differences in perceptions regarding the benefits and impacts of invasive species between the public, managers and researchers; (2) investigate how consistently managers and researchers group invasive species into the three management categories both using and not using the framework; and (3) identify, with the help of managers and researchers, issues linked to the framework and give suggestions to overcome the identified issues.

The achievement of these three aims will allow us to: a) identify whether managers have similar knowledge and perceptions about the benefits and impacts of individual species as subject experts (invasion biology researchers) and members of the public; b) evaluate whether using the decision framework leads to different and perhaps more consistent decisions among managers (i.e., do different users come to more similar conclusions); and c) incorporate users' feedback to improve the management framework.

Methods

Face-to-face surveys among residents of Cape Town were used to gain insights into the public's perceptions of the impacts and benefits of five invasive species. A panel of experts comprising invasive species managers and researchers was convened and asked, first via email and then in a workshop setting, to test the framework to assess its suitability to support decision-making for invasive species management in Cape Town.

Study area

Cape Town is a good study system for elucidating the complexity of managing invasive species in cities because it highlights several interwoven social and ecological dimensions. It has a very high conservation significance due to its location in the Cape Floristic Region, a global centre of plant endemism (Cowling et al., 1996). The city (2445 km^2) surrounds the Table Mountain National Park (221 km^2) and 17 smaller nature reserves and 500 biodiversity network sites that together cover 270 km^2. The city has a population of 3.8 million people, and is growing more rapidly than any other southern African metropolis on a per capita basis (Boraine et al., 2006). At present, 26% of the area within the city boundaries is urban, 35% is agricultural, and 39% is natural and semi-natural vegetation concentrated in mountainous areas (mainly within Table Mountain National Park). Many lowland areas have been transformed, with remnants being highly threatened and thus a priority for conservation (Rebelo et al., 2011).

The city has a long history of European colonization and associated introductions of non-native invasive species (van Wilgen, 2012). For example, invasive tree species such as pines (*Pinus* species), grown in plantations, and Australian wattles (*Acacia* species), planted mainly for sand stabilization, have spread widely into natural vegetation and increase the severity of wild fires near residential areas (van Wilgen & Scott, 2001). Aquatic invasive species such as *Eichhornia crassipes* (water hyacinth), introduced as an ornamental, block waterways and affect water quality (Richardson & van Wilgen, 2004). The ornamental plant and pet industries and other enterprises that rely on non-native taxa continue to introduce new species into the city, many of which are invaders that remain undetected and/or unregulated (e.g., van Wilgen & Richardson, 2012, Cronin et al., 2017).

Invasive species control programs in Cape Town date back to the 1940s (MacDonald et al., 1989), and in 2008 the city established an Invasive Species Management Unit which manages 55 teams with an annual budget of approximately 1.9 million USD.

Species selection

Gaertner et al. (2016) used several examples of invasive species in Cape Town to derive a framework for grouping species into different management categories. In this study, we selected our study species from those used by Gaertner et al. (2016) to allow for comparisons between the two studies. We selected five species out of the 20 described in Gaertner et al. (2016). We chose three plant species, one from each management category: *Acacia elata A. Cunn. ex Benth.* (Peppertree wattle)*, Eucalyptus diversicolor* (Karri gum)*, and Pinus pinea* (Stone pine). We added a second pine species (*Pinus radiata*; Monterey pine) to contrast the case of two congeners with different benefits and negative impacts. We also added an animal species, *Sciurus carolinensis* (Eastern grey squirrel), because we expected differing responses for the animal species based on experiences from invasive animal species control in Cape Town (Gaertner et al., 2016) and elsewhere (e.g., Bonesi & Palazon, 2007). *Acacia elata* was introduced to South Africa as an ornamental species on several occasions between 1904 and 1940 and has since naturalized and become invasive in many regions of the country. The species is considered a substantial threat for native biodiversity as it is increasing in abundance and range (Donaldson et al., 2014), but it has great aesthetic value and is a popular ornamental species in urban areas; for this reason it was considered an 'active engagement' species by Gaertner et al. (2016). *Eucalyptus diversicolor* trees occur in plantations that were established more than a century ago in the Table Mountain National Park. These trees grow to an impressive size, and are not highly invasive. Plantations of this species are popular among hikers, cyclists and tree enthusiasts (van Wilgen, 2012), but affect water resources (Scott & Lesch, 1997). The species is currently tolerated but is monitored. Similarly, *Pinus pinea* trees are often viewed as "heritage trees" on Table Mountain National Park and elsewhere (van Wilgen, 2012). Although the species is widespread, it is not highly invasive and is being monitored and is tolerated where appropriate. In contrast, *P. radiata,* which occurs in commercial plantations that are popular for the same reasons as *E. diversicolor*, is highly invasive (Richardson & Brown, 1986) and poses a substantial threat to the biodiversity of Table Mountain National Park (Richardson et al., 1996). Hence, the City of Cape Town planned to systematically remove the species from plantations and protected areas. Finally, Eastern grey squirrels (*Sciurus carolinensis*) are tolerated for several reasons. They were introduced to the Cape Peninsula more than a century ago, but they have not invaded native ecosystems (Long 2003). Populations are confined to urban, agricultural and afforested environments; they are therefore classified as low-impact species. The species is very popular for its aesthetic value and control of the species would almost certainly be met with strong resistance, as was the case in northern Italy where animal-rights groups initiated legal action to stop the eradication of *S. carolinensis* in the country (Bertolino and Genovesi 2003).

Questionnaire-based survey

To get a snapshot (Thomas 2011) of how members of the public in Cape Town perceive the benefits and impacts of the selected invasive species, we conducted a short paper-based questionnaire survey (Supplementary material 1). The aim of the questionnaire was to compare the perceptions held by the public with those of managers and researchers. Using a shopping mall visited by a broad range of Capetonians, we selected 30 people who were willing to complete the questionnaire (n=30). As part of our case study, we aimed to include a mix of people from different gender, age and ethnic groups.

The questionnaire had two sections: (1) A general section assessed familiarity with the selected species. Here, we showed respondents pictures of the target species and asked whether they were familiar with or had seen the species before. (2) A section designed to assess perceptions on the benefits and impacts of the target species. We asked respondents to evaluate the benefits and impacts of each target species in Cape Town, using a 5-point scale ranging from -2 (very low) to 2 (very high). This approach differs slightly from the one used by Gaertner et al. (2016) because we wanted to simplify the complex graph (Supplementary material figure 1) for the public. However, results are comparable since the verbal descriptors used were similar.

