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How science communications can help build societal perceptions of invasive alien species and their impacts on the environment

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Perspectives

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Summary

While scientific research highlights the threats of invasive alien species (IAS) to the environment and human livelihoods, another voice is rising that recognizes their beneficial impacts. With evidence increasing of the contrasting impacts of some IAS, the lack of communication between science and society makes decision-making processes more complex. Here, we consider the beneficial aspects of invasive alien plant species and take examples from other life forms to argue that, over time and space, the detrimental impacts of IAS might endanger sustainable livelihoods by increasing invasion debt manyfold. We therefore suggest that future studies reporting the positive impacts of IAS and those encouraging the management of IAS through their utilization should include value judgements that acknowledge the potential risks involved in the practice and the scale and context specificity of such studies. Studies highlighting the negative impacts of IAS should also recognize the context dependency of their findings and emphasize the benefits to be gained from the management of the IAS. We provide a more complete picture of IAS impacts that could help to inform management decisions in the face of different potential choices and the possible impacts of these choices on sustainable livelihoods in the long term.

Background

Scientific research and the knowledge gained from it can guide societal responses to various economic and environmental challenges (Rosen 2018). Biological invasion is considered to be a defining feature of the Anthropocene (Stoett et al. 2019). Since the beginning of modern invasion science in the mid-1980s (Simberloff 2011), many studies have been conducted aiming to characterize the negative impacts of invasive alien species (IAS; self-sustaining populations in the wild with individuals dispersing, surviving and reproducing across multiple habitats; Blackburn et al. 2011) on native species, ecosystems and human well-being (e.g., Pyšek et al. 2020). The studies that focus solely on ecological processes and entities recommend the eradication of IAS to protect biodiversity (e.g., Jones et al. 2016). The negative economic impacts of IAS have also led many to advocate strongly for IAS management in numerous countries (e.g., Fantle-Lepczyk et al. 2022).

Yet some IAS have always been regarded as valuable assets because of their aesthetic, ecological and economic values (e.g., *Acacia* species; Shackleton et al. 2019). Due to the continued change in recipient communities due to rapid globalization, the 'novel ecosystems' concept has been proposed (Hobbs et al. 2009). The last decade has seen increasing numbers of studies exploring how to harness the potential positive effects and usefulness of these novel ecosystems, including the IAS introduced by human actions. This school of research highlights the ability of some of these species to provide environmental benefits and improve human well-being by providing novel resources (e.g., Vimercati et al. 2020, Kourantidou et al. 2022).

That some IAS can have both negative and positive impacts in different socio-economic and spatiotemporal contexts has gradually been recognized by both academic (scientists and academics) and non-academic (practitioners and policymakers) communities (Osborne & Gioria 2022, Shackleton & Vimercati 2022). However, divergence in opinions between these two communities persists. For example, a survey has shown that practitioners and policymakers are less likely to acknowledge the benefits of IAS than scientists and academics, and a higher percentage of respondents think that the beneficial impacts of IAS are understated than those who do not (Shackleton & Vimercati 2022). Multiple attempts have been made to consider the beneficial effects of some IAS in order to make better regulatory decisions. For example, the Environmental Impact Classification for Alien Taxa (EICAT+) framework has been proposed to categorize the magnitude of such positive impacts (Vimercati et al. 2022), whereas the Risk Analysis for Alien Taxa (RAAT) framework includes beneficial impacts as one of the criteria for the risk management of alien taxa (Kumschick et al. 2020). Ideally, the trade-offs between the

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overall costs and benefits of IAS on sustainable livelihoods (i.e., livelihoods that can cope with economic, environmental and social stresses and maintain or enhance their capabilities and assets both now and in the future while not undermining natural resource bases; DFID 2000) should be integrated into IAS-specific studies (Shackleton et al. 2019). Practically, these issues are often outside the specific scopes of research activities, particularly in the empirical studies (e.g., Wang et al. 2021).

