Forestry An International Journal of Forest Research

Institute of Chartered Foresters

Forestry 2020; **93**, 557–566, doi:10.1093/forestry/cpz060
Advance Access publication 18 November 2019

Stakeholders' perceptions towards non-native acacias and implications for their management in Portugal

Ana Sofia Vaz[1,2,3,*], Joana Ribeiro[3,4], João P. Honrado[3,5] and Joana R. Vicente[3]

[1]*Departamento de Botanica, Universidad de Granada, Facultad de Ciencias, Campus Fuentenueva s/n, 18071, Granada, Spain*
[2]*Laboratorio de Ecología (iEcolab), Instituto Interuniversitario de Investigación del Sistema Tierra en Andalucía (IISTA-CEAMA), Universidad de Granada, Avenida del Mediterráneo s/n, 18006, Granada, Spain*
[3]*Research Network in Biodiversity and Evolutionary Biology, Research Centre in Biodiversity and Genetic Resources (InBIO-CIBIO), Campus Agrário de Vairão, Rua Padre Armando Quintas, PT4485-661 Vairão, Portugal*
[4]*Research Network in Biodiversity and Evolutionary Biology, Research Centre in Biodiversity and Genetic Resources (InBIO-CIBIO), Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisbon, Portugal*
[5]*Faculdade de Ciências, Universidade do Porto, Rua do Campo Alegre, s/n, PT4169-007 Porto, Portugal*

*Corresponding author. E-mail addresses: asofia.vaz@fc.up.pt

Received 24 April 2019

Humans act as drivers for the introduction of non-native trees. Some non-native species may become invasive and cause undesirable impacts, thereby motivating targeted decision-making and management actions. Australian acacias (or wattles; genus *Acacia* subgenus *Phyllodineae*) have been introduced worldwide, offering both opportunities and risks for local communities. Understanding how stakeholders perceive invasive acacias is paramount to assist effective decision-making. We assessed stakeholders' perceptions about these non-native acacias, their invasion process, social-ecological impacts and management. We conducted a questionnaire-based survey with experienced managers and decision-makers in Northern Portugal, where acacia invasions are widespread. We found that most stakeholders are not able to recognize non-native species, failing to identify the introduction period, drivers of dispersion and appropriate management methods of Australian acacias. We could also identify different stakeholder perceptions on the benefits and negative impacts provided by these species. We call for the implementation of technical training and information outreach strategies to address stakeholders' lack of knowledge (and experience) on the recognition and identification of non-native trees, as well as on their introduction and invasion history, drivers of dispersion, costs and benefits, and effective management actions. Stakeholders' engagement should be promoted in the design and implementation of biosecurity efforts to control (and/or adapt to) invasive acacias at relevant scales of invasion management.

Introduction

For centuries, non-native trees have been transported and introduced for different purposes, such as wood production, landscape restoration and ornamental use (Krumm and Vítková, 2016; Brundu and Richardson, 2016). Nowadays, non-native trees still offer natural resources and ecosystem services, supporting economic revenues and the well-being of local communities (Vaz *et al.,* 2017a; Castro-Díez *et al.,* 2019; Shackleton *et al.,* 2019a). In many regions worldwide, these trees are also valued aesthetically (e.g. colourful flowers; Kueffer and Kull, 2017), historically and scientifically (e.g. from overseas expeditions; Crews, 2003; Carruthers *et al.,* 2011). Nevertheless, non-native trees can also produce undesirable impacts, especially when becoming invasive outside planted sites and competing with service-providing native species (Dickie *et al.,* 2014; Brundu and Richardson, 2016; Castro-Díez *et al.,* 2019). For instance, invasive non-native species can reduce water provision, promote soil erosion and disrupt fire regimes, particularly under neglected management (e.g. Castro-Díez *et al.,* 2012; Pyšek *et al.,* 2012).

From its beginning, invasion science has focused on ecological aspects of non-native species, mostly associated to the understanding of the invasion process and of their impacts on ecosystems and native biodiversity (Davis *et al.,* 2001; Vaz *et al.,* 2017a). The socio-economic consequences of biological invasions gained attention latter in the 2000s (Pimentel *et al.,* 2005; Brunson and

Tanaka, 2011). However, the lack of social insights on biological invasions has been widely recognized (Rotherham and Lambert, 2011; Matzek *et al.,* 2014; Vaz *et al.,* 2017b). Despite increasing attention on the human dimension of non-native species (Kull *et al.,* 2011; Head *et al.,* 2015; Essl *et al.,* 2017; Shackleton *et al.,* 2019b), social-ecological perspectives on invasions remain largely underexplored (Vaz *et al.,* 2017b; Estevez *et al.,* 2015; Abrahams *et al.,* 2019; Kapitza *et al.,* 2019).

Humans are a key dimension of biological invasions, acting as drivers for the introduction of non-native species, but also experiencing the consequences of their uncontrolled expansion and deciding (and acting) on the management of those species (McNeely, 2001; Kueffer and Hadorn, 2008; Vaz *et al.,* 2017b; Shackleton *et al.,* 2019d). When it comes to making decisions about non-native species, social awareness and perceptions are key for achieving successful management actions, including their control or eradication (Dickie *et al.,* 2014; Shackleton *et al.,* 2019b,c). The lack of awareness on potential impacts of non-native species can lead to the absence of management actions or inefficient decisions towards invaders (Sharp *et al.,* 2011; Novoa *et al.,* 2017). In addition, contrasting perceptions of non-native species can originate complex challenges for land management, associated, for instance, to social conflicts, unacceptance of decisions or options and ineffective management implementation (García-Llorente *et al.,* 2008; Novoa *et al.,* 2017).

Considering differences in social awareness and perception can be particularly important for stakeholders capable of making and changing the decision context, depending on the uncertainty of management options at particular social-ecological contexts (Estevez *et al.,* 2015; Shackleton *et al.,* 2019a,c,d). The need to understand local knowledge and perceptions has been recently emphasized in relevant initiatives on non-native and invasive species, namely the EU Regulation 1143/2014 (on the *prevention of invasive alien species*), or the sixth Plenary of the Intergovernmental Platform on Biodiversity and Ecosystem Services (*IPBES-6: on the thematic assessment of invasive alien species and their control*).

Nevertheless, understanding perceptions on non-native invasive species requires considering the diversity of socioecological contexts among stakeholders. For instance, changes in invasion dynamics (e.g. occupancy area, residence time and impact level) affect human concern, perceptions and attitudes, thus influencing the formulation and prioritization of policies towards non-native species (Estevez *et al.,* 2015; Shackleton *et al.,* 2019b). Therefore, understanding how decision-makers and managers perceive invasive species is essential for governance and management actions, e.g. allowing to identify priority areas for invasion management, considering the time scale at which efforts can be successful and allocating management efforts with greater efficiency (Novoa *et al.,* 2017; Kapitza *et al.,* 2019; Shackleton *et al.,* 2019c).