Panel of Experts

a) Email-based survey

An email-based expert survey of invasion biology researchers and managers with a connection to the City of Cape Town was conducted in July and August 2016. The survey consisted of two phases. In the first phase, participants were asked to place the five species on a graph to indicate the benefits and impacts of each target species in Cape Town (Supplementary material figure 1). After we received their response to this first email, we then invited them to use the framework developed by Gaertner et al. (2016) to place the target invasive species into the three management categories. In a follow-up email, we invited them to reflect on their experience of using the proposed framework, and to identify issues with framework and to suggest ways it could be improved. This survey was sent to 10 researchers and 10 managers in Cape Town. However, we received only a small number of complete survey responses from researchers (n=5) and managers (n=3).

b) Workshop

We then conducted a workshop with managers (n=10) and researchers (n=14). Managers included people responsible for managing invasive species and giving input into invasive species policies in the City of Cape Town, including managers from the city's Invasive Species Management Unit and from the South African National Biodiversity Institute's (SANBI) Invasive Species Programme. The latter included people doing research on invasive species in the city, whose work is used to inform managers, including researchers from SANBI and the DST-NRF Centre of Excellence for Invasion Biology.

We conducted the workshop at Stellenbosch University in August 2016. We began the workshop similarly to the email survey, asking participants to individually and anonymously indicate on a graph the benefits and impacts of each of the five target species in Cape Town (Supplementary material figure 1). In a second step, we separated participants into mixed break-out groups of four to six people. Each group discussed the benefits and impacts of the target species and then again graphed their perspectives, thereby indicating a consensus between the group members. In the next step we asked all workshop participants to use, individually and anonymously, the framework developed by Gaertner et al. (2016) (Figure 1) to place the target invasive species into the three management categories (control priority, active engagement and tolerance). Finally, we invited participants to reflect on their experience of using the proposed framework, and to identify issues with the framework.

Statistical analysis

As the number of experts, researchers and managers of invasive species for the city of Cape Town is limited, our data was restricted to 14 researchers and 10 managers. We therefore decided to combine both the email survey and the workshop to increase the sample size to n=24.

To illustrate the differences in perceptions regarding the benefits and impacts of invasive species between the public, managers and researchers, we combined the results of our workshop/e-mail survey and of the questionnaire-based survey for each species in one graph. We treat all target species separately due to the high variation in benefits, impacts, invaded area and management options among them. We generated boxplots to enable us to display differences in perceptions regarding benefits and impacts among stakeholders. As our aim was to see if there were any statistically significant differences between stakeholder perceptions, we also compared the differences in the median values between the different respondent groups' estimates for individual species impacts and benefits, respectively.

Because the medians were not normally distributed, a Kruskal-Wallis One Way Analysis of Variance in Ranks was run. Significant mean differences were separated using the All Pairwise Multiple Comparison Procedures (DUNNs method). To determine how consistently managers and researchers group invasive species into the three management categories when both using and not using the framework, we used qualitative visual assessments based on the boxplot graphs.

Results and Discussion

Perceptions

We found no clear consistency in perceptions regarding perceived benefits and negative impacts within the groups (i.e., managers, researchers and the public, independently of their familiarity with the species), and also no significant differences among the groups for most of the species. Instead, the answers were widely scattered among all groups for most of the species (Figure 2).

However, there were some exceptions. For example, most researchers and managers considered *Acacia elata* to have relatively high impacts and low benefits, whereas most members of the public perceived the species as having high benefits but low impacts. For this species, the median values for perceptions of benefits differed significantly between the different groups ($p=0.009$). Moreover, only members of the public perceived *Pinus radiata* as having low impacts ($p=0.005$) and *P. pinea* as having high benefits ($p=0.003$). Interestingly, and with the exception for *P. pinea*, almost only members of the public (both those that recognized or did not recognize the species) perceived the selected species as having very high benefits and very low impacts (Figure 2).

Grouping species into management categories with and without the framework

Despite the above mentioned differences in perceptions, our results show that using the framework leads to a higher consistency in placing the species into management categories, for both researchers and managers. The only exception is *P. pinea*, for which researchers and managers' answers are divided: without using the framework, 50% of the researchers agree to tolerate the species while 30% call for control and 20% for active engagement. Using the framework, slightly more researchers agree on tolerating the species (60%). Most of the managers, however, agree to tolerate the species (75%) or group the species into the active engagement category (25%) irrespectively of using the framework or not (Figure 3).

Interestingly, when using the framework, both researchers and managers tend to group the species more into the tolerance or control priority management categories, and less into the active engagement category (Figure 3).

Issues and amendments

The identified issues include the subjectivity of the framework – i.e. perceptions differ from person to person – and equitability – i.e. certain groups might perceive benefits of a species as high, whereas other groups might perceive the benefits of the same species as low. The framework also assumes fixed human attitudes whereas in fact people can learn about impacts, values, meanings and benefits which can change their understanding and behaviour (i.e. support or resistance) as a result of this learning (e.g. Novoa et al., 2016). Another issue that was raised is that people might use the framework (as a tool) differently even if they share the same perceptions. An interesting comment that was received is that the framework is binary, and therefore cannot accommodate win-win situations. For example, in the case where biological control of *Acacia mearnsii* reduces impacts while sustaining benefits. More specific issues are that the framework should be linked to classic strategies of prevention, eradication, containment and control (asset protection) and that control feasibility should be included. Finally, societal reaction should be included for 'low perceived benefits' as people might disagree with the prospect of controlling a species even if the species has low benefits and high impacts (e.g. Thars). Based on the mentioned issues (Table 1), we developed a new revised framework (Table 1, Figure 4). The novel/amended aspects of this new framework are illustrated and discussed below.

Members of the public often have differing understanding and perceptions about invasive species (Garcia Llorente et al., 2008; Lindemann-Matthies 2016, Novoa et al., 2016, 2017). However, experts on biological invasions (e.g. researchers and managers) are expected to have a very thorough understanding of the impacts and benefits of invasive species. For example, Andreu et al. (2009) found that environmental managers in Spain are consistent in their perceptions of the impacts generated by alien plants. On the contrary, our finding show that, not only the public, but also researchers and managers may have mixed perceptions regarding both the benefits and impacts of invasive species and their management. These findings correspond with those of Humair et al. (2014) who found that valuations of effects of invasive plant species and the understanding of, and attitudes towards, biological invasions as a societal problem differed between invasion biologists and landscape experts.

Such lack of consistency among the perceptions of experts on biological invasions suggests that managers and decision makers might be subjective when making management decisions, which would prevent them from developing effective invasive species management actions (Stokes et al., 2006, Fischer et al., 2014).

The availability of clear guidelines could help experts to make effective management decisions. In fact, our results show that the framework developed by Gaertner et al. (2016) increases the consistency of researchers and managers placing species into management categories. However, our results also show a need for more specific guidelines; even using the framework, researchers and managers did not completely agree on which is the ideal management category for each target species. The revised framework presented in this paper aims to provide such specific guidelines. Firstly, we added a set of questions as an annexure to the framework to guide users in defining whether a target species has high or low impacts (Supplementary material 2). The questions were adapted from the Environmental Impact Classification for Alien Taxa (EICAT), a tool specifically designed for helping scientists, managers and conservation practitioners to classify alien species depending on the magnitude of their impacts (Hawkins et al., 2015). We believe that this set of questions will help users to quantify more objectively the impacts of the target species.