We ask how future science communications can address the gap between scientific research and societal perceptions of beneficial IAS. We first investigate the reported beneficial aspects of invasive alien plant species (IAPS) and argue that, over time and space, the detrimental impacts of IAS might endanger sustainable livelihoods. We acknowledge that both the positive and negative impacts of IAS are very much context dependent and therefore propose that it is time for scientists to acknowledge diverse possibilities regarding these complex human–nature interactions in order to better inform decisions about them.

Benefits of invasive alien species: the evidence lists are growing longer

We used the Institute for Scientific Information (ISI) Web of Science literature database to search for peer-reviewed studies highlighting the positive impacts of IAPS published within the last two decades (see Appendix S1 for the detailed workflow). We found 154 studies reporting on 33 countries, among which South Africa, the USA and China were the most represented (Fig. 1). Most of the studies for which country information was available (n = 134) originated from 26 mainland nations (n = 114), whereas 20 studies were from 7 island nations. The number of studies on the positive impacts of IAPS has increased over time (Fig. 2a). Most studies reported these positive impacts on a regional scale (Fig. 2b). Some notorious IAPS such as *Lantana camara*, *Eichhornia crassipes* and *Acacia mearnsii* have been reported to have beneficial impacts in a large number of studies (Fig. 2c). Most of the species reported as having positive impacts belonged to the legume family Fabaceae (Fig. 2d).

The positive impacts reported in these studies were categorized according to the Level-1 states (the first of three economic botany data collection standards that covers all uses of plants; Cook 1995). A large number of the studies reported environmental uses (Fig. 3a), among which positive impacts of the IAPS were reported in terms of both human (e.g., *Prosopis juliflora*, one of the world's 100 most dominant IAPS, as a source of fuel, food, fodder and medicine) and non-human (excluding domestic animals; e.g., *Lonicera tatarica* in North America providing resources for the hybridization of two native fly species; Jachuła et al. 2019) livelihood strategies. Some IAPS improve human livelihood strategies by providing regulatory (e.g., erosion control, Charbonneau et al. 2017; urban landscape regeneration, Rastandeh et al. 2018) and cultural services, while some provide provisioning services (e.g., raw material for producing environmentally benign fertilizer; Wang et al. 2021). Reports of IAPS providing resources for vertebrate (Nelson et al. 2017) and invertebrate (Salisbury et al. 2017) taxa and providing refugia for rare and endangered animal species are plentiful.

Categories of uses were more diverse in countries such as South Africa and Kenya than in the USA and Australia (Fig. 3b). Studies on the role of IAPS in improving human livelihoods have originated primarily from southern and eastern Africa (e.g., Ugya et al. 2019) and South and South-East Asia (e.g., Wang et al. 2021). High-income countries such as the USA and Australia have explored the possible roles of IAPS in providing faunal habitats and resources (e.g., Utz et al. 2020) and in conserving native and endangered flora and fauna (e.g., Dunwiddie et al. 2017). This geographical pattern of beneficial impacts could be because numerous IAS were introduced and are still being promoted for the economic development of local rural livelihoods in lower-, lower-middle- and upper-middle-income countries (e.g., in Africa; Shackleton & Vimercati 2022).

Benefits, but at what cost?

With so many positive impacts of IAPS being reported and the 'novel ecosystems' concept gaining support, it is unsurprising to see the increased denialism of their negative impacts (Boltovskoy et al. 2018), and invasion biologists are struggling to translate their findings into meaningful management actions (Russell & Blackburn 2017). The 'novel ecosystems' concept has met with strong opposition from invasion biologists, who have recognized the disastrous effects that IAS can have on a community if the 'novel ecosystems' attitude is followed inconsiderately (Murcia et al. 2014, Miller & Bestelmeyer 2016).

Indeed, the impacts of IAS as perceived by humans are very much scale dependent and context specific (Kapitza et al. 2019), as evidenced by most studies reporting beneficial impacts at a regional scale (Fig. 2b). The impacts of IAS on islands are greater in terms of biodiversity, agriculture, economy, health and culture than on continents (Russell et al. 2017). However, very little is known about the beneficial impacts of IAS on islands (20 studies compared to 114 conducted on continents). In addition, the positive impacts of IAS are often reported at a single time point, thereby providing no information regarding how these IAS–human interactions may change over time (Pergl et al. 2020). The few studies that empirically investigated human–IAS interactions at a temporal scale have revealed decreasing benefits and increasing negative impacts of IAS on human livelihoods over time if the IAS populations are left unchecked (Shackleton et al. 2017).

