SEICAT+: a comprehensive assessment framework for positive socio-economic impacts of alien species

Giovanni Vimercati[1,*], Anna F. Probert[2], Sabrina Kumschick[3], Sven Bacher[1]

[1]University of Fribourg, Fribourg, Switzerland

[2]Zoology Discipline, School of Environmental and Rural Science, University of New England, Armidale, New South Wales, Australia

[3]Centre for Invasion Biology, Stellenbosch University, Stellenbosch, South Africa

[*]Corresponding author: gvimercati@outlook.com

Abstract

Despite their recognized harms to humans and biodiversity, alien species outside of domestication/cultivation can also provide socio-economic benefits, which are essential to consider when identifying stakeholder conflicts and informing managers and policymakers. These benefits often result from the enhancement of ecosystem services, such as the provision of food, timber, and other natural resources, or from the reduction of ecosystem disservices, such as the control of medical or agricultural pests. While such positive impacts are generally acknowledged, there is still no unified framework to classify them in a way that allows systematic and rigorous comparisons across species and contexts. A major obstacle is the lack of a common metric for evaluating the diverse socio-economic impacts of alien species. Monetary approaches can capture some benefits —such as income from logging or biocontrol programs—but fall short in their ability to assess non-market values, such as cultural benefits or health outcomes. Ecosystem Services (ES) and Nature's Contributions to People (NCP) provide broader perspectives but often rely on non-comparable or context-specific metrics. We argue that framing the benefits of alien species for humans through the lens of the capability approach—and assessing changes in people's preferred activities and states of being as proxies for well-being—offers a holistic concept and relevant and comparable metric for socio-economic impact assessments. We introduce SEICAT+ (the positive Socio-Economic Impact Classification for Alien Taxa), a framework designed to capture impacts of varying magnitudes across all constituents of human well-being, i.e. basic materials for a good life, security, health, good social relations and freedom of choice and action. We demonstrate how SEICAT+ can complement existing approaches based on monetary quantification, ES and NCP, and how it can integrate with other, similarly-structured, impact assessment frameworks for alien species—thereby enhancing the scope and robustness of their socio-economic evaluations.

Keywords: biocontrol, capability approach, ecosystem services, nature's contributions to people, non-native species, stakeholder conflicts, well-being

Glossary

Alien species: species introduced beyond their native range by humans. Synonyms: non-native species, non-indigenous species, exotic species.

Burdensome activities: activities undertaken by people to prevent or mitigate declines in their well-being caused by environmental pressures.

Taxa: species or lower taxonomic levels (subspecies, varieties, cultivars, or breeds), including those that are not yet formally described.

Constituents [of human well-being]: the basic elements that contribute to what people value in life.

Established [alien species]: alien species that maintain self-sustaining populations in their recipient ecosystem, i.e. persist without human intervention. Synonym: naturalized alien species.

Invasive [alien species]: established alien species that cause significant harm to biodiversity or people.

Preferred activities: activities undertaken by people that contribute to their well-being.

States of being: conditions experienced by people that contribute to their well-being. Synonym: valued beings.

Well-being: the ability of people to do and be what they value in life.

Introduction

Throughout human history, the transportation and release of species beyond their native range (hereafter referred to as **alien species**, see Glossary) has often been motivated by the effort to enhance the services that natural resources provide to people. This process has profoundly altered the distribution of living species on Earth (Capinha et al., 2015). Intentional introductions of organisms into ecosystems have been undertaken to provide food, timber and firewood, to (re)create ecological or cultural conditions humans are familiar with, or in the attempt to control pests, enhance agricultural productivity or limit soil erosion (Roy et al., 2024). While such deliberate attempts are not always successful, species whose introduction and release are associated with benefits to certain sectors of society have often caused unwanted consequences to other sectors or local biodiversity, generating conflicts of interest among stakeholders (Zengeya et al., 2017).

Notably, such conflicts can also arise in cases where the introduction of alien species is unintentional. Some accidentally introduced species, such as those escaping captivity/cultivation or hitchhiking via human transportation pathways, once **established**, have been integrated into the socio-economic fabric of local communities, therefore becoming fundamental components of their economies, livelihoods, or cultural practices (Jarić et al., 2025). Regardless of whether introductions are intentional or unintentional,

conflicts among stakeholders are intensified when benefits are linked to **invasive species**—alien species that establish and harm biodiversity, ecosystem services, or human well-being (Roy et al., 2024). While only a subset of alien species become invasive, it remains to be assessed how the benefits of alien species more generally compare to the socio-economic harms they have caused (De Carvalho-Souza et al., 2024). .