We also added two extra decision steps. The first additional step requires an assessment of whether it is feasible to prevent the spread of the target species while sustaining its benefits of the target species. An example would be the invasion of *Acacia mearnsii* in KwaZulu-Natal, South Africa, where the species has both high benefits and high impacts. The biological control agent *Melanterius maculatus* (a seed-attacking weevil) has reduced seed production and therefore invasiveness of *A. mearnsii* but allows the sustained use of the species in forestry (Moran et al., 2000). The second added step, the determination of whether funding and effective control methods are available, allows users to consider the feasibility of management. This means that if there is a lack of funding or if no effective control methods are available for a species would it should be placed in the category "Research for management options and raise funding". This is be the case, for example, for *Sambucus canadensis* in Cape Town, for which effective control methods are not currently available (Gaertner et al., 2016).

We also included feedback arrows in the framework. These allow for adaptive management – i.e. the process of using monitoring to adjust and improve management actions (Leffler & Sheley, 2012). Adaptive management allows managers to adjust management actions depending on the results of the interventions (Zalba & Ziller, 2007). An example of adaptive management is the management of the cactus *Opuntia stricta* (Haworth.) in Kruger National Park (KNP), South Africa (Foxcroft et al., 2004).

In 1985 a chemical control programme was implemented to control invasions of *O. stricta* in the park. However, the programme was found to be unsuccessful because of the large *O. stricta* seed bank in the soil, the difficulty of spotting small plants, and the lack of follow-up work (Foxcroft et al., 2004). After undertaking research in biocontrol, a second management programme was implemented which included both chemical and biological control (using the two biocontrol agents *Cactoblastis cactorum* and *Dactylopius opuntiae*). This programme was also unsuccessful (Foxcroft & Hoffmann, 2000). In 1997, a new biotype of *D. opuntiae* was released in KNP, established quickly and destroyed *O. stricta* plants. *O. stricta* is currently controlled by *D. opuntiae*, while scattered individual plants are chemically treated (Foxcroft et al., 2017).

Adaptive management will also allow managers to adjust the management actions in the case of public opposition. Novoa et al. (2016) showed that interaction and dialogue between stakeholders can increase the knowledge and improve the willingness of stakeholders to collaborate and support invasive species management. Other studies have shown that awareness raising campaigns can also successfully change people's attitudes towards invasive species management (Garcia Llorente et al., 2008; Marchante et al., 2010; Novoa et al., 2017). Therefore, in case of public opposition, the target species can be placed in the management category "Tolerate and raise awareness". Once an awareness campaign is developed – i.e. through public events, divulgation articles, popular magazines, social media, outreach and education activities, workshops, or training programs (e.g. Ford-Thompson et al., 2012; Estévez et al., 2015) – managers can return to the decision step "Is there public opposition?" If public opposition persists, active stakeholder engagement techniques can be applied (Reed et al., 2009; Young et al., 2016). Moreover, public opposition might appear after the control of certain species – i.e. the management approach *per se* might be met with opposition by certain stakeholder groups (Sharp et al., 2011). For example, in northern California, a management programme aimed to implement aerial spraying actions to eradicate the light brown apple moth (*Epiphyas postvittana*), a major threat to agriculture. However, the management programme was challenged by a popular opposition movement who claimed that the spray posed a risk to human health (Lindeman, 2013). In such cases, after monitoring, the target species will also be placed in the category "Tolerate and raise awareness". If the invasive species is known by managers to be highly problematic and in need of control, but public opposition to its control is persistent "control using manager's discretion" might be the last option and management might have to proceed with decisions ultimately enforced through legislation (van Wilgen & Richardson, 2012).

Overall, we linked the framework to a single final endpoint, which is when “No more actions are needed”. However, we provide five intermediate management categories:

1) Species with a low potential for negative impact, regardless of the benefits they deliver, would fall in the “Tolerance” category.
2) Species for which there is public opposition to their management would fall in the “Tolerance and raise awareness” category.
3) Isolated species with low or no benefits are generally feasible do eradicate, and therefore would fall in the “Eradication” category.
4) Species with low or no benefits for which eradication is not feasible (either because the species is not isolated or because its benefits need to be sustained) would fall in the “Containment and impact reduction” category.
5) Species for which funding or control methods are not yet available, would fall in the “Research for management options and raise funding” category.

Novelty and significance of our framework

Frameworks for managing invasive species have been developed for many cities around the world). They are designed to: (1) raise awareness about invasive species impacts; (2) focus research on biology of invasive species and control methods; and (3) inform management to prevent introductions of novel invaders and to minimise the impacts of existing invaders. Invasive species are typically grouped into management categories with the following aims: prevention of spread to non-invaded areas, local eradication of isolated populations, or containment where local eradication is not possible (Auld & Johnson, 2014). These goals are very useful in decision-making protocols in protected areas and rural situations. However, in cities where divergent stakeholder views and resulting conflicts of interest often complicate decisions, additional management options are needed. Our framework was specifically designed to meet these additional challenges in cities, firstly by explicitly and transparently considering stakeholders’ perceptions, and secondly by providing pragmatic solutions for situations where conflicts of interest arise.

Conclusions

Management frameworks for invasive species in cities need to be adapted and fine-tuned to the specific situations that exist in particular urban centres. Testing the framework developed by Gaertner et al. (2016) showed that such frameworks can assist researchers and managers to arrive at a higher consistency in terms of placing species into management categories. However, we also showed that even more specific guidelines are needed to arrive at the highest possible consistency. We propose that our revised framework now provides a tool to guide individual and collective decision making around urban invasive species management.

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Tables and figures

Table 1: Issues concerning the framework identified by workshop participants and amendments of the revised framework.

Identified issue	Amendment of the framework
People might use the tool in different ways, even if they consider the perceived benefits and impacts in the same way	An annex was included
Framework users might have problems defining high or low impact	
The framework does not take feasibility into account	An extra decision step was added to the framework (“Are there funding and effective control methods available?)
The framework does not accommodate win-win situations, in which control limits the impacts of the invader while the benefits are sustained	An extra decision step was added to the framework (“Is it feasible to prevent the spread while sustaining the benefits?”)
The framework assumes fixed human attitudes. However, the understanding and behaviour of stakeholders might change with time.	Feedback arrows were included in the framework
There might be public opposition to the management of certain species, independently of their impacts or benefits	
Lack of feedback arrows	
The framework should be linked to the classic strategies of eradication, containment and control	The strategies were modified