An IAS having a positive impact on one organism does not necessarily mean that it will be beneficial to others (Vimercati et al. 2022). However, using IAS to improve human livelihoods often ignores the requirements of a broad spectrum of other life forms that are directly or indirectly affected by the IAS. For example, *Robinia pseudoacacia* is regarded as a species with high socio-economic value in both the Northern and Southern Hemispheres (Martin 2019), but it has severe detrimental impacts on the richness and diversity of the plant–soil communities of the invaded ecosystems (Lazzaro et al. 2018). *Lantana camara* growing at the periphery of a protected area for use in the handicraft industry improves rural community livelihoods (Negi et al. 2019), although it can also reduce rural livelihoods through reducing incomes, increasing the fragmentation of farmlands and damaging grasslands and trees in the core and buffer regions of forests (Ranjan 2019). These detrimental impacts on biodiversity, both direct (loss of species richness) and indirect (impacts on species inhabiting these ecosystems), cannot be fully evaluated in monetary terms (but see Hanley & Roberts 2019) and therefore are often unaccounted for when assessing impacts on human livelihoods.

Another point of view advocates for using IAS as resource providers for non-human life forms. However, these studies often do not view the community in its entirety. IAS that may help in the conservation of rare fauna may still threaten the existence of groups of marginal species and might even lead to irrecoverable losses of biodiversity. For example, although *L. tatarica* provides

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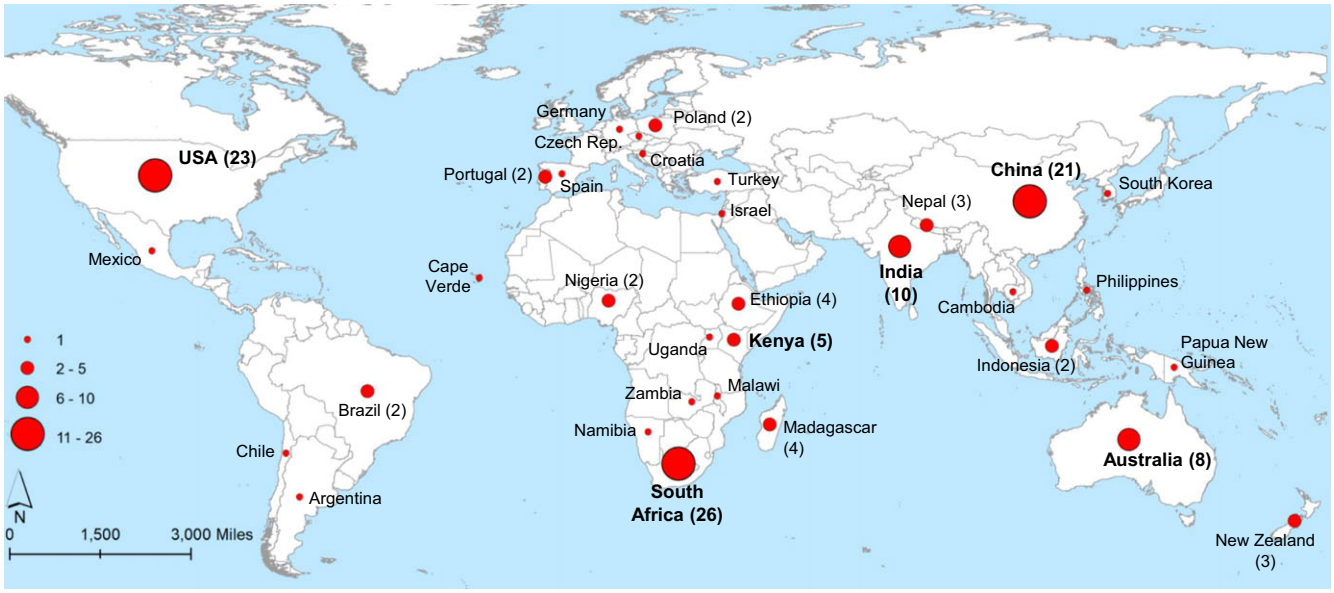

Fig. 1. Global pattern of peer-reviewed studies (n = 154) that have highlighted beneficial impacts of invasive alien plant species during 2000–2020: countries having at least five studies are in bold, island nations are in blue.