However, to date, there is no standardised methodology to comprehensively quantify how alien species have benefitted human well-being. While certain approaches have been pursued or suggested, they generally lack the capacity to provide a holistic assessment that integrates both positive and negative impacts on human **well-being** across its various **constituents**. These constituents—i.e. basic material for a good life, health, security, good social relations, and the freedom of choice and actions (Millennium Ecosystem Assessment, 2005)—represent the fundamental components through which people experience and value changes in their lives, and thus provide a comprehensive basis for assessing the socio-economic impacts on human well-being.

Quantifying and comparing the socio-economic benefits of alien species has been attempted through monetary approaches, which are mainly adopted by industries and disciplines involved in the exploitation of natural capital, such as those linked to forestry, agriculture, horticulture and fishery (Bekele et al., 2018; Pienkowski et al., 2015). The revenue generated from harvesting naturalized alien trees and hunting alien game species, or the cost savings achieved by using self-sustaining alien biocontrol agents in agriculture, can be quantified and compared. However, the perceived value of monetary gains or losses can vary significantly among individuals and communities depending on cultural, economic, and contextual factors, making money an inconsistent proxy for broader socio-ecological impacts. Additionally, monetary quantification of both harms and benefits is of little use to assess impacts concerning intangible, social and relational resources, or health (Kourantidou et al., 2022).

Approaches based on ecosystem services allow for the identification and measurement of a wider spectrum of gains and losses acquired by humankind from nature, but different services are measured with different metrics and are not directly comparable (Liss et al., 2013; McElwee, 2017; Pandeya et al., 2016). For instance, Gallardo and colleagues (2024) identified widespread potential impacts of 94 alien species on seven key ecosystem services in Europe, particularly on outdoor recreation, habitat maintenance, crop provisioning, and soil and nitrogen retention. However, in their spatially explicit analysis, the harms of alien species on ecosystem services were assessed separately for each service due to the lack of a standardized approach for comparing different types of services. A similar approach has been pursued by Hoffman et al. (2025), who estimated the effects of alien species on the ecosystem services in the Noronha archipelago by using the INvasive Species Effects Assessment Tool (INSEAT) (Martinez-Cillero et al., 2019). While the INSEAT framework uses expert judgment and a categorical scale to estimate the magnitude of both positive and negative impacts of alien species on individual ecosystem services, it remains unclear how changes across different services can be meaningfully compared.

Finally, more integrated approaches based on the interdependencies between nature, human well-being, and culture—such as the Nature's Contributions to People (NCP) or the One Health Framework—can capture context-specific and plural perspectives (Hill et al., 2021; Panel (OHHLEP) et al., 2022; Pascual et al., 2017), but are often applied using qualitative methods (Pires et al., 2020) and rely on highly diverse and subjective indicators (Liu et al., 2023). For example, the recent IPBES report listed 3424 negative impacts and 1103 positive impacts caused by alien species on all nature's contributions to people in terrestrial realms (Bacher et al., 2025); however, these figures represent a broad spectrum of impact types whose magnitude could not be consistently quantified or compared across contexts (Bacher et al., 2024). Alternatively, incorporating biological invasions into the One Health concept has helped reveal links between alien species and health-related emergences (Odgen et al. 2019), such as zoonotic disease emergences (Zhang et al., 2022), although a stronger biosecurity approach has been advocated by some to achieve more effective integration. It remains to be established, however, whether One Health can be extended to other constituents of well-being, beyond narrative or descriptive terms (Gozlan et al., 2024).

The current lack of a unified metric to compare the benefits of alien species to humans across different contexts restricts our understanding of complex impact dynamics, as previously highlighted by various authors (Rickowski et al., 2025; Sax et al., 2022; Vimercati et al., 2020). Standardized and comprehensive comparisons would help to identify which alien species provide the greatest benefits to humans across contexts, elucidate the ways through which these species have been integrated into the socio-economic fabric of local communities, and advise on which management measures should be taken for conflicting-generating species (*sensu* Zengeya et al., 2017). Additionally, quantifying the socio-economic benefits of alien species may pave the way for identifying the key ecosystem services they provide, highlighting opportunities to substitute them with native species when necessary, and informing management decisions for sustainable biodiversity conservation and human well-being.