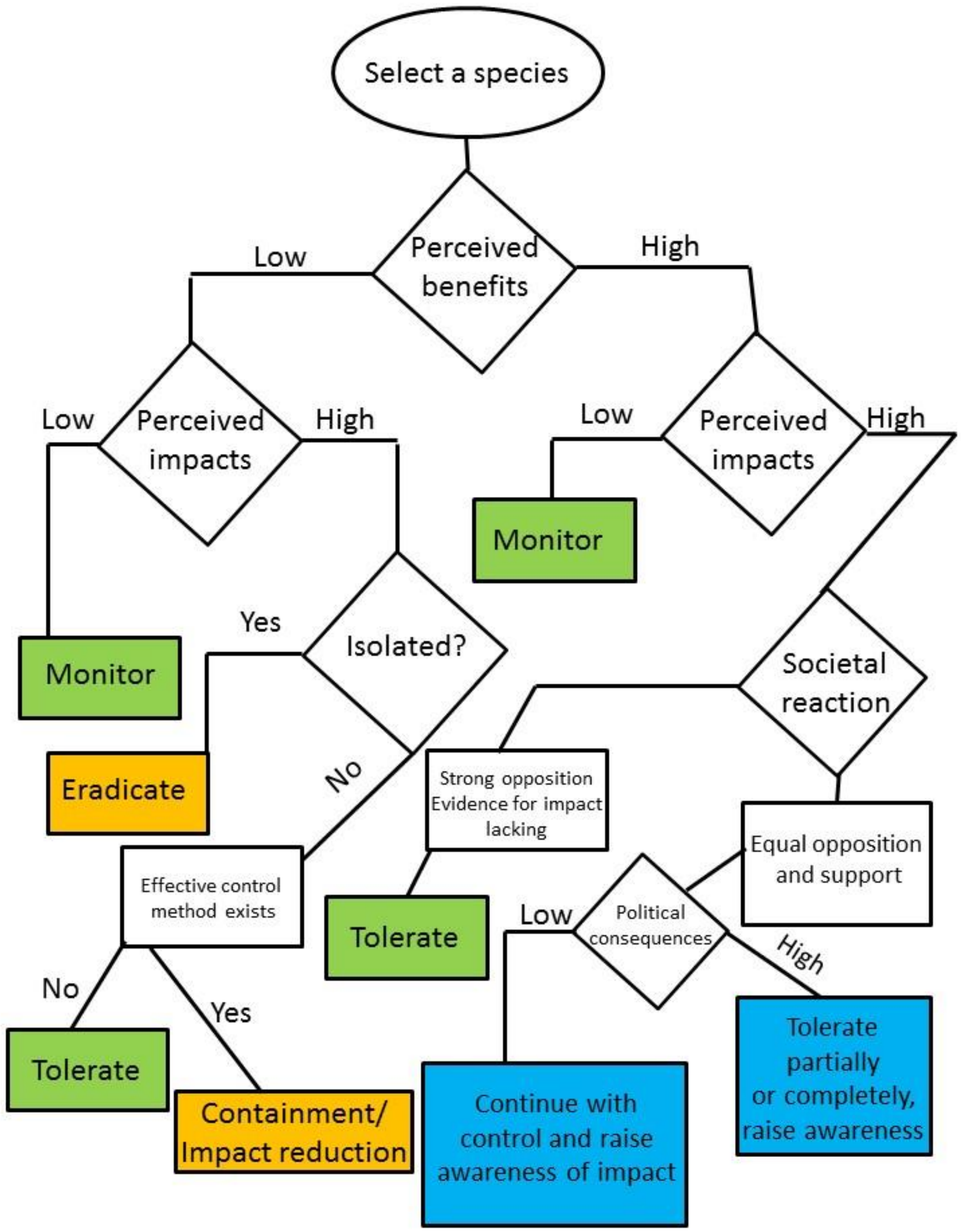
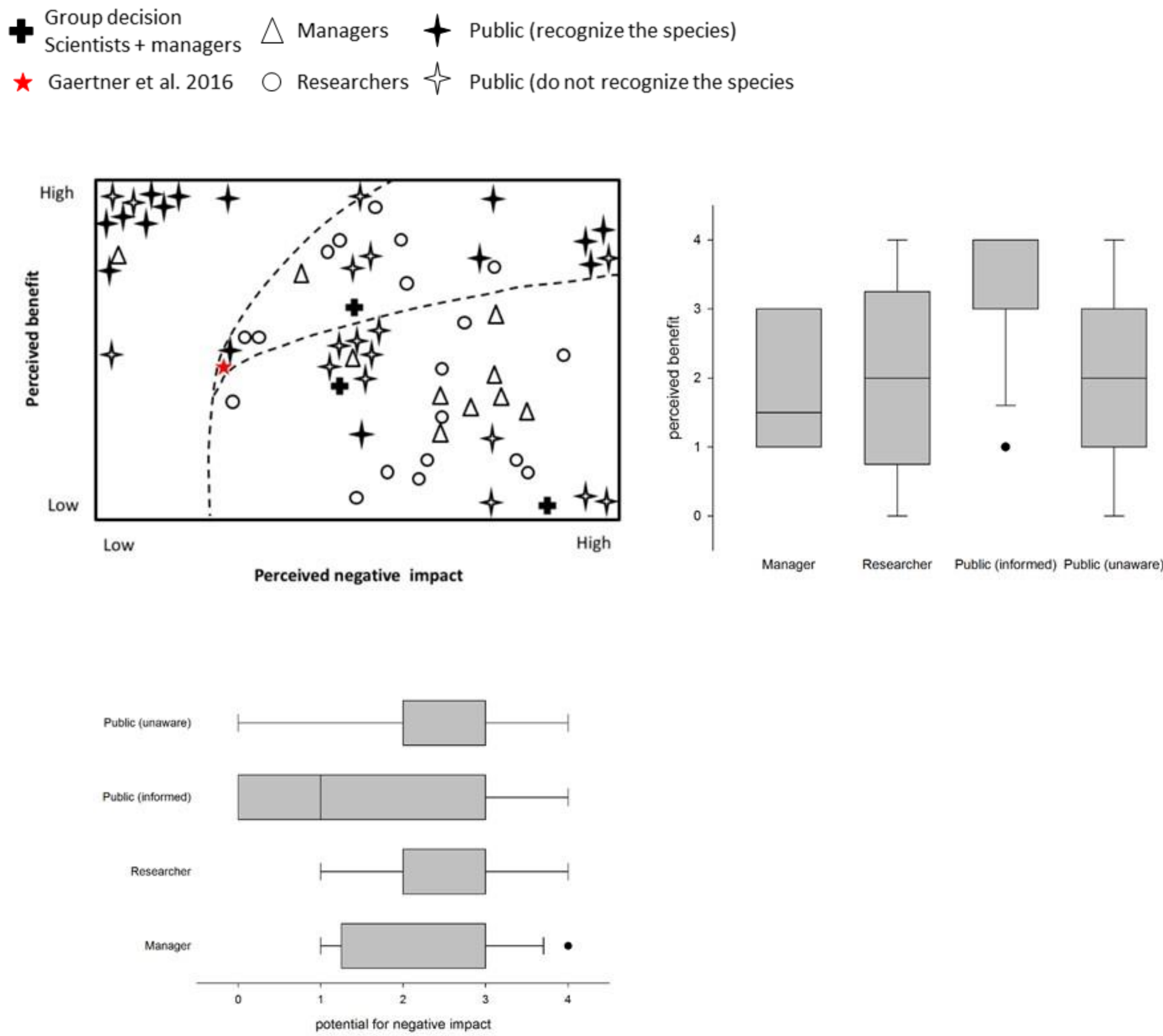
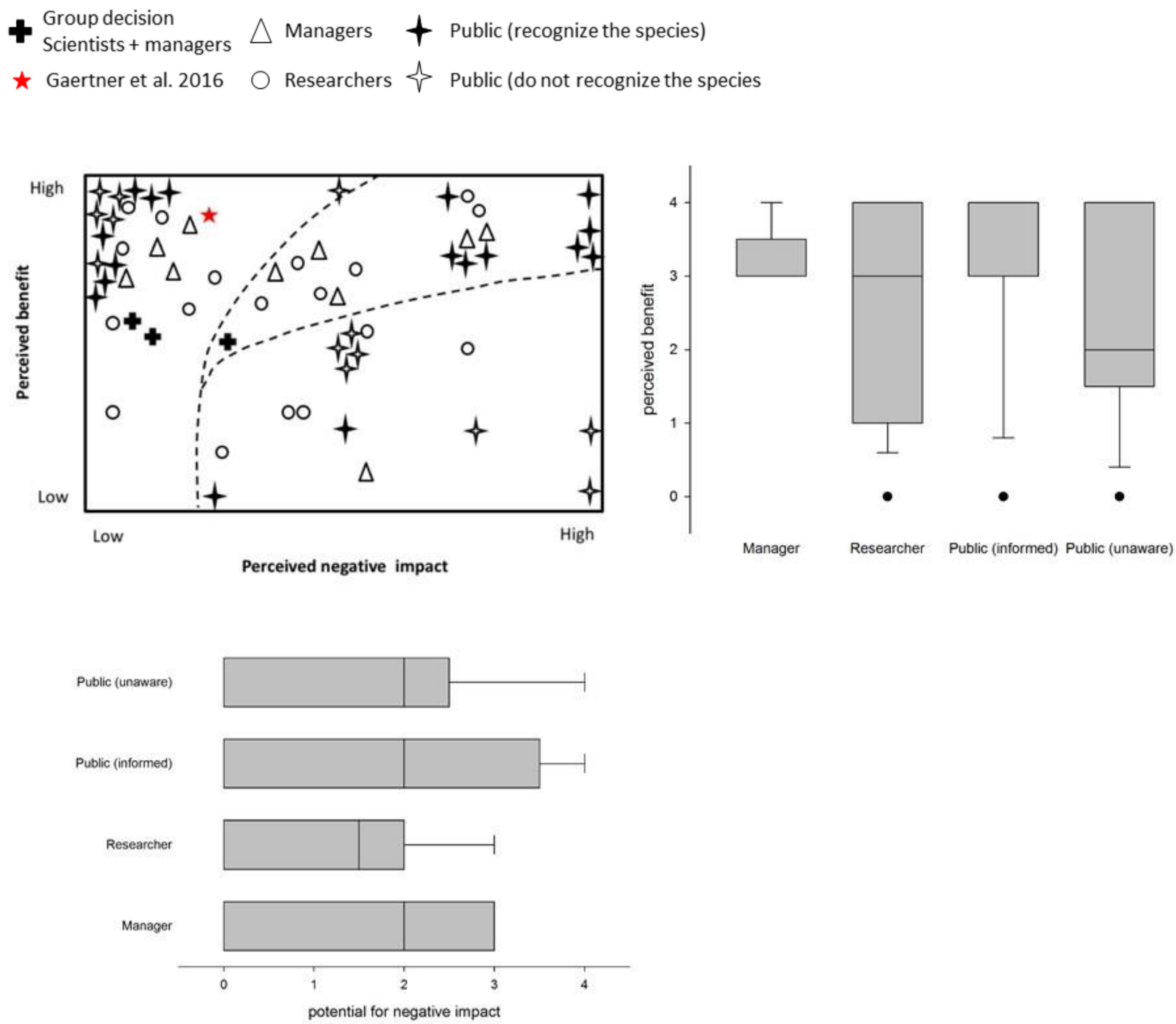