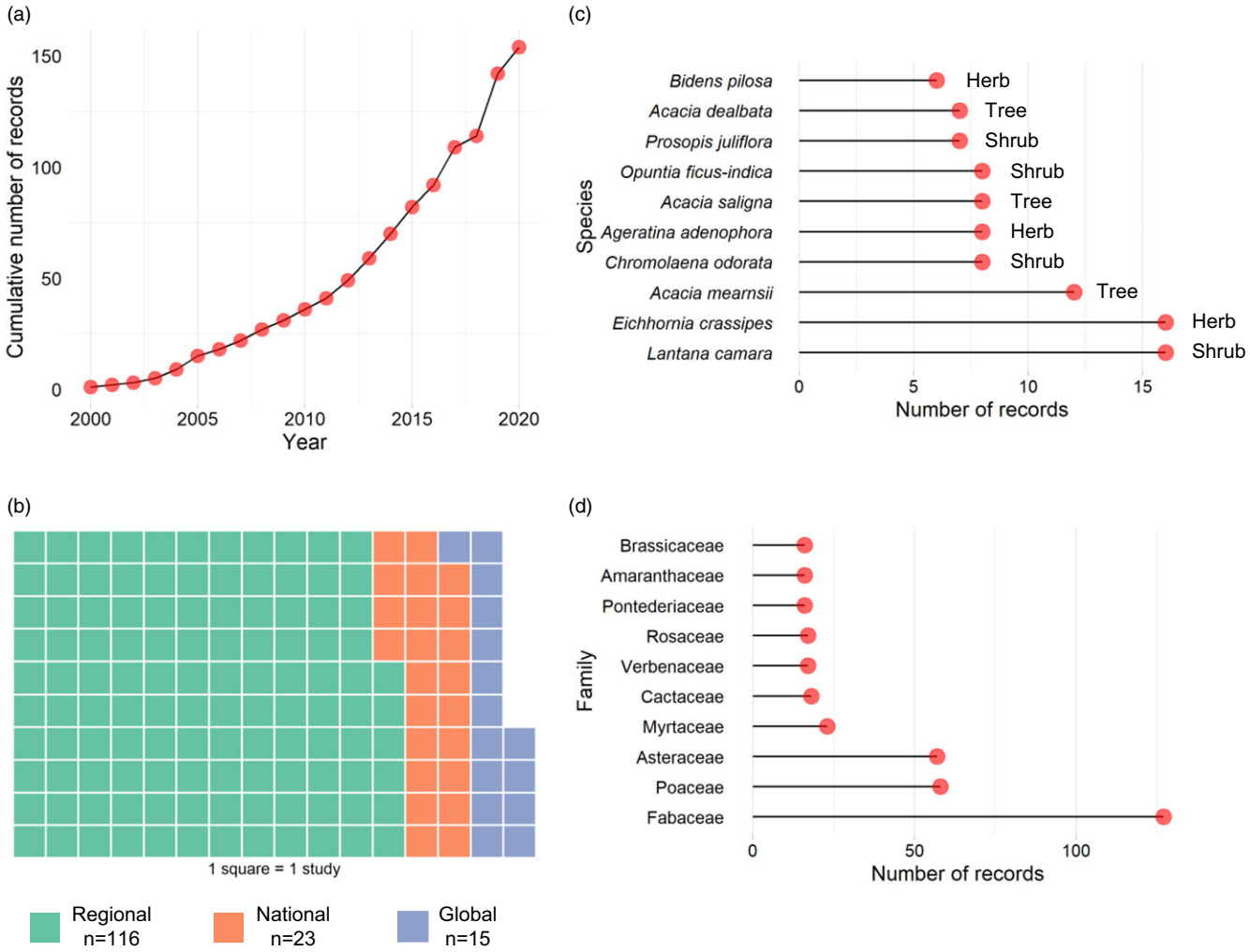

Fig. 2. Number of studies indicating positive impacts of invasive alien plant species (IAPS): (a) cumulative number of studies over time; (b) number of studies conducted at regional, national and global scales; (c) taxonomic identities of 10 IAPS having more than five records; and (d) 10 families having more than 10 records.