Here, we build on the Socio-Economic Impact Classification for Alien Taxa (SEICAT; Bacher et al., 2018), a framework based on the capability approach (Sen, 1999), which emphasizes both people's capabilities i.e. the opportunities they have, and their functionings i.e. what they are effectively able to do and be—to reach certain levels of well-being (Robeyns, 2005). SEICAT assesses the negative impacts of alien species on human well-being. By using an analogous rationale, we develop the positive Socio-Economic Impact Classification for Alien Taxa, or SEICAT+, as a complimentary framework to assess positive socio-economic impacts of alien species. SEICAT+ can be applied across all constituents of well-being. These constituents describe the essential components that contribute to a fulfilling life (Millennium Ecosystem Assessment, 2005): i) basic material for a good life, ii) health, iii) security, iv) good social relations, and v) the freedom of choice and actions. After defining the foundations and main elements of SEICAT+, we use key examples to illustrate how it differs from more traditional approaches adopted in environmental economics. We also suggest that SEICAT+ can be used in combination with similarly structured impact assessment frameworks from the Impact Classification for Alien Taxa (ICAT) family developed in invasion science, such as SEICAT (Bacher et al., 2018), EICAT (Blackburn et al., 2014; IUCN, 2020a, 2020b) and EICAT+

(Vimercati et al., 2022) to identify contexts under which trade-offs in benefits and costs exist, thereby informing managers and policymakers.

Currency and structure of SEICAT+

Well-being is a multidimensional concept that comprise both objective and subjective components that vary across socio-economic contexts, prompting the development of various approaches and indicators for its quantification (Hicks et al., 2016). Under SEICAT+, positive socio-economic impacts of alien species are assessed using three indicators—changes in (i) people's preferred activities (Fig. 1), (ii) states of being, and (iii) burdensome activities (Fig. 2)—which together capture improvements in well-being. The concept of **preferred activities**, as outlined by Probert et al. (2023), refers to activities undertaken by individuals that contribute to their well-being (e.g., fishing, farming, collecting firewood), thus aligning with Sen's notion of functionings—the valued "doings" that people have reason to pursue (Sen, 1999). Building on Sen's notion of functionings, **states of being**, or "valued beings", denote valued conditions, such as being healthy, happy, or safe, which likewise constitute integral dimensions of well-being. Preferred activities are distinguished from non-preferred, or **burdensome activities**, which, by contrast, are undertaken to prevent or mitigate decreases in well-being (Probert et al., 2023), for example in response to ecosystem disservices caused by other species—both alien and native—or by broader environmental pressures, including climate extremes, land/water degradation, or pollution. The inclusion of burdensome activities as an additional indicator of changes in well-being (Fig. 2) enables assessors to capture a broader range of reported impacts, addressing a gap in the literature, which often focuses on how alien species trigger indirect compensatory responses rather than direct impacts on human well-being (Probert et al., 2023). In accordance with SEICAT, SEICAT+ assigns each reported impact to one of five ascending categories of impact magnitude by considering semi-quantitative scenarios. The scenarios describe increases in preferred activities, improvements in states of being or decreases in burdensome activities, relative to the period before the introduction and establishment, or in the absence of, an alien species.

The first scenario, Minimal Positive Impact (ML+)**,** describes cases where people experience no improvement in well-being due to an alien species—indicated by no increase in preferred activities or states of being (Fig. 1). Alternatively, if only burdensome activities are examined, they show no decrease due to the alien species (see Fig. 2). This scenario may occur when the introduction of an alien species did not translate into a measurable change in people's preferred activities or states of being. This may also occur when a change of activity is not perceived as a measurable improvement to well-being by the people involved in the impact. For instance, an alien fish species could have been introduced for recreational fishing, but there is no evidence that anglers spend more time on their recreational activity or experience an increased level of satisfaction after the alien fish species was introduced. Similarly, it might have been hypothesized that a self-sustaining population of introduced conifers benefited the timber industry, but there is no evidence that the income generated from timber sales has increased. Likewise, the introduction of a self-sustaining alien

biocontrol agent with the scope to facilitate corn farming might not translate into a higher corn yield or a lower usage of pesticide (Fig. 1).

The second scenario, Minor positive impact (MN+), describes cases where people experience improvements to well-being due to an alien species, as indicated, for instance, by increased frequency of, or satisfaction with, preferred activities among individuals who already participate in those activities However, such improvements do not translate into a higher number of people participating in a preferred activity (i.e. no increase in activity size, Fig. 1). These changes, which facilitate the performance of existing preferred activities by individuals, involve activity attributes measured at the individual level, such as, income generated, degree of satisfaction, or resources acquired. Note that while well-being improvements measured at the individual level may also manifest as decreases, such as reduced effort or time spent, these can quickly be reframed as increases when viewed in terms of activity-related efficiency. Examples of Minor positive impacts include: an alien fish species increasing the time spent on recreational fishing by individual anglers; an alien fish species decreasing the time spent by commercial fishers to reach the same level of target catch, thus increasing fishing efficiency; an alien tree species increasing the income of workers employed in the timber industry; an alien biological control agent suppressing a crop pathogen, resulting in an increased yield (Fig. 1). Improvements in valued states of beings (e.g. feeling well, being happy or healthy) are also captured in this scenario. Examples of Minor positive impacts related to improvements in valued states of being include: an aesthetically appealing alien plant increasing the level of psychological satisfaction among residents in the area; an alien beetle decreasing the allergenic pollen load produced by an alien plant population, thereby improving the physical health of individuals with airborne allergies. Improvements in states of being, without further information if these lead to changes in activities, can only be captured by the Minimal and Minor levels as under SEICAT (see Probert et al., 2023), because they are measured at the individual level and cannot be aggregated across populations. For example, it may be relatively straightforward to determine whether the physical health of some individuals has improved due to an alien beetle (i.e. reports in reduced seasonal allergies), but it is much harder to estimate how many people are now healthy, given the qualitative and continuous nature of states of being. In contrast, the number of people that undertake preferred activities can be readily quantified, and these activities are therefore used as indicators at all levels of positive impact, including those beyond Minor, from Minimal to Massive.