Fig. 1: Decision tree proposed by Gaertner et al (2016) to assign species to management categories within the boundaries of the City of Cape Town. "Tolerance" (in green), "control priority" (in orange) and "active engagement" categories (in blue) are described in detail in the text.

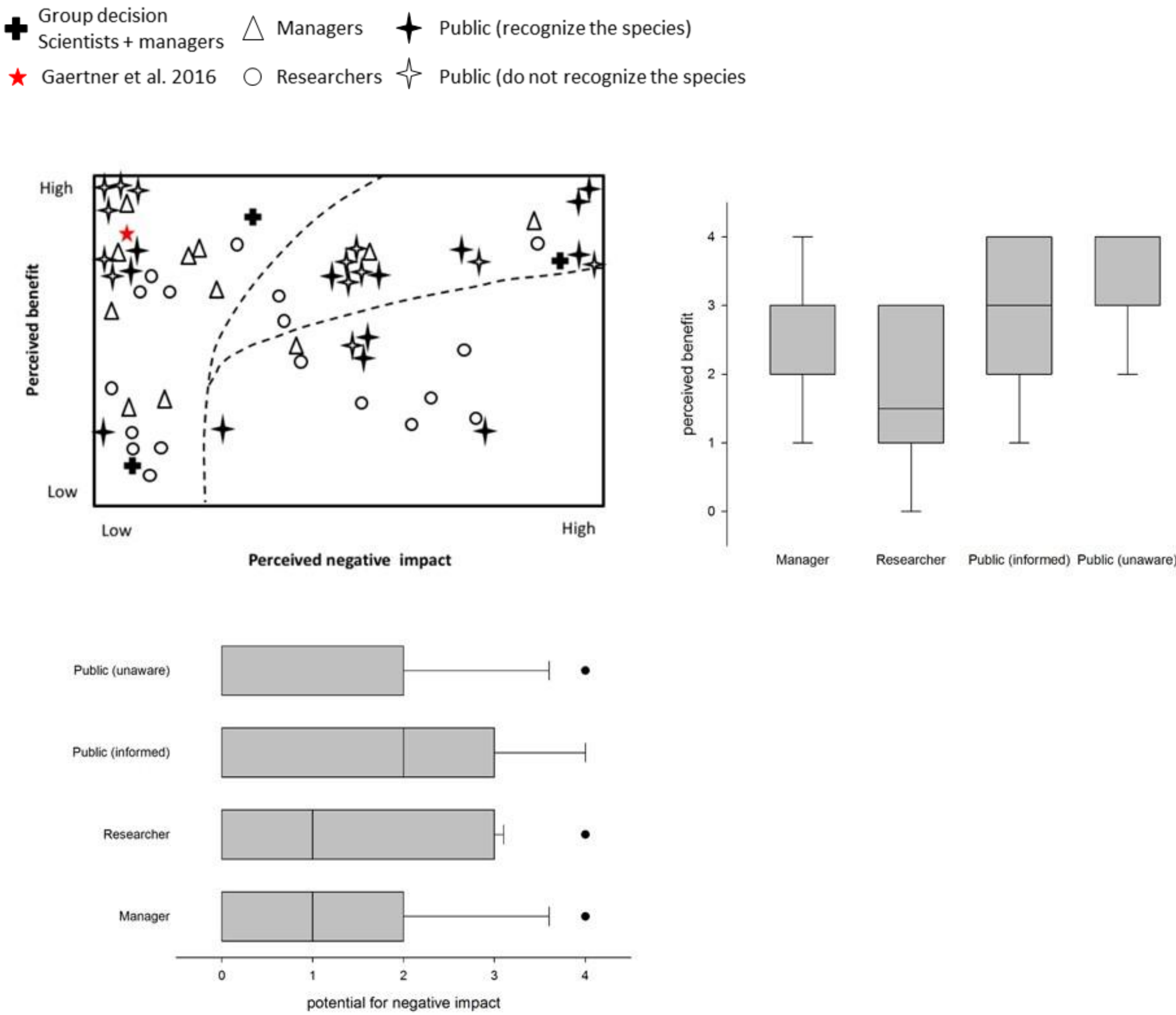
A. *Acacia elata* (Peppertree wattle)