In this study, we assessed stakeholders' perceptions, knowledge and experience about the invasion process, social-ecological impacts and management of non-native Australian acacias. Australian acacias are an interesting test case for understanding stakeholders' perceptions, since these trees have been introduced worldwide, mainly for ornamental reasons and for wood provision (Kull *et al.,* 2011; Richardson *et al.,* 2011). Nevertheless, Australian acacias have been associated with the emergence of novel ecosystems, where they produce profound, often irreversible, negative impacts on native species and ecosystem functioning (Le Maitre *et al.,* 2011; Richardson and Rejmánek 2011). We conducted a participatory approach focused on stakeholders (including key decision-makers and managers) from social-ecological contexts characterized by distinct invasion extents and management concern levels on Australian acacias in Northern Portugal. We hypothesize that higher awareness and experience levels will be found for those stakeholders taking decisions in regions under more severe invasion extents and higher management concerns. Implications of our results for the management of Australian acacias in Portugal (and elsewhere) are discussed.

Methods

Study area and test species

Our survey was conducted in Northern Portugal, located in southwest Europe (Figure 1). The area covers almost 22 000 km^2 in the transition between the Eurosiberian and the Mediterranean biogeographic region. The study area has a heterogeneous topography, with a diversity of environmental conditions, land uses and land covers. The climate varies from temperate Atlantic in the western areas to subcontinental Mediterranean in eastern areas. Mean annual rainfall ranges from ca. 400 mm in the eastern valleys to over 2500 mm in the western mountain tops. Altitude ranges between 0 and 1545 m. The area is dominated by granite and schist and by acid soils. Northern Portugal includes protected areas of high conservation value (ca. 25 per cent of the area), designated under national legal protection, the European Natura 2000 network and the UNESCO Biosphere Reserve network. From the socio-economic point of view, the Northern Portugal includes eight districts (NUTS III EU administrative regions) with about 3.6 M inhabitants. From west to east, it spreads from an urban and industrialized coastal area, to an inland area dominated by the primary sector. The GDP per capita (78.1 per cent) and unemployment rates (13.6 per cent) are considered to be below the national averages (reference data for 2015, available at: https://ec.europa.eu).

We focused on Australian acacias, more specifically on the species with the highest expression in mainland Portugal: *Acacia dealbata* Link (silver wattle), *A. melanoxylon* R.Br. (Australian blackwood) and *A. longifolia* (Andrews) Willd (golden wattle). Australian acacias are among the most challenging tree invaders worldwide for several reasons. On one hand, these trees cause many negative ecological impacts, modifying native vegetation structure and species composition and affecting ecosystem health and functioning (Le Maitre *et al.,* 2011; Richardson and Rejmánek 2011). On the other hand, Australian acacias can be used to obtain natural resources and ecosystem services, functioning as an alternative to native vegetation in supporting local livelihoods (Kull *et al.,* 2011; Richardson *et al.,* 2011). This duality of risk versus opportunistic views over acacias is not an exception in mainland Portugal. *A. dealbata* and *A. longifolia* have been mainly introduced for aesthetic goals and to help controlling soil erosion in mountain and in coastal regions (Fernandes, 2018). *A. melanoxylon* has also been cultivated as a forestry species. Currently, the three acacias are widespread

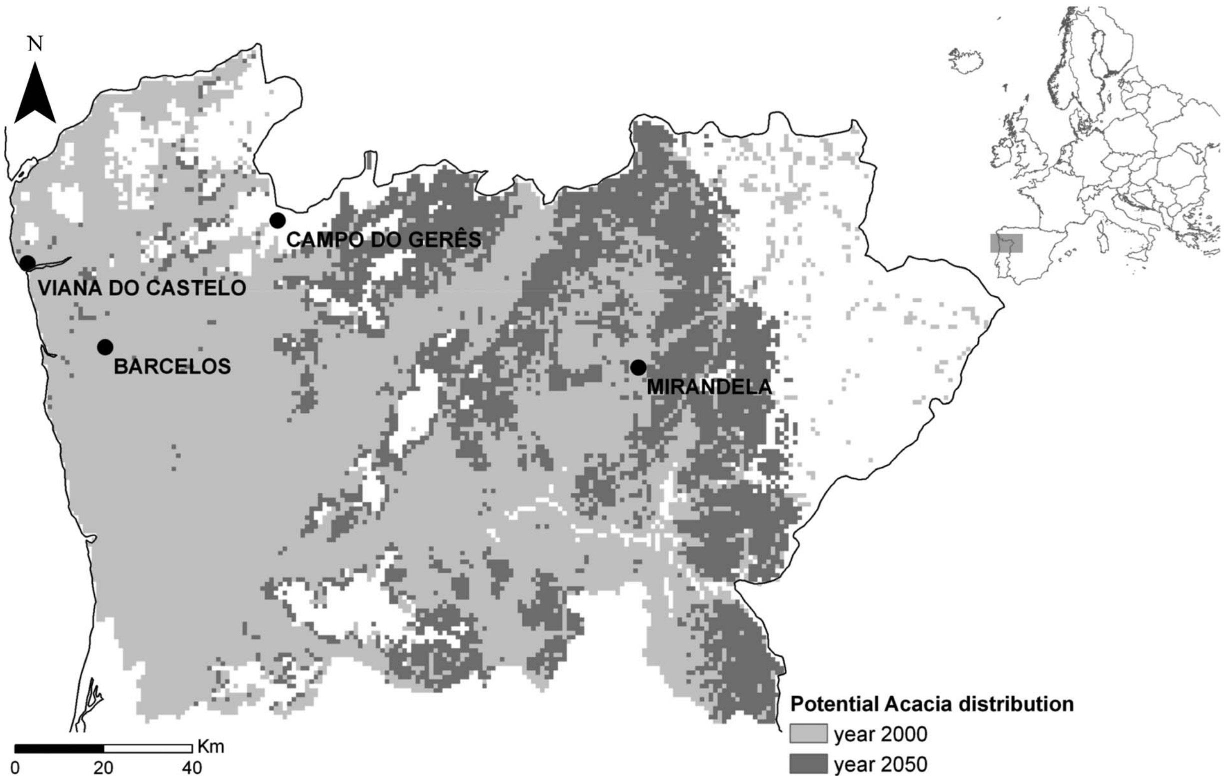

Figure 1 Study area at the European context (top-right), illustrating the distribution of three Australian acacias (*A. dealbata*, *A. longifolia*, *A. melanoxylon*) considering the years 2000 individually or in combination with the projections for the year 2050 (based on Vicente *et al.*, 2013).

invaders, particularly in forest areas, scrublands and sand dune habitats, as well as along rivers, roads and train railways. In Northern Portugal, the area occupied by these species is expected to expand towards easternmost areas under future environmental conditions (Vicente *et al.*, 2013; Figure 1).