All reductions of burdensome activities due to alien species, in the absence of accompanying information on changes in preferred activities or states of being, are classified exclusively within this scenario. Conceptually, such reductions make it easier for individuals to engage in preferred activities or attain desired states of being (see Table 1 and brown bracket in Fig. 2). For example, the introduction of an alien biocontrol agent may reduce farmers' reliance on pesticides, reducing farming costs.

The third scenario, Moderate positive impact (MO+), refers to cases in which the alien species improves well-being by increasing the number of people participating in an established preferred activity. Such increases in activity size may involve individuals who had

previously undertaken a preferred activity, later discontinued it, and are now resuming it, as well as those who have never engaged in this existing preferred activity. Examples of moderate positive impacts include: an alien biological control agent suppressing an agricultural pest, thereby enabling a subgroup of farmers—who had ceased farming due to the pest—to recommence their activities (Fig. 1); an alien fish species resulting in an increase in the number of recreational anglers in a lake, including people who never fished before; an alien parakeet species increasing the number of wildlife enthusiasts visiting urban parks (Crowley et al., 2019). As noted above, improvements in states of being and reductions in burdensome activities cannot be assessed beyond the Minor positive level and so cannot be assigned Moderate positive impacts under SEICAT+ (Fig. 1-2).

The fourth and fifth scenarios**,** Major positive impacts (MR+) and Massive positive impacts (MV+), refer to cases in which the alien species improves well-being by either: i) enabling preferred activities which did not exist or were completely abandoned before the introduction of the alien species; or ii) preserving existing preferred activities that would have disappeared if the alien species had not been introduced. The latter (ii) encompasses situations in which the continuation of a preferred activity depended on the presence of a particular alien species. The assessment of such positive impacts is done with a counterfactual approach, provided that the use of experimental and quasi-experimental designs, baseline data and controls for confounding factors enable causal inference (Ferraro, 2009). As in EICAT+ (Vimercati et al., 2022), for instance, it must be clear that (i) the activity was locally heading towards cessation before the establishment of the alien species; and (ii) the alien species, through a specific constituents, prevented an activity cessation that would otherwise have occurred in its absence. Note that the availability of alternative measures to preserve the preferred activity—for example, in farming, replacing the main crop with another one more resistant to a pathogen instead of relying on an alien self-sustaining biocontrol agent—does not affect the impact classification, provided the activity would have ceased in the absence of any intervention. Massive positive impacts (MV+) are those that persist even after the alien species is removed or disappears from the area. In contrast, Major positive impacts (MR+) end once the alien species is no longer present—such as in case of the cessation of an activity. In other words, the key distinction is that Major positive impacts are contingent on the continued presence of the alien species, whereas Massive positive impacts are not.

Examples of Major positive impacts include: the recommencement or maintenance of a farming activity—previously abandoned or heading towards cessation because of an agricultural pest (Fig. 1)—made possible or sustained through the introduction of an alien biocontrol agent; the creation of a new fishing activity in a formerly fishless lake after the introduction of an alien fish species that would cease if the latter were removed; the practice of firewood collection in an area, enabled by the presence of wild alien trees, would cease if the trees were removed. Cases relevant to Massive positive impacts include, for example, those where following the introduction and establishment of an alien biocontrol agent, a previously abandoned farming activity resumes and continues but (Fig. 1) is not conditional on the ongoing presence of the biocontrol agent. This is because the alien biocontrol agent enabled the eradication of the pest that had prevented farming, allowing

the activity to persist even if the alien species is eventually removed. Another example classified as a Massive positive impact is the post-mining phytoremediation of contaminated soils carried out by an alien plant capable of absorbing heavy metals from the soil (Reeves et al., 2018), thus enabling farming or recreational activities that were previously unfeasible, even after the alien plant has been removed.