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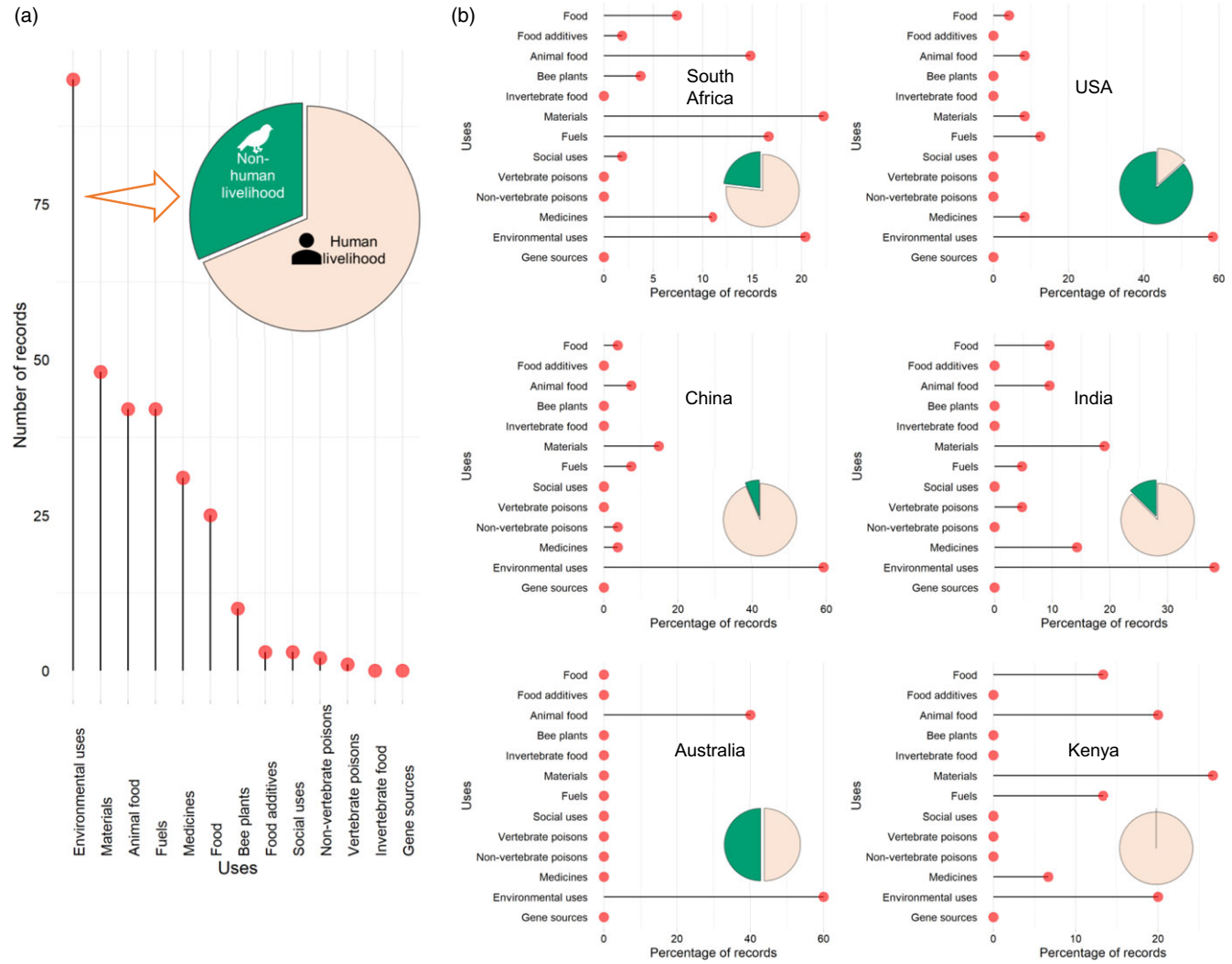