Study regions and groups

We evaluated stakeholders' perceptions on Australian acacias across four regions with distinct social-ecological contexts in Northern Portugal. The context of each region was defined based on their known: (1) invasion extent—considering the observed and expected distribution of the three acacias in the study area (based on Vicente *et al.*, 2013, 2016) and (2) management concern—considering existing territorial planning instruments and the need to allocate management efforts to deal with the impacts of those acacias (based on discussions with the regional agency for agriculture and fisheries of Northern Portugal, DRAPN—*Direção Regional de Agricultura e Pescas do Norte*). The following regions were considered: (A) 'Viana do Castelo'—characterized by high levels of invasion extent and management concern; (B) 'Barcelos'—showing medium levels of invasion extent, but lower management concern; (C) 'Campo do Gerês'—including the only National Park in Portugal, with medium levels of invasion extent, yet high management concern and (D) 'Mirandela'—under low levels of invasion extent and management concern. Levels of invasion extent are expected to be maintained (A and C) or to increase (B and D) under future scenarios of environmental change (Vicente *et al.*, 2013, 2016).

For each of the four regions, we identified key stakeholders directly responsible for making and/or implementing land management decisions in the region. These were identified in collaboration with DRAPN, and included stakeholders acting individually or on behalf of private businesses (including landowners), public agencies or non-governmental organizations, across all relevant economic sectors (e.g. industry, agriculture and tourism) and decision-making responsibility (e.g. operational, tactical and strategic; following Novoa *et al.*, 2018).

Workshops and questionnaires

After the identification of key stakeholders, we organized four workshops (i.e. one *per* social-ecological region) to evaluate the levels of stakeholders' knowledge and perception on Australian acacias. For each region, we invited the participation of key stakeholders through email and phone (e.g. through DRAPN's contact database), as well as through social media platforms (e.g. Facebook). The dates of the workshops (in April and May of 2018) were previously negotiated with potential participants in order to engage with the maximum number of attendees (but with up to 25 people *per* workshop; Newing, 2010).

In each workshop, we conducted a questionnaire-based survey. After a piloting process, the questionnaire was administrated interactively to each individual stakeholder (following Newing, 2010). Questionnaires focused on: (1) respondents'

Table 1 General information considered in the questionnaire. The questionnaire intended to gather information on (1) socio-demography (anonymous); (2) knowledge on invasive species; (3) knowledge on the invasion process; (4) perceived benefits and negative impacts; (5) experience with management methods and (6) attitudes and responsibility.

Information	Description
(1) Socio-demography	Information on: (1.1) gender, (1.2) educational qualification, (1.3) years of work experience, (1.4) level of decision responsibility (e.g. advisor, director), (1.5) main area of decision
(2) Invasive species	Indicates the number of: (2.1) identified invasive tree species, (2.2) correctly identified invasive tree species, (2.3) correctly recognized acacias
(3) Invasion process	Knowledge about: (3.1) time period of introduction of acacias, (3.2) invasion extent, (3.3) rate of acacias dispersion and (3.4) promoters of the invasion process (e.g. human action, wildfires, roads)
(4) Benefits and nuisances	The participant: (4.1) recognizes benefits or negative impacts from acacias, (4.2) their perceived level of impact on natural resources (e.g. timber production, fire risk, landscape aesthetics)
(5) Management actions	Experience level with: (5.1) management actions applied to prevent, control or reduce the prevalence of acacias in the region (e.g. girdling, cutting, biocontrol)
(6) Attitudes and responsibility	Level of agreement with several statements focused on: (6.1) acceptance of commercialization, (6.2) effectiveness of existing legal instruments, (6.3) management responsibility of Australian acacias

sociodemographic information; (2) knowledge on invasive species; (3) knowledge on the invasion process; (4) perceived benefits and negative impacts; (5) experience with management methods and (6) management attitudes and responsibility (Table 1; see Supplementary Table S1 for details). We had the participation of a total of 65 stakeholders (i.e. 65 questionnaires). The participation of stakeholders was voluntary, and all participants were informed about their rights to refuse to answer any question and withdraw from participation at any time. Informed consent was obtained, anonymity and confidentiality were explicitly granted and questionnaires did not include any information that could be used to identify individual respondents. Detail on the questionnaire design and administration are shown in Appendix 1.

Data analysis

We used descriptive statistics on categorical data, to explore participants' sociodemographic information (1.1–1.5 in Table 1) and their knowledge on the time periods of acacia introduction (3.1 in Table 1). We further assessed whether stakeholders exhibited statistically significant differences in their perception and knowledge levels across the four social-ecological regions. Non-parametric Kruskal–Wallis tests, followed by post hoc Dunn's tests, were used to test for differences in numerical variables, namely on the number of identified invasive tree species (2.1 in Table 1), correctly identified invasive tree species (2.2), and correctly recognized acacias (2.3). These tests were also applied to check for differences in stakeholders' perceptions of benefits and/or negative impacts from acacias across the four regions (4.1 in Table 1), as well as in their experience with different management methods (coded as dummy variables; 5.1 in Table 1).

One-way ordinal regressions were used to analyse differences among stakeholders from the four regions for the remaining information (ordinal data). Due to sample size limitations, ordinal regressions were applied over individual perception/-knowledge levels of: invasion extent (3.2 in Table 1), expansion of acacias (3.3), drivers of the invasion process (3.4), acacias' impacts on natural resources (4.2), applied management actions (5.1), acceptance of acacia trading (6.1), effectiveness of existing legal instruments (6.2) and responsibility towards management. One-way ordinal regressions were performed considering stakeholders' information from region D ('Mirandela') as the prognostic group for comparison (i.e. corresponding a baseline group; in our case, with the lowest invasion extent and management concern). This means that, for a given variable, a significantly higher or lower value for stakeholders of a given region (A–C) should be interpreted as significantly higher or lower than the value of that variable for stakeholders of region D. All statistical analyses were carried out using software R (R Team, 2016).

Results

Study groups

The study had the participation of 65 participants, from which 58 per cent and 39 per cent were respectively females and males (3 per cent of replies not stated). The number of participants was 20 in region A, 17 in regions B and D and 11 in region C. Overall, 43 per cent of participants presented more than 15 years of work experience and 94 per cent exhibited a university-level education. Forty-eight per cent of all participants were dedicated to technical work; 12 per cent held a top-level decision-making position (i.e. directors or delegates) and 14 per cent were dedicated to research or communication occupations. Their main working areas were agriculture, forestry and environment (60 per cent of all participants), followed by other fields in the natural and social sciences (e.g. veterinary, geography, law and tourism). The

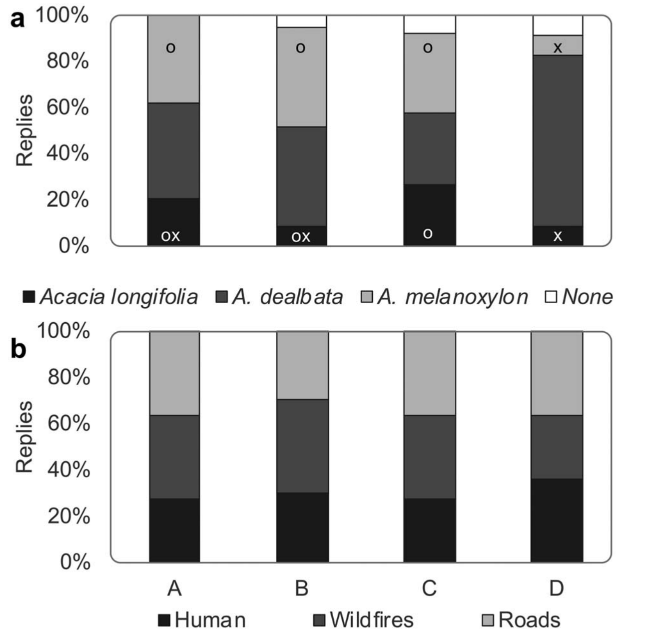

Figure 2 Number of replies from stakeholders of different regions (A–D) regarding (a) which Australian acacias they were able to recognize and (b) their perception level of the main drivers of acacia distribution in Northern Portugal. The same symbol in (a) indicates those regions which stated similar recognition levels for each species; regions with distinct symbols indicate significant differences (Dunn's tests).

sociodemographic characteristics of the participants are shown in detail in Appendix 2.