Note that cases where alien species have displaced native species used in an existing preferred activity—subsequently becoming the sole resource for that activity—must not be classified as Major or Massive positive impacts. These situations do not reflect the preservation of an activity that would have otherwise disappeared without the alien species; without the introduction of the alien species, the native species would still be there, and the activity would have continued normally. Rather, these cases represent a mere substitution of one species for another, which might lead to: no positive impacts on preferred activities or state of being (Minimal positive impacts); positive impacts on preferred activities or states of being measured at the individual level (Minor positive impacts); an increase in the number of people participating in an existing preferred activity (Moderate positive impacts). Note that if such a substitution leads to a decrease or the disappearance of the existing preferred activity, these negative impacts should be assessed with SEICAT (Bacher et al., 2018), not SEICAT+. Also note that native species displacement caused by alien species can be assessed as a Major or a Massive negative impact under EICAT.

Importantly, ***the five scenarios*** (and their corresponding impact categories) are used to classify each reported impact, but only when suspected improvements in well-being (i.e., increases in preferred activities, improvements in states of being, or decreases in burdensome activities) have been measured using an appropriate study design, allowing the SEICAT+ assessor to reliably interpret the data. Absence of reported improvements to well-being is therefore not automatically equivalent to the absence of improvements. It also follows that cases assigned a ML+ score or higher differ from those classified as Data Deficient (DD), which applies when available information or the methodology employed is insufficient to assign an alien species to one of the five SEICAT+ impact categories. For example, in the case illustrated in Fig.1, if the introduction of an alien biocontrol agent to reduce corn pests is not accompanied by measurements of changes in corn yield, pesticide usage, or farmer satisfaction, then no increase in well-being—i.e., no positive impact under SEICAT+—can be assessed.

Moreover, impact reports should contain sufficient information to identify the community of interest, which is essential for accurately assessing the impacts of alien species on human activities and well-being (Probert et al., 2023). In SEICAT+, a community of interest is defined as the specific group of people whose participation in a preferred activity, or whose state of being, is improved (or thought to be improved) by the presence of an alien species in the wild. Communities of interest can be identified using information on individual participation or responses, collected through questionnaires, interviews, or other direct observations.

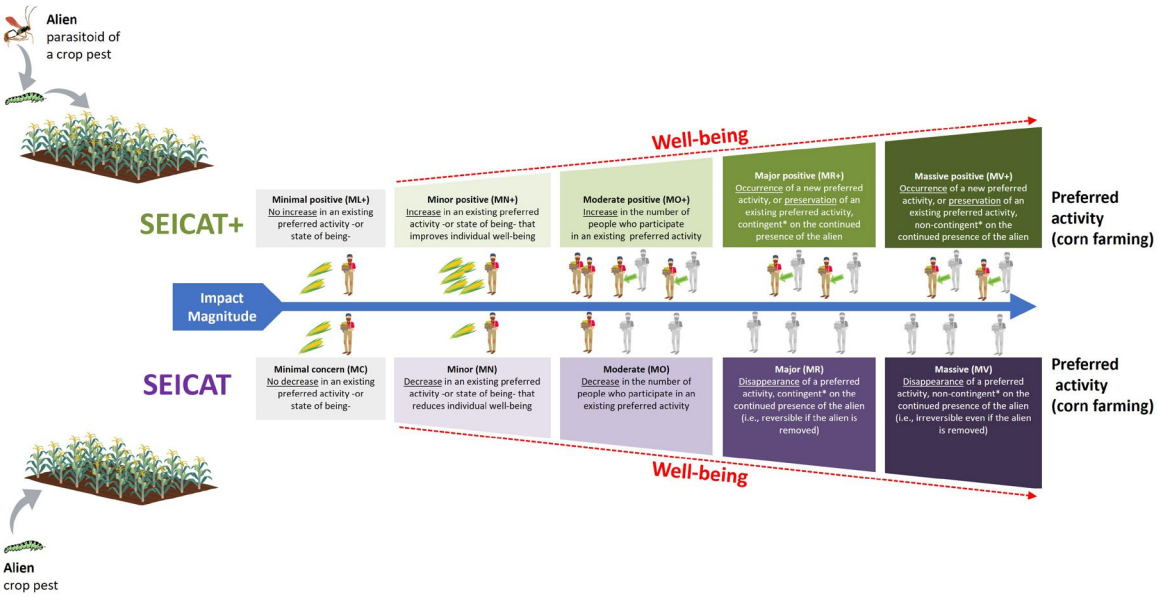

Figure 1. Conceptual scheme for the five semiquantitative scenarios used in SEICAT+ and SEICAT to assess positive impacts (above the blue arrow) and negative impacts (below the blue arrow) caused by two hypothetical alien species (a parasitoid wasp intentionally introduced as biocontrol agent and a crop pest unintentionally introduced in the area) on the same preferred activity (corn farming). In both SEICAT and SEICAT+, only preferred activities—not states of being—are relevant for assigning moderate, major, or massive impacts. Underlined text indicates the direction and type of change in human activities caused by alien species, while asterisks denote whether a preferred activity's existence is contingent on the continued presence of the alien species. Symbols were courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/media-library).