Fig. 3. Overview of the uses reported for invasive alien plant species (IAPS): (a) bar graph showing the number of studies for each of the 13 uses categorized as Level-1 states (the first of three economic botany data collection standards that covers all uses of plants; Cook 1995); (b) comparative assessment of TDWG Level-1 uses between the six countries with the greatest number of studies; the pie charts within the bar graphs show the percentages of environmental uses of the IAPS for improving human and non-human livelihood strategies.

resources for the hybridization of native insects, it decreases plant species richness and abundance (Maynard-Bean & Kaye 2019) and reduces the nesting success of forest birds in urbanizing landscapes through increased nest predation (Borgmann & Rodewald 2004).

With evidence increasing regarding the contrasting impacts of some IAS, a third research trend is emerging rapidly, focusing on selected IAS having positive impacts and suggesting their management through the utilization or overexploitation of these 'beneficial' IAS (e.g., Borokini & Babalola 2012). Such ideas provide the fuel to drive utilization initiatives of IAS at multiple scales. Various non-governmental organizations often promote utilizing IAS, primarily for marginalized people in rural economies of lower- and lower-middle-income countries (Sharma & Raghubanshi 2012). Although this sounds promising, scientific evidence to support this management approach is rare, if not absent entirely (but see Wakie et al. 2016). In fact, the very few studies that empirically tested this notion have revealed the ineffectiveness of this approach beyond a very localized scale for managing abundant IAS (Kannan et al. 2016).

Maximizing efforts focused on living with the invaded ecosystem also increases community dependency on the IAS and develops new markets. A positive attitude towards IAS begets more positivity, leading to more research exploring other IAS in terms of them yielding similar benefits (Sinclair et al. 2020). The monetary incentives attached to this approach may facilitate the introduction and spread of IAS to hitherto uninvaded regions (e.g., Driscoll et al. 2014, van Wilgen & Richardson 2014). The properties that make the aliens a treasured commodity also promote their successful establishment and naturalization in the wild (van Kleunen et al. 2018), thereby creating one or more such 'novel ecosystems' where their impacts remain largely unknown. When these impacts on human livelihoods – not to mention on other life forms – are recognized, the damage is already done, and the feedback loop of IAS utilization makes effective management more complex. Exploiting IAS for resource provisioning therefore increases invasion debt (Essl et al. 2011), and '[n]ature is an expert in cost–benefit analysis. As for debts, she always collects in the long run' (Atwood 2008).

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Table 1. Potential factors to consider when providing an objective statement on the research findings focused on the positive impacts (beneficial impacts and control through utilization) and the negative impacts of an invasive alien species (IAS).

Positive impacts of IAS			Negative impacts of IAS	
Factors	Beneficial impacts	Control through utilization	Factors	Harmful impacts
Potential risk	Detrimental impacts of the IAS – short-term (e.g., effect on non-human life forms) and long-term (e.g., chance of novel invasions) costs	Impact on local economy (e.g., chance of creating new markets or creating dependence)	Observed benefits of the taxa	Economic values and ecosystem services if there are any
Regulatory mechanism	Ability of the existing biosecurity infrastructure to regulate the further promotion and spread of the IAS	Ability of the existing biosecurity infrastructure to regulate the further promotion and spread of the IAS	Potential benefits of the proposed management measure	Reported evidence showing that damage costs or costs of inaction may surpass perceived benefits in the long terms Benefits to be gained from managing the IAS should highlight the improvement of environmental quality (both for human and non-human life forms) and socio-economic factors
Scale	Spatial scale and landscape characteristics at which the findings should be interpreted Taxon specificity; avoid generalization	Scale specificity; feasibility of the proposed measure at a large scale or for widespread IAS	Transforming proposed measures to meaningful actions	Identify possible obstacles (e.g., dependency on IAS) and solutions to them (e.g., native species having near-similar benefits)
Alternative options	Identity of native and near-native species having similar benefits Future exploration and encouragement of further studies	Evidence of prior management initiatives (e.g., biological control for widespread IAS); successes and failures Comparative accounts considering investments and returns	–	–

Road ahead

With the predicted increase in novel introductions of alien species across the globe (Seebens et al. 2017) and the increasing exploration of the beneficial impacts of IAS, it is time for science communications to help readers make better-informed decisions regarding biological invasion. To do so, we suggest that the authors of future empirical studies push the boundaries of their personal opinions and disciplinary training and include value judgements regarding their findings in their publications; Table 1 offers advice as to how to prepare such statements.