Knowledge on invasive species and invasion process

Participants were first presented with a list of 18 tree species and were asked to indicate whether they recognized those species (2.1 in Table 1). Among the recognized species, they were invited to classify them as non-native or native trees (2.2 in Table 1). The proportion of correct classifications of non-native trees ranged from 16 to 95 per cent (mean accuracy: 59 per cent). The proportion of correctly classified non-native trees did not hold statistical differences (Kruskal–Wallis, $P > 0.05$) and was similar across stakeholders from the four regions: mean accuracy of 60 per cent for region A, 64 per cent for region B, 65 per cent for region C and 50 per cent for region D.

When asked to recognize different species of acacias (i.e. *A. longifolia*, *A. dealbata* or *A. melanoxylon*; 2.3 in Table 1), statistical differences could be detected among stakeholders from the four regions (Kruskal–Wallis, KW = 15.97; $P = 0.001$). Stakeholders from region D showed lower ability to discriminate acacias compared to regions A (Dunn, $Z = 2.99$; $P = 0.010$), B ($Z = -3.45$; $P = 0.003$) and C ($Z = -3.20$; $P = 0.006$). Among the three acacias considered, the most frequently recognized species were *A. dealbata* and *A. melanoxylon* (Figure 2a). Differences in the recognition of acacias across stakeholders from different regions were found to be significant for *A. longifolia* (KW = 10.00; $P = 0.018$) and *A. melanoxylon* (KW = 24.94; $P < 0.0001$, Figure 2; see Appendix 3 for full results).

Most participants indicated the periods 1950–2000 (47 per cent of all participants) and 1900–1950 (31 per cent) as the time intervals at which Australian acacias have been introduced in mainland Portugal (3.1 in Table 1). Only a minor proportion identified the periods before 1900 (17 per cent) and after 2000 (5 per cent) as the time intervals of introduction. The perception of the invasion process of acacias showed significant differences between stakeholders from distinct regions. Region D's stakeholders perceived smaller invasion extents (3.2 in Table 1) than those from regions A ($r = -2.99$; $P < 0.0002$) and C ($r = -2.79$; $P = 0.002$). No differences were found for region B ($P > 0.05$; see Supplementary Table S4.1 for full results). No differences were also found regarding the perception of invasion expansion (3.2 in Table 1), with stakeholders from the four regions perceiving a high rate of acacias' expansions in Northern Portugal. Concerning the determinants of expansion (3.3 in Table 1), direct human influence was found to be particularly significant in region B ($r = -1.38$; $P = 0.03$). The influence of wildfires was also mostly significant for stakeholders in region B ($r = 1.65$; $P = 0.009$) and C ($r = 1.93$; $P = 0.08$; Figure 2b).

Awareness of impacts, and management actions, attitudes and responsibilities

When asked about the type of impacts, only 22 per cent identified benefits associated to acacias (4.1 in Table 1). The use of acacias for domestic wood (mainly heating) was the most identified benefit (58 per cent of cases in which benefits were identified), followed by ornamental purposes (32 per cent), timber wood (9 per cent), soil fixation (8 per cent) and support to bean production (as stakes; 7 per cent; see Supplementary Table S5.1 for full list of perceived benefits). Acacias were also perceived as fire promoters and benefiting honey production, with no statistical differences among regions. Stakeholders from region D also recognized benefits from acacias on hunting activities and wild fauna (Figure 3).

Ninety-seven per cent of all participants could perceive negative impacts of acacias on natural resources (4.2 in Table 1). Stakeholders from region A perceived the highest level of negative impacts on several natural resources, such as landscape aesthetics, agriculture production or wild flora (Figure 3). The results from ordinal regressions suggest that the negative impacts of acacias on wild fauna ($r = -1.72$; $P = 0.03$), flora ($r = -1.85$; $P = 0.03$) and hunting activities ($r = -1.85$; $P = 0.03$) were particularly significant for region C (see Supplementary Table S4.2 for full results).

When asked about different management methods to deal with Australian acacias (5.1 in Table 1), 25 per cent of the participants did not have any experience. Among those who had, cutting (46 per cent of all participants), physical removal (e.g. pulling; 35 per cent) and application of herbicides (i.e. chemical control; 40 per cent) were the most applied methods (Figure 4). Significant differences on the experience with management methods among regions were only identified for physical removal (KW = 10.00; $P = 0.018$), which was particularly relevant for region B ($Z = 2.84$; $P = 0.03$; see Supplementary Table S3.3 for full results).

Our survey showed that, in general, the participants did not agree or disagree with the trading of acacias (6.1 in Table 1). Nevertheless, the stakeholders from the four regions agreed that existing legal instruments to deal with these trees are

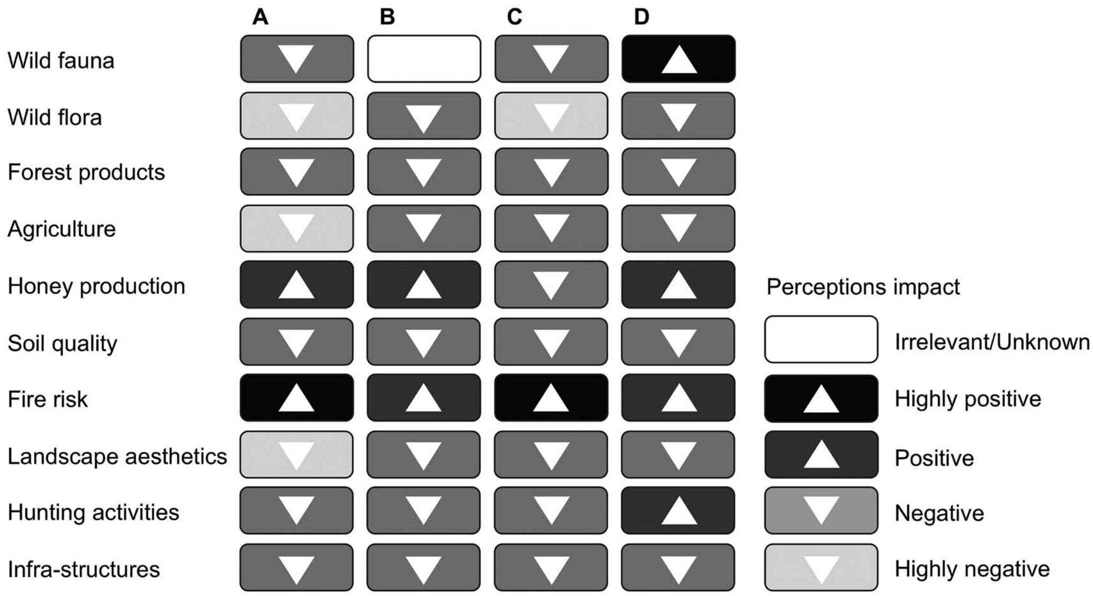

Figure 3 Average level of perceived impacts of Australian acacias on native biodiversity and on natural resources, as indicated by the participants of the four study groups (A–D).