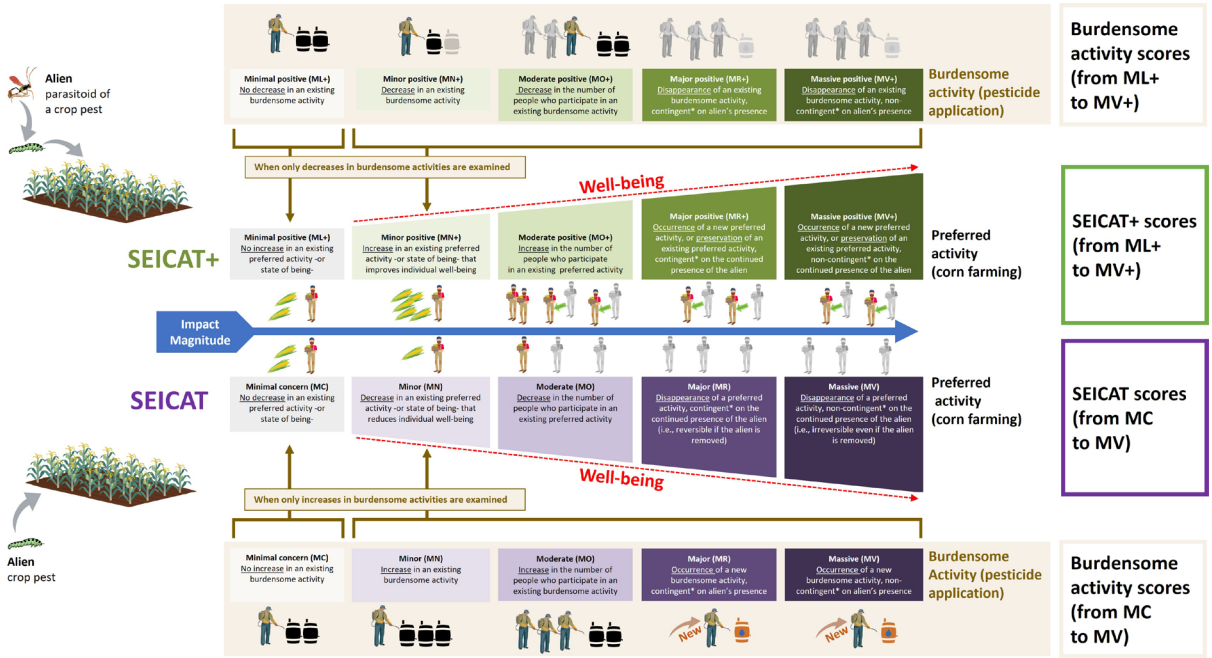

Figure 2. Illustration of SEICAT+ and SEICAT scenarios including the use of burdensome activities as an additional indicator for human well-being impacts. Conceptual scheme for the five semiquantitative scenarios used in SEICAT+ and SEICAT to assess positive impacts (above the blue arrow) and negative impacts (below the blue arrow) caused by two hypothetical alien species (a parasitoid wasp intentionally introduced as biocontrol agent and a crop pest unintentionally introduced in the area) on the same preferred activity (corn farming) and/or on a burdensome activity (pesticide application). In both SEICAT and SEICAT+, hereafter collectively referred to as SEICAT(+), only preferred activities—not states of being or burdensome activities—are relevant for assigning moderate, major, or massive impacts. While preferred activities can be undertaken regardless of burdensome activities (brown insets), the latter are pursued only to prevent or mitigate ecosystem disservices caused by alien species or other environmental stressors. Given the link between preferred and burdensome activities, any change caused by an alien species on the latter implies at least a Minor impact under both frameworks, as the species either facilitates (under SEICAT+) or hinders (under SEICAT) a certain preferred activity or state of being. When only changes in burdensome activities are found without further details on preferred activities or states of being (brown brackets and insets), the impact should be classified as Minor under SEICAT(+). When no change in burdensome activities are found without further details on preferred activities or states of being, the impact should be classified as Minimal under SEICAT(+).Changes in burdensome activities cannot be used to generate SEICAT(+) scores (purple and green boxes on the right) beyond the minor level, although they can still be used to obtain similarly structured scores that span from MC/ML+ to MV/MV+ (brow boxes on the right) allowing the assessor to capture and compare the full spectrum of changes associated with burdensome activities in a structured and consistent way (Probert et al. 2023). Underlined text indicates the direction and type of change in human activities caused by alien species, while asterisks denote whether a preferred activity's existence is contingent on the continued presence of the alien species. Symbols were courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/media-library).