First, researchers and practitioners of the 'beneficial' school can acknowledge that utilizing IAS and leaving the invaded ecosystem as it stands will increase the invasion debt manyfold and may have irrecoverable consequences (e.g., loss of marginal life forms) and severely retard the progress of IAS management (e.g., by creating human dependence). Authors can explicitly mention the taxon and scale specificity of their studies to avoid generalization, highlight the potential risks involved with the species in focus and explain how the existing biosecurity infrastructure can regulate the further promotion and spread of the species. These studies could also encourage the exploration of native and near-native species for achieving similar benefits (e.g., Everard 2020).

Second, studies reporting on IAS management through their utilization could highlight the possible impacts of the utilization measure on the local economy (e.g., creating economic dependence and shifting livelihood strategies; Kent & Dorward 2015). The authors of such studies could also evaluate existing and potential future measures to manage the promotion and spread of the IAS resulting from the revenue-generating practice in question. They could critically assess the economic and ecological feasibility of the proposed management measure at a large spatiotemporal scale, especially for widespread IAS, and provide information about previous management attempts, if any, and their successes and failures.

We also acknowledge that the harmful impacts associated with some IAS can also be context dependent (Catford et al. 2022). Thus, studies highlighting the detrimental impacts of the IAS could mention any positive roles they might play, especially if they have been previously reported at the specific scale of the study in question. The authors of such studies could emphasize the benefits gained from managing the IAS and the consequences of exploiting these resources without any regulatory mechanism. That the positive roles of the IAS in question might also hinder the implementation of the proposed management measures also needs to be acknowledged, and it would be important to suggest how best to overcome such hindrances. Studies highlighting the negative impacts of IAS should strive to present their arguments (negative over positive) as being supported by the available and most current scientific evidence (Russell & Blackburn 2017).

While value judgements can be placed in the discussion sections of articles (e.g., Jachuła et al. 2019), a dedicated section for such judgements might be more effective in terms of drawing readers' attention. Importantly, this section should not be viewed as representing a caveat of the study; instead, the value judgements of the authors should complement the study's findings to provide a more complete pictures of the IAS in question (Vimercati et al. 2022). Journal editors and reviewers should also encourage authors' engagement with this practice. Many journals are already exercising a similar practice (e.g., encouraging authors to structure their study methods following a standard protocol). Such value judgements could be hindered by a lack of sufficient information on the species in question, which can be highlighted by authors to prevent further generalization of the impacts reported.

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Conclusion

Human–IAS interactions are very much context dependent, and their interpretations vary depending on the scale of the study. IAS studies are often biased towards alien species having major negative impacts (Guerin et al. 2018), but this pattern might change with a shift in focus to relatively benign IAS and the provision of novel insights into such relationships. Nevertheless, irrespective of their current perceived impacts, IAS can endanger ecosystem functioning in the long term and/or in different contexts. Arguably, the negative impacts of an IAS might not be accurately extrapolated over space and time; however, highlighting the beneficial end of the spectrum may increase misconceptions regarding the IAS in question, which could incite negative cascading effects if the IAS is introduced into other contexts. We wish neither to question the ability of readers to assess the implications of research published in the public domain nor to impose any kind of restriction on authors' academic publishing practices. Given the influence of scientific research on public opinion and policy-making, we think that authors should be motivated to present a complete picture to the readers, inside and outside of the biological invasion domain, in order to help them consider the different options and imagine the possible outcomes of their choices on sustainable livelihoods in the long run (Anonymous 2021).

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S0376892923000103.

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