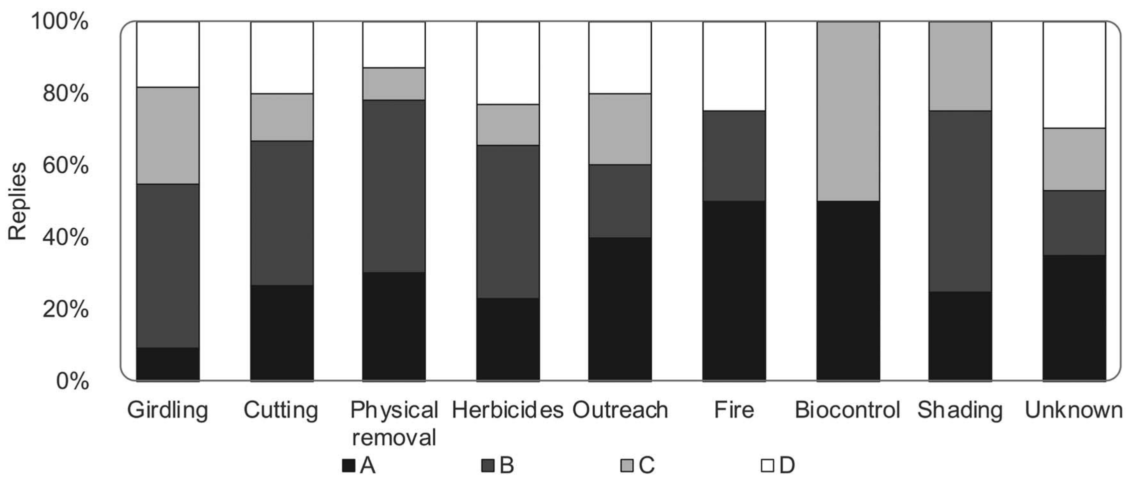

Figure 4 Average awareness level of distinct management methods applied for dealing with Australian acacias, as indicated by the participants of the four study groups (A–D).

insufficient (6.2 in Table 1), and that management responsibilities (6.3 in Table 1) should be shared among forest landowners and associations as well as national and regional municipalities (see Supplementary Table S5.2 for full results).

Discussion

This study explored stakeholders' perceptions and knowledge towards non-native Australian acacias across regions under distinct invasion extents and management concern in the North of Portugal. The participants included in this study were mostly represented by university-level and work-experienced stakeholders, being responsible for decision-making and technical activity in the areas of agriculture, forestry and environment. Our questionnaire-based survey showed distinct perceptions on invasive species, on the invasion process and on the resulting impacts, depending on the social-ecological context.

Contrasting perceptions of Australian acacias and their introduction

The effectiveness of management actions towards non-native species can be compromised by the inability to distinguish the invader from apparently similar native species (Maki and Galatowitsch, 2004; Corbett *et al.*, 2005). The responses to our questionnaires showed that almost half of the stakeholders did not correctly distinguish native from non-native tree species. Other studies had shown a lack of public ability to recognize native species (e.g. Genovart *et al.,* 2013) or even to acknowledge the broader concept of biodiversity (e.g. Lindemann-Matthies and Bose, 2008). Severe consequences can emerge when biosecurity actions—i.e. measures designed to prevent the origin and spread of biological threats (Sutcliffe *et al.,* 2018)—are mistakenly applied to native species instead of non-native species (e.g. Somaweera *et al.,* 2010). Examples include the misidentification of the native Noisy Miner bird (*Manorina melanocephala*) as an invasive Indian Myna bird (*Acridotheres tristis*), in Tasmania (Lloyd, 2006); of native wood-boring beetles as an invasive Asian Longhorn beetle (*Anoplophora glabripennis*), in Europe (MacLeod *et al.,* 2002); or of several invasive plants as natives in eastern USA (Sarver *et al.,* 2008).

Misidentification of invasive species can reduce management effectiveness, while the lack of awareness on invasive species can lead to the absence of any management decision or action (Sharp *et al.,* 2011; Novoa *et al.,* 2017). Our study showed different awareness levels on acacia species (Figure 2a), with stakeholders from eastern regions (i.e. region D) presenting the lowest ability to recognize *Acacia longifolia* and *A. melanoxylon*. These acacia species are the least widespread species in eastern regions of the study area (with *A. longifolia* even absent in those areas), and thus the more unlikely to be identified. However, particular attention should be paid given the likelihood of future environmental changes to promote the expansion of these species towards eastern parts of the study area (Vicente *et al.,* 2013, 2016).

Australian acacias are known to have been introduced in Portugal before 1900, and at least since the middle of the 17th century (Fernandes, 2018). However, less than a fifth of the targeted stakeholders (i.e. 17 per cent) indicated that these trees were introduced before 1900. Most of the stakeholders indicated the period 1950–2000 (47 per cent), followed by 1900–1950 (31 per cent), and only a few mentioned the period after 2000 (5 per cent). The interval dates indicated by the majority of participants seem to correspond to the periods, during which acacias were already widespread in the study area. Increase in abundance of invasive species and longer coexistence time between these species and local people can lead to higher awareness of invasive species occurrence and of their impacts (Shackleton *et al.,* 2019b). It was also during the period 1950–2000 that the notion of 'invasive', 'aggressive' and 'damaging' species became prominent in conservation dialogues about Australian acacias in Portugal (Fernandes, 2018). Legal instruments, awareness efforts and management interventions focused on invasive acacias also increased rapidly during this period (Fernandes, 2018).

Differential awareness of expansion and impacts of acacias

There is a general agreement that Australian acacias have been deliberately introduced in Portugal to support ecosystem functions and produce resources and goods (Fernandes, 2018). In our study, direct human action (e.g. cultivation) and the influence of wildfires were reported as especially relevant for the dispersion of Australian acacias in the territory, and particularly in the National Park (i.e. region C; Figure 2b). Wildfires can act as drivers of seed germination for acacias (Lorenzo *et al.,* 2010). This is particularly evident in Northern Portugal, which is among the European regions with the highest incidence of fires (San-Miguel-Ayanz *et al.,* 2017).