In summary, only preferred activities are used as indicators to generate SEICAT+ scores that span across all levels of positive impact, from Minimal to Massive (Table 1, Fig. 1). In contrast, improvements in states of being are assessed only at the Minimal and Minor levels, reflecting individual-level well-being (Table 1, Fig. 1). As in SEICAT (Probert et al., 2023), the five-tier structure of SEICAT+ can also be applied to burdensome activities (see Fig. 2), but they should be classified and reported separately, since the full classification cannot be used—changes in burdensome activities are restricted to Minimal and Minor levels in both SEICAT and SEICAT+, hereafter collectively referred to as SEICAT(+), and are evaluated based on their impact on individual preferred activities or states of being (Fig. 1). In practice, this means that the core indicator of SEICAT(+) is based on changes in preferred activities; however, when these are not explicitly examined, as is often the case (Probert et al., 2023), changes in states of being and burdensome activities can still provide complementary evidence and allow for a partial classification of positive impacts (Table 1, Fig 2.).

Table 1. Detailed descriptions and examples illustrating how to assign SEICAT+ impact categories across the five levels of impact magnitude.

SEICAT+ levels of impact magnitude	**Illustrative examples**				
	Preferred activity: *farming a certain crop for income*.	**Preferred activity: *recreational hiking.***	**Preferred activity: *recreational fishing.***	**State of being (when no specific preferred activity is examined): *being healthy.***	**Burdensome activity (when no specific preferred activity or state of being is examined): *pesticide application*.**
Minimal positive impact (ML+) No positive impacts on preferred activities or states of being measured at the individual level, despite availability of studies conducted to quantify these impacts. Also, no decreases in burdensome activities detected. Note that although some alien species might have been expected to have positive impacts on human well-being —for instance, by providing alternative food resources or other material assets previously absent— these impacts should be considered minimal under SEICAT+ if the alien simply interacts with humans without notably altering any of their activities or states of being. Only alien species for which positive impacts on human well-being have been investigated but not detected are assigned an ML+ category. Alien species that have been evaluated under the SEICAT+ process but for which impacts have not been assessed in any study should not be classified in this category, but rather should be classified as Data Deficient.	The introduction of a biocontrol agent does not alter the farming activities measured at the individual level. For instance, farmers achieve the same yield, or neither the quality nor the revenue from selling crops changes.	Hikers maintain the same frequency of visits or report analogous levels of satisfaction in areas where an alien shrub has been introduced.	Recreational fishers maintain the same fishing frequency or report analogous levels of satisfaction in lakes where an alien fish species has been introduced.	The introduction of a fish species intended to control malaria-vector mosquitoes does not produce any measurable increase in individual people's survival.	The introduction of a biocontrol agent does not reduce pesticide application.
Minor positive impact (MN+) Positive impacts on preferred activities or states of being measured at the individual level, but no increase in the number of people participating in an activity (i.e. no increase in activity size). By making it easier for people to participate in their "pre-alien" activities or by enhancing their state of being, individuals benefit in at least one constituent of well-being (i.e. basic material for good life, health, security, good social relations, and the freedom of choice and actions). Increases of well-being can be detected	The introduction of a biocontrol agent alters the farming activities measured at the individual level so that well-being is improved. For instance, farmers achieve better yield, or the quality or the revenue from selling crops increase. Alternatively, the cost of controlling	People hike more often than before or with a higher satisfaction, because an area invaded by an alien shrub appears more attractive than before.	Fishers fish more often, with greater satisfaction or with improved catches in a lake where an alien fish species was introduced.	The introduction of a fish species intended to control malaria-vector mosquitoes produces a measurable increase in individual survival.	The introduction of a self-sustaining biocontrol agent reduces pesticide application; with a lower use of pesticide, a lower number of people involved in the application or its disappearance from the area. The presence of a self-sustaining alien biocontrol agent lowers