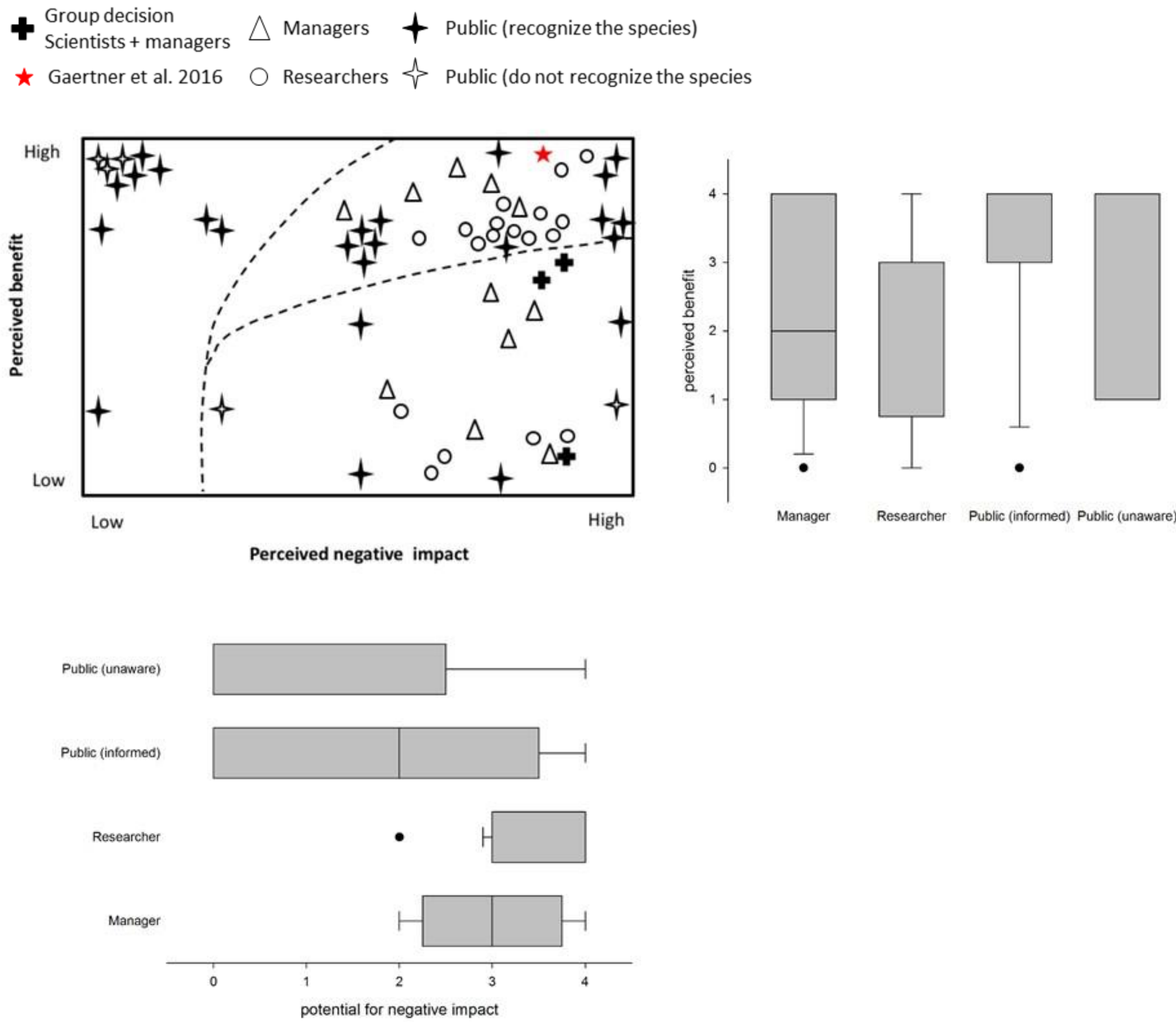
B. *Eucalyptus diversicolor* (Karri gum*)*



C. *Pinus pinea* (Stone pine)



D. *Pinus radiata* (Monterey pine)



E. *Sciurus carolinensis* (Eastern grey squirrel)

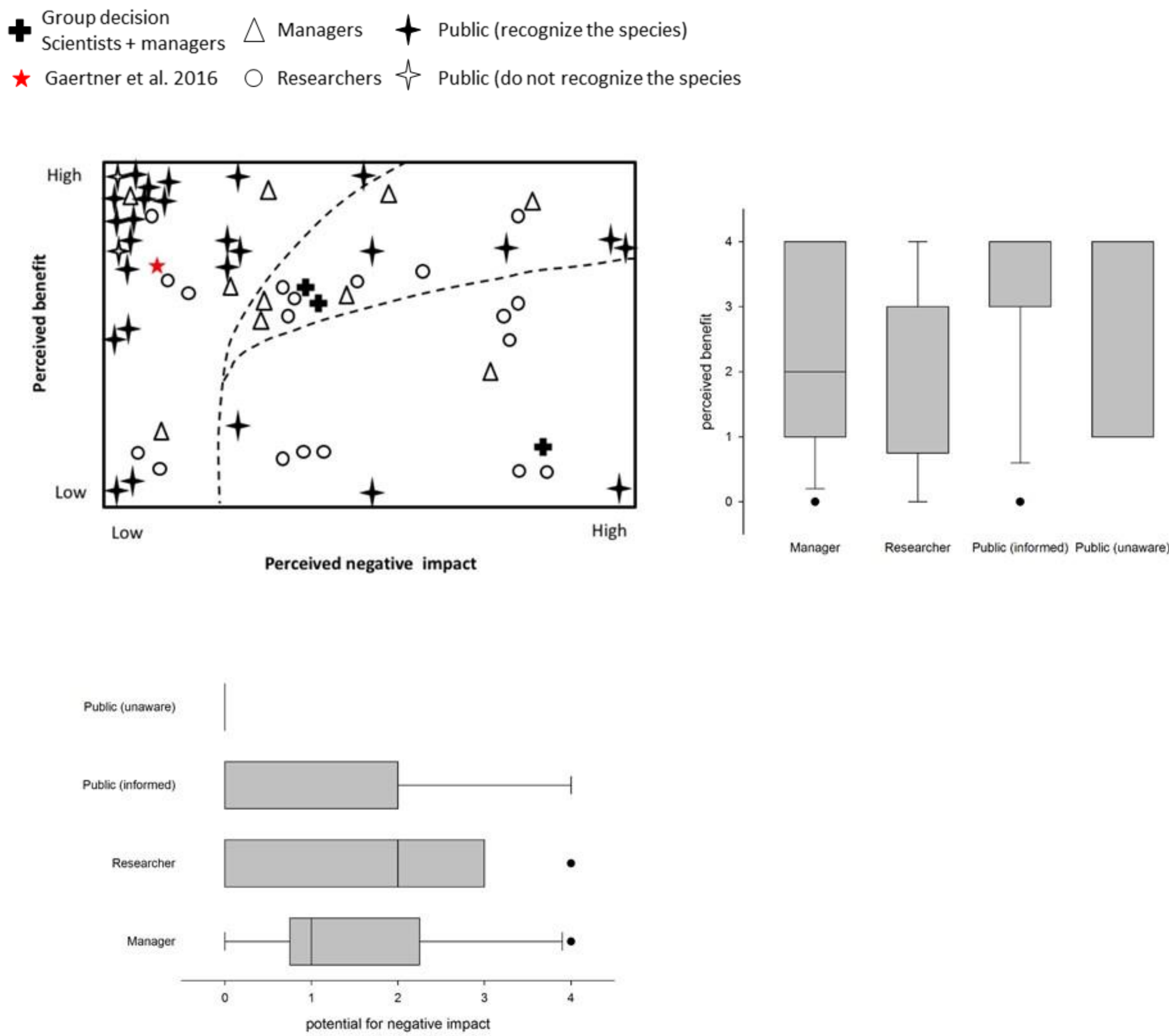


Fig. 2a-e. Categorization of the selected species according to their perceived benefits and negative impacts in Cape Town as done by the public, managers and researchers.

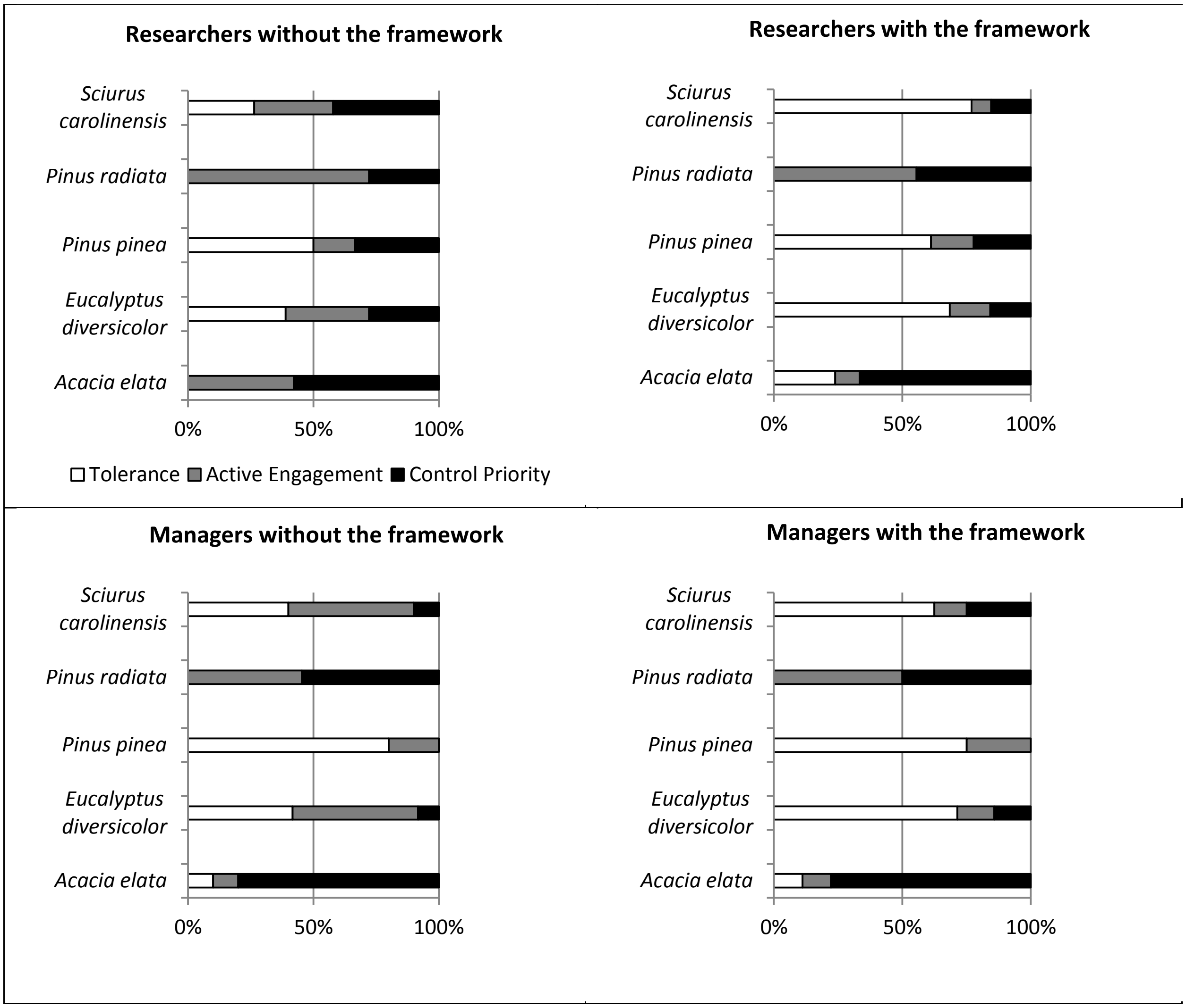


Figure 3: Consistency of researchers and managers in placing selected urban invaders as known in the city of Cape Town into management categories, with and without using the framework developed by Gaertner et al. (2016).