The cultivation of Australian acacias has been mainly justified by ornamental usage (*A. dealbata*), to assist on coastal dune stabilization (*A. longifolia*), and to obtain timber goods and products (*A. melanoxylon*; Lorenzo *et al.,* 2010; Fernandes 2018). Our survey indicates several benefits from Australian acacias in the study region, namely domestic heating and aesthetics, as well as timber, soil fixation, honey and bean production. Longer coexistence between people and invasive species can lead to societal adaptation to those species with alternative uses (Vaz *et al.,* 2017b; Shackleton *et al.,* 2019a). An emblematic example is the adaptation of local communities and respective sociocultural practices to the invader prickly pear (*Opuntia ficus-indica*), in South Africa and Madagascar (Shackleton *et al.,* 2007; Middleton, 2012). Despite their invasive behaviour, local communities worldwide have also adapted to Australian acacias by taking advantage of their wood, tannins, flowers and seeds, among others (Kull *et al.,* 2011).

Although invasive trees can provide many benefits, there are also risks to the environment, culture, health and socio-economy (Dickie *et al.,* 2014; Vaz *et al.,* 2017a). Our survey indicates a general agreement on that Australian acacias pose more risks (negative impacts) than opportunities (benefits). Nevertheless, different perception levels among stakeholders from the four regions were identified (Figure 3). Specifically, stakeholders under higher invasion exposure (i.e. region A) recognized the highest levels of negative impacts, namely on landscape aesthetics, agriculture and wild biodiversity. Impacts of Australian acacias on wild fauna and flora were also widely reported by stakeholders responsible for decision-making in the National Park (i.e. region C). Conversely, fewer impact levels were recognized by the stakeholders under less concern about acacias (regions B) or exposure to their invasion (region D). The plurality of stakeholder perceptions on the benefits and impacts of invasive species has been previously highlighted (Dickie *et al.,* 2014; Gaertner *et al.,* 2017a,b). In the study area, the different impact levels perceived can be explained by: (1) differences in the coexistence time with Australian acacias, and hence distinct awareness of their impacts (i.e. region A versus D; Shackleton *et al.,* 2019b) and (2) distinct motivations, priorities and funding support associated to decisions on conservation management (i.e. region B versus C; Novoa *et al.,* 2017, 2018; Shackleton *et al.,* 2019c).

Implications for management: the role of stakeholders' perceptions and awareness

Stakeholders are key in invasion management and general environmental governance, since their perception and knowledge on the social-ecological system inevitably influences the decision-making process (Novoa *et al.,* 2017; Reed, 2008; Shackleton *et al.,* 2019d). Our survey showed that a quarter of the inquired stakeholders were inexperienced with any method for managing Australian acacias. Moreover, stakeholders who experienced at least one method, indicated cutting as the prevailing management action, followed by chemical control and physical removal (Figure 4). Since cutting alone can be ineffective for controlling these species (actually stimulating acacia seed germination and sprouting from rhizomes), our results highlight that awareness strategies should be rapidly promoted, e.g. through scientific-based learning and technical training, including environmental education and information outreach campaigns (Marchante and Marchante, 2016; Schreck Reis *et al.,* 2013). These campaigns would allow the improvement of stakeholders' knowledge on invasive species (and wider biodiversity values; e.g. Lindemann-Matthies and Bose, 2008), their impacts and management (Novoa *et al.,* 2017, 2018; Shackleton and Shackleton, 2016).

Considering the results from our survey, these campaigns could be particularly useful to: (1) avoid non-identifications and misidentifications of non-native (and native) tree species; (2) elucidate on the introduction and invasion history of Australian acacias to better address future management measures; (3) clarify the role of other, often indirect, human activities acting as drivers for the dispersion of acacias (e.g. roads and rivers as dispersion corridors or even climate change) and (4) inform on effective management methods to deal with Australian acacias, while providing adequate training for their implementation. By doing so, further engagement from stakeholders could be expected to strengthen biosecurity efforts focused on the control of areas already invaded by acacias (i.e. the western part of our study area). Also, they would assist on invasion prevention in areas where acacias are expected to expand in the future (i.e. the eastern part of the study area; Vicente *et al.,* 2013, 2016).

The targeted stakeholders agreed that existing legal instruments to deal with Australian acacias are insufficient, and that management responsibilities should be shared among forest landowners, forestry associations and national and regional municipalities (and perhaps others). Therefore, any effort to promote stakeholders' engagement should be developed using collaborative and communicative approaches (Schreck Reis *et al.,* 2013; Vaz *et al.,* 2017b; Abrahams *et al.,* 2019). This would allow to better manage potential conflicting perceptions or interests emerging from trade-offs between risks and opportunities associated to the socio-economic, ecological and cultural values of acacias (Estevez *et al.,* 2015; Novoa *et al.,* 2018; Shackleton *et al.,* 2019b). It could also pave the way to establish adaptive mechanisms, such as the controversial economic exploitation control (Geesing *et al.,* 2004), which could constitute an option, together with biocontrol measures (van Wilgen *et al.,* 2012), to deal with acacias in landscapes where eradication is already unfeasible and control methods are too costly. The recent EU Regulation 1143/2014 (on *the prevention of invasive alien species*), transposed to the national law, and the upcoming efforts from the IPBES-6 (on *the assessment of invasive alien species and their control*), will constitute important instruments for further clarifying stakeholders' perceptions and advancing their engagement in the management of invasive species.

Conclusions

In this study, we assessed stakeholders' perceptions and knowledge on non-native Australian acacias in Northern Portugal. We applied a questionnaire-based survey to experienced stakeholders and found that the majority of participants: (1) did not correctly distinguish native from non-native tree species, with stakeholders less exposed to invasions presenting the lowest ability to recognize Australian acacias; (2) failed to identify the time period at which these acacias were introduced, and missed the identification of important drivers of dispersion, and management methods and (3) recognized more risks than opportunities, but likely depending on the coexistence time with acacias, and on distinct motivations, priorities and funding support associated to their management. We argue that technical training, environmental education and information outreach are needed to improve the identification of: (1) non-native trees; (2) their introduction and invasion history; (3) drivers of dispersion; (4) benefits and costs and (5) effective management methods. By doing so, we are confident that stakeholders' engagement would contribute to the implementation of biosecurity efforts to control and even adapt to Australian acacias, under collaborative and adaptive approaches, converging with European obligations (EU Regulation 1143/2014) and wider international strategies (IPBES—thematic assessment 6).

Supplementary data

Supplementary data are available at *Forestry* online.

Acknowledgements

J.R. acknowledges support from FCT through Grant ICETA 2017-38 within project PTDC/AAG-GLO/0463/2014-POCI-01-0145-FEDER-016583 and J.R.V. was supported as a post-doc researcher at ICETA CIBIO/ InBIO no âmbito da Norma Transitória - DL57/2016/ICETA/EEC2018/13. This work was developed in the context of the FPS COST Action FP1403 *NNEXT: Non-Native Tree species for European Forests – experiences, risks and opportunities*, and the project *ALIENTRADE: Something in the way they move: how global patterns of wildlife trade influence global invasion success* (PTDC/BIA-ECO/30931/2017), financed by FCT/MCTES and co-financed by the ERDF, through Compete 2020 (POCI). The authors thank Dr. Helena Santos (www.terrawise.eu) for English revision and proofreading, as well as Dr. Katharina Kapitza (Leuphana Universität Lüneburg) and the two anonymous Reviewers for their very pertinent reviews and useful comments. The authors also thank the participation of the Regional Agency for Agriculture and Fisheries of Northern Portugal, DRAPN (http://www.drapnorte.gov.pt/) and of the anonymous stakeholders in this study.