through e.g. income/salary gains, greater satisfaction, greater happiness, health improvements, lower effort or expenses to participate in activities, decreased difficulty in accessing goods, enhancement of social activities and reduction of fear. When decreases in burdensome activities are found but no further details on preferred activities or states of being are provided, the impact should be classified in this category.	crop pathogens decreases, or the health status of farmers increases as they use a lower amount of pesticides.				a plant's production of allergenic pollen, decreasing people's reliance on—and expenditure or—antihistamines.
Moderate positive impact+ (MO+) Increase in the number of people participating in an existing preferred activity (i.e. increase in the activity size). This occurs through a partial restart of an activity (that has been dismissed by some) or a participation of additional people in the activity (consider also positive relative changes, as in EICAT+, Vimercati et al. 2022).	The introduction of a biocontrol agent improved the farming activities measured at the community level, as new individuals take up farming or former farmers resume their farming activities.	More hikers undertake the activity because an area invaded by an alien shrub appears more attractive than before.	More fishers take up the activity in a lake where an alien fish species was introduced.	Not applicable at this level of impact magnitude.	Not applicable at this level of impact magnitude.
Major positive impact (MR+) Re-establishment of an historical preferred activity, creation of a new one or preservation of an activity that would have disappeared if the alien taxon had not been introduced. Activity existence is conditional. i.e. depends on the presence of the alien taxon (if the alien taxon is removed, the activity disappears).	The introduction of a self-sustaining biocontrol agent allowed the preservation of a farming activity that would have disappeared if the agent had not been introduced.	Hikers begin undertaking the activity in an area that has become attractive due to the invasion of an alien shrub; however, the area stops being attractive once the shrub is removed.	The introduction of an alien fish enables the re-establishment of fishing in a lake where all native fish had disappeared due to anthropogenic changes.	Not applicable at this level of impact magnitude.	Not applicable at this level of impact magnitude.
Massive positive impact (MV+) Re-establishment of an historical preferred activity, creation of a new one or preservation of an activity that would have disappeared if the alien species had not been introduced. Activity existence is not conditional, i.e. does not depend anymore on the presence of the alien species (i.e. if the alien species is removed, the activity does not disappear).	The introduction of self-sustaining biocontrol agent allowed the preservation of a farming activity that would have disappeared if the agent had not been introduced. Since the alien biocontrol agent caused the extirpation of the crop pest, it is no longer essential for sustaining farming and could therefore be removed or allowed to go extinct.	Hikers begin undertaking the activity in an area that has become attractive due to the invasion of an alien shrub; however, since this has allowed people to discover and establish the area as a desirable hiking destination, the alien shrub is no longer essential for sustaining hiking and could therefore be removed or allowed to go extinct.	The introduction of alien algae contributes to bioremediation by absorbing pollutants from the water, thereby improving water quality and safeguarding the presence of local fish species in a lake in which fishing is undertaken. The removal of the alien algae removes the pollutants they absorb but does allow continuing the fishing activity that has been kept up during periods of acute pollution.	Not applicable at this level of impact magnitude.	Not applicable at this level of impact magnitude.

Key differences between SEICAT+ and other approaches

The development of SEICAT+ enables a standardised and holistic comparison of the positive socio-economic impacts of alien species across various dimensions of human well-being, ecological contexts, and global regions—something that was not achievable with the previous approaches used in environmental economics. Table 2 illustrates how SEICAT+ fills key methodological and conceptual gaps in environmental economics by expanding the framework's capacity to capture relevant, nuanced, context-specific impacts and enhancing comparability across diverse socio-ecological systems.

Table 2. Real-world examples of positive impacts from alien species, evaluated using the SEICAT+ framework and other prominent frameworks in environmental economics. These frameworks are compared based on their inclusion of key features that enhance their applicability across a range of species and socio-ecological contexts. All examples are drawn from Bacher et al. (2025), who conducted their impact assessment using the Nature's Contributions to People (NCP) approach (Díaz et al., 2018). They also carried out SEICAT-like assessments for Good Quality of Life impacts (i.e., well-being), which did not quantitatively classify impact magnitude but identified the key constituents of human well-being affected. Symbols were courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/media-library).

	Impact (1): Alien marbled crayfish used as a healthy and cheap source of protein by a local community in Madagascar (Andriantsoa et al., 2020). 	**Impact (2)**: Alien rapa whelk has created commercial fishing opportunities with dredges and hookah systems since the early 1980s along the Turkish coast of the Black Sea (Aydın, 2016). 	**Impact (3):** Alien date palm, being present throughout the lifetimes of living people, has been positively perceived and considered as a part of the landscape by some members of aboriginal communities in Millstream area, Queensland, Australia (Trigger, 2008). 	**Impact (4):** Alien *Prosopis* spp. has offered microclimate regulation by regulating temperature, reducing the occurrences of sandstorms and offering shade in arid and semi-arid ecosystems used by pastoralists in Afar Region, Ethiopia, and Baringo County, Kenya