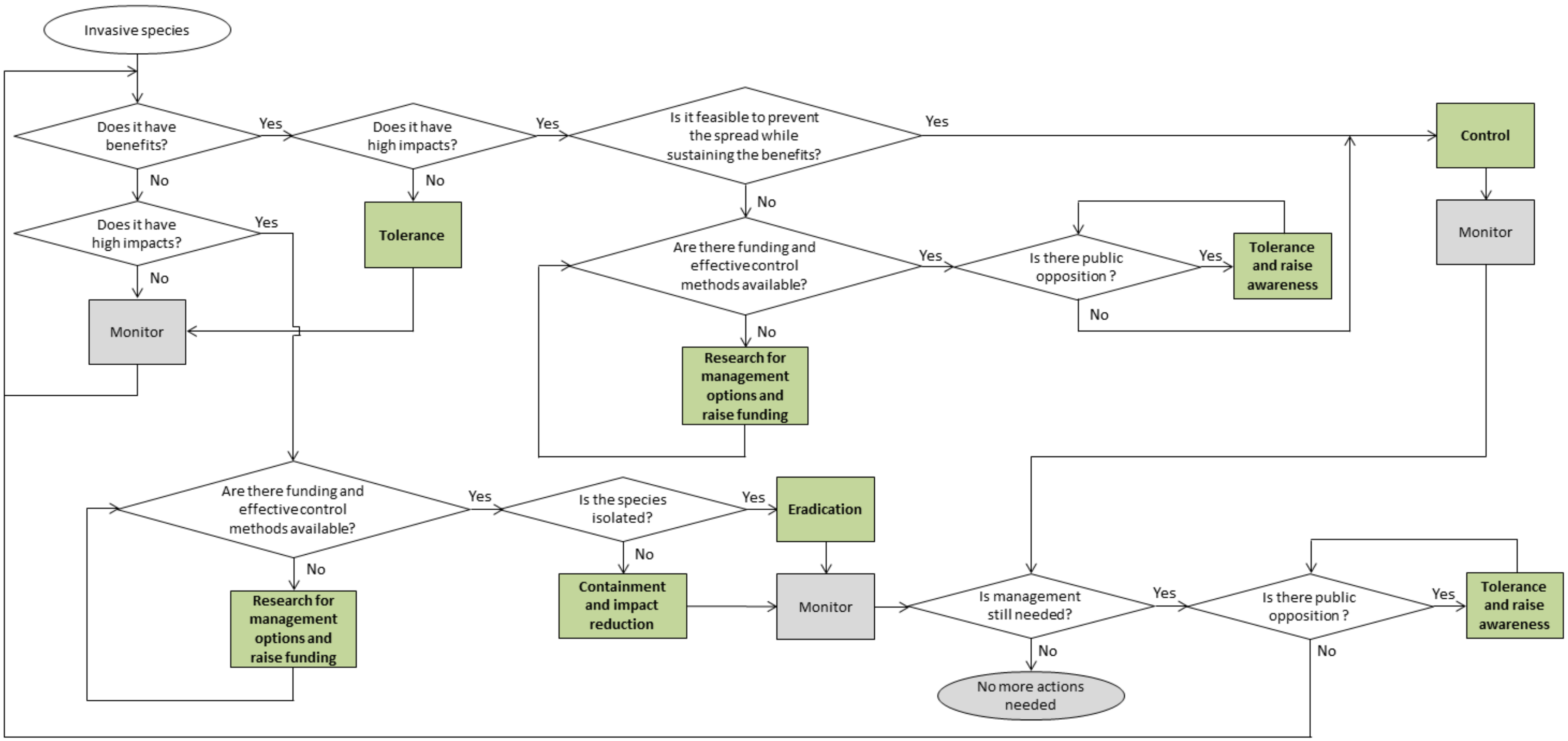
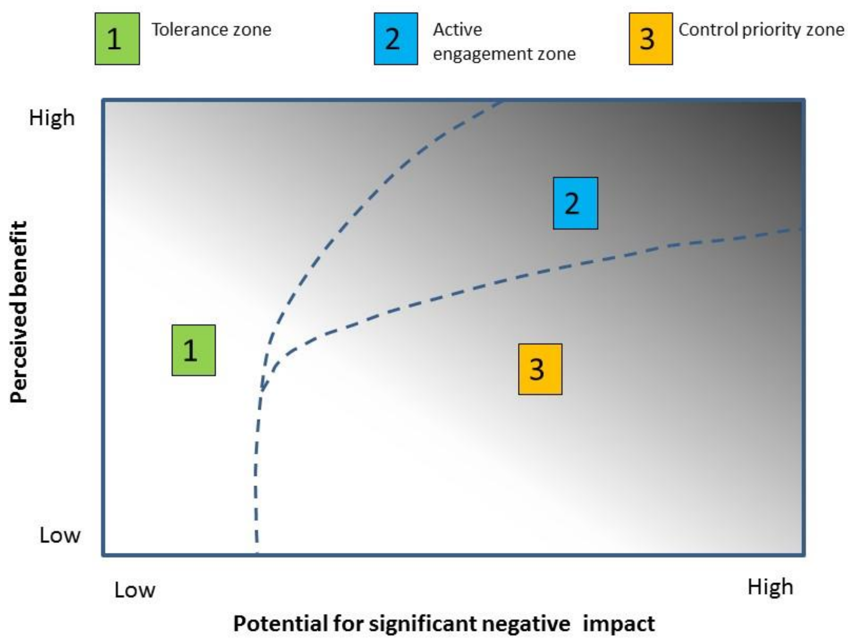


Figure 4: Adapted and revised decision support framework from Gaertner et al. (2016) for the management of invasive species in urban areas.

Supplementary material: The surveys used and the workshop programmes will be included as supplementary material:

Supplementary material 1: Paper-based questionnaire used to get a snapshot (Thomas 2011) of how members of the public in Cape Town perceive the benefits and impacts of the selected invasive species.

Supplementary material figure 1:



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Supplementary material 2:

Questions to arrive at low or high impact/benefit (adapted from EICAT scheme Hawkins et al 2015).

Species of **low impact** would fall under the Hawkins et al (2015) impact categories of minimal concern and minor or moderate impact. Summarising these categories, the species of low impact would:

(1) be unlikely to have caused deleterious impacts on the native biota or abiotic environment or;
(2) cause reductions in the fitness of individuals in the native biota, but no declines in native population sizes or;
(3) cause declines in the population size of native species, but no changes to the structure of communities or to the abiotic or biotic composition of ecosystems.
(4) Species of low impact are unlikely to cause economic and/or health impact for humans

Species of **high impact** would fall under the Hawkins et al (2015) impact categories of major or massive impact and would:

(1) cause the local or population extinction of at least one native species, and leads to reversible changes in the structure of communities and the abiotic or biotic composition of ecosystems;
(2) lead to the replacement and local extinction of native species, and produces irreversible changes in the structure of communities and the abiotic or biotic composition of ecosystems;
(3) cause economic impacts and/or would have negative influences on human health.

The benefits of non-native species in urban areas arise mainly from aesthetic value and appeal, food for humans, fodder for livestock and energy such as for household cooking and heating and carbon sequestration.