References

Abrahams, B., Sitas, N. and Esler, K.J. 2019 Exploring the dynamics of research collaborations by mapping social networks in invasion science. *J. Environm. Manag.* **229**, 27–37.

Brundu, G. and Richardson, D.M. 2016 Planted Forests and Invasive Alien Trees in Europe: A Code for Managing Existing and Future Plantings to Mitigate the Risk of Negative Impacts from Invasions. C.C., Daehler, M., van Kleunen, P., Pyšek, D.M., Richardson (eds.). NeoBiota, pp. 5–47.

Brunson, M.W. and Tanaka, J. 2011 Economic and social impacts of wildfires and invasive plants in American deserts: lessons from the Great Basin. *Rangeland Ecol. Manag.* **64**, 463–470.

Carruthers, J., Robin, L., Hattingh, J.P., Kull, C.A., Rangan, H. and van Wilgen, B.W. 2011 A native at home and abroad: the history, politics, ethics and aesthetics of acacias. *Divers. Distrib.* **17**, 810–821.

Castro-Díez, P., Fierro-Brunnenmeister, N., González-Muñoz, N. and Gallardo, A. 2012 Effects of exotic and native tree leaf litter on soil properties of two contrasting sites in the Iberian Peninsula. *Plant Soil.* **350**, 179–191.

Castro-Díez, P., Vaz, A.S., Silva, J.S., Van Loo, M., Alonso, Á., Aponte, C., *et al.* 2019 Global effects of non-native tree species on multiple ecosystem services. *Biol. Rev.* . doi: https://doi.org/10.1111/brv.12511.

Corbett, S.W., Anderson, B., Nelson, B., Bush, S., Hayes, W.K. and Cardwell, M.D. 2005 Most lay people can correctly identify indigenous venomous snakes. *Am. J. Emerg. Med.* **23**, 759–762.

Crews, J. 2003 Forest and tree symbolism in folklore. In *Perceptions of Forests*. A., Perlis (ed.). FAO - Food and Agriculture Organization of the United Nations, Rome, Italy.

Davis, M.A., Thompson, K. and Grime, J.P. 2001 Charles S. Elton and the dissociation of invasion ecology from the rest of ecology. *Divers. Distrib.* **7**, 97–102.

Dickie, I., Bennett, B., Burrows, L., Nuñez, M., Peltzer, D., Porté, A., *et al.* 2014 Conflicting values: ecosystem services and invasive tree management. *Biol. Invasions*. **16**, 705–719.

Essl, F., Hulme, P.E., Jeschke, J.M., Keller, R., Pyšek, P., Richardson, D.M., *et al.* 2017 Scientific and normative foundations for the valuation of alien-species impacts: thirteen core principles. *BioScience*. **67**, 166–178.

Estevez, R.A., Anderson, C.B., Pizarro, J.C. and Burgman, M.A. 2015 Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. *Conservation Biol.* **29**, 19–30.

Fernandes, M.M. 2018 Acacias errantes, acacias infestantes: Notas sobre a ascenção e queda de uma utopia Florida. *Lucanus* 180–191.

Gaertner, M., Novoa, A., Fried, J. and Richardson, D.M. 2017a Managing invasive species in cities: a decision support framework applied to Cape Town. *Biol. Invasions*. **19**, 3707–3723.

Gaertner, M., Wilson, J.R., Cadotte, M.W., MacIvor, J.S., Zenni, R.D. and Richardson, D.M. 2017b Non-native species in urban environments: Patterns, processes, impacts and challenges. *Biol. Invasions*. **19**, 3461–3469.

García-Llorente, M., Martín-López, B., González, J.A., Alcorlo, P. and Montes, C. 2008 Social perceptions of the impacts and benefits of invasive alien species: Implications for management. *Biol. Conserv.* **141**, 2969–2983.

Geesing, D., Al-Khawlani, A. and Abba, M.L. 2004 Management of introduced Prosopis species: can economic exploitation control an invasive species? *Unasylva*. **55**, 289–299.

Genovart, M., Tavecchia, G., Enseñat, J.J. and Laiolo, P. 2013 Holding up a mirror to the society: children recognize exotic species much more than local ones. *Biol. Conserv.* **159**, 484–489.

Head, L., Larson, B.M., Hobbs, R., Atchison, J., Gill, N., Kull, C., *et al.* 2015 Living with invasive plants in the Anthropocene: the importance of understanding practice and experience. *Conserv. Soc.* **13**, 311–318.

Kapitza, K., Zimmermann, H., Martín-López, B. and von Wehrden, H. 2019 Research on the social perception of invasive species: a systematic literature review. *NeoBiota*. **43**, 47–68.

Krumm, F. and Vítková, L. 2016 *Introduced Tree Species in European Forests: Opportunities and Challenges*. European Forest Institution.

Kueffer, C. and Hadorn, G.H. 2008 How to achieve effectiveness in problem-oriented landscape research: the example of research on biotic invasions. *Liv. Rev. Landsc. Res.* **2**. doi: 10.12942/lrlr-2008-2.

Kueffer, C. and Kull, C. 2017 Non-native species and the aesthetics of nature. In: Vilà, M., Hulme, P. (Eds.), Impact of Biological Invasions on Ecosystem Services. Springer, pp. 311–324.

Kull, C.A., Shackleton, C.M., Cunningham, P.J., Ducatillon, C., Dufour-Dror, J.-M., Esler, K.J., *et al.* 2011 Adoption, use and perception of Australian acacias around the world. *Divers. Distrib.* **17**, 822–836.

Le Maitre, D.C., Gaertner, M., Marchante, E., Ens, E.-J., Holmes, P.M., Pauchard, A., *et al.* 2011 Impacts of invasive Australian acacias: implications for management and restoration. *Divers. Distrib.* **17**, 1015–1029.

Lindemann-Matthies, P. and Bose, E. 2008 How many species are there? Public understanding and awareness of biodiversity in Switzerland. *Human Ecol.* **36**, 731–742.

Lloyd, S. 2006 A miner concern – birdwatching on the east coast. Newsletter of the Land for Wildlife Scheme Tasmania. **11**, 4–5.

Lorenzo, P., González, L. and Reigosa, M.J. 2010 The genus acacia as invader: the characteristic case of Acacia dealbata link in Europe. *Ann. For. Sci.* **67**, 101.

MacLeod, A., Evans, H.F. and Baker, R.H. 2002 An analysis of pest risk from an Asian longhorn beetle (Anoplophora glabripennis) to hardwood trees in the European community. *Crop Protect.* **21**, 635–645.

Maki, K. and Galatowitsch, S. 2004 Movement of invasive aquatic plants into Minnesota (USA) through horticultural trade. *Biol. Conserv.* **118**, 389–396.

Marchante, E. and Marchante, H. 2016 Engaging society to fight invasive alien plants in Portugal-one of the main threats to biodiversity. In *Biodiversity and Education for Sustainable Development*. P., Castro, U.M., Azeiteiro, P., Bacelar-Nicolau, W.L., Filho, A.M., Azul (eds.). Springer International Publishing, pp. 107–122.

Matzek, V., Covino, J., Funk, J.L. and Saunders, M. 2014 Closing the knowing–doing gap in invasive plant management: accessibility and interdisciplinarity of scientific research. *Conserv. Lett.* **7**, 208–215.

McNeely, J.A. 2001 *The Great Reshuffling Human Dimensions of Invasive Alien Species*. IUCN – The World Conservation Union, Gland, Switzerland and Cambridge, UK.

Middleton, K. 2012 Renarrating a biological invasion: historical memory, local communities and ecologists. *Environm. Hist.* **18**, 61–95.

Newing, H. 2010 *Conducting Research in Conservation: Social Science Methods and Practice*. Routledge.

Novoa, A., Dehnen-Schmutz, K., Fried, J. and Vimercati, G. 2017 Does public awareness increase support for invasive species management? Promising evidence across taxa and landscape types. *Biol. Invasions*. **19**, 3691–3705.

Novoa, A., Shackleton, R., Canavan, S., Cybele, C., Davies, S.J., Dehnen-Schmutz, K., *et al.* 2018 A framework for engaging stakeholders on the management of alien species. *J. Environ. Manage.* **205**, 286–297.

Pimentel, D., Zuniga, R. and Morrison, D. 2005 Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecol. Econ.* **52**, 273–288.

Pyšek, P., Jarošík, V., Hulme, P.E., Pergl, J., Hejda, M., Schaffner, U., *et al.* 2012 A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. *Glob. Change Biol.* **18**, 1725–1737.

Reed, M.S. 2008 Stakeholder participation for environmental management: a literature review. *Biol. Conserv.* **141**, 2417–2431.

Richardson, D.M. and Rejmánek, M. 2011 Trees and shrubs as invasive alien species – a global review. *Divers. Distrib.* **17**, 788–809.

Richardson, D.M., Carruthers, J., Hui, C., Impson, F.A.C., Miller, J.T., Robertson, M.P., *et al.* 2011 Human-mediated introductions of Australian acacias – a global experiment in biogeography. *Divers. Distrib.* **17**, 771–787.

Rotherham, I.D. and Lambert, R.A. 2011 *Invasive and Introduced Plants and Animals: Human Perceptions, Attitudes and Approaches to Management*. Earthscan, London.

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Libertà, G., Branco, A., de Rigo, D., *et al.* 2017 *Forest Fires in Europe* In *Middle East and North Africa.* JRC European Union, Luxembourg.

Sarver, M., Treher, A., Wilson, L., Naczi, R. and Kuehn, F. 2008 *Mistaken Identify? Invasive Plants and Their Native Look-Alikes-an Identification Guide for the Mid-Atlantic*. Delaware Department Agriculture.

Schreck Reis, C., Marchante, H., Freitas, H. and Marchante, E. 2013 Public perception of invasive plant species: assessing the impact of workshop activities to promote young students' awareness. *Int. J. Sci. Educ.* **35**, 690–712.

Shackleton, C.M. and Shackleton, R. 2016 Knowledge, perceptions and willingness to control designated invasive tree species in urban household gardens in South Africa. *Biol. Invasions*. **18**, 1599–1609.

Shackleton, C.M., McGarry, D., Fourie, S., Gambiza, J., Shackleton, S.E. and Fabricius, C. 2007 Assessing the effects of invasive alien species on rural livelihoods: case examples and a framework from South Africa. *Hum. Ecol.* **35**, 113–127.

Shackleton, R.T., Shackleton, C.M. and Kull, C.A. 2019a The role of invasive alien species in shaping local livelihoods and human well-being: a review. *J. Environ. Manag.* **229**, 145–157.

Shackleton, R.T., Richardson, D.M., Shackleton, C.M., Bennett, B., Crowley, S.L., Dehnen-Schmutz, K., *et al.* 2019b Explaining people's perceptions of invasive alien species: a conceptual framework. *J. Environ. Manag.* **229**, 10–26.

Shackleton, R.T., Adriaens, T., Brundu, G., Dehnen-Schmutz, K., Estévez, R.A., Fried, J., *et al.* 2019c Stakeholder engagement in the study and management of invasive alien species. *J. Environ. Manag.* **229**, 88–101.

Shackleton, R.T., Larson, B.M., Novoa, A., Richardson, D.M. and Kull, C.A. 2019d The human and social dimensions of invasion science and management. *J. Environ. Manag.* **229**, 1–9.

Sharp, R.L., Larson, L.R. and Green, G.T. 2011 Factors influencing public preferences for invasive alien species management. *Biol. Conserv.* **144**, 2097–2104.

Somaweera, R., Somaweera, N. and Shine, R. 2010 Frogs under friendly fire: How accurately can the general public recognize invasive species? *Biol. Conserv.* **143**, 1477–1484.

Sutcliffe, C., Quinn, C.H., Shannon, C., Glover, A. and Dunn, A.M. 2018 Exploring the attitudes to and uptake of biosecurity practices for invasive non-native species: views amongst stakeholder organisations working in UK natural environments. *Biol. Invas.* **20**, 399–411.

R Team 2016 *RStudio: Integrated Development for R*. RStudio, Inc., Boston, MA.

van Wilgen, B.W., Forsyth, G.G., Le Maitre, D.C., Wannenburgh, A., Kotzé, J.D., van den Berg, E., *et al.* 2012 An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa. *Biol. Conserv.* **148**, 28–38.

Vaz, A.S., Kueffer, C., Kull, C.A., Richardson, D.M., Vicente, J.R., Kühn, I., *et al.* 2017a Integrating ecosystem services and disservices: insights from plant invasions. *Ecosys. Serv.* **23**, 94–107.

Vaz, A.S., Kueffer, C., Kull, C.A., Richardson, D.M., Schindler, S., Muñoz-Pajares, A.J., *et al.* 2017b The progress of interdisciplinarity in invasion science. *AMBIO*. **46**, 428–442.

Vicente, J.R., Alagador, D., Guerra, C., Alonso, J.M., Kueffer, C., Vaz, A.S., *et al.* 2016 Cost-effective monitoring of biological invasions under global change: a model-based framework. *J. Appl. Ecol.* **53**, 1317–1329.

Vicente, J.R., Fernandes, R.F., Randin, C.F., Broennimann, O., Gonçalves, J., Marcos, B., *et al.* 2013 Will climate change drive alien invasive plants into areas of high protection value? An improved model-based regional assessment to prioritise the management of invasions. *J. Environ. Manag.* **131**, 185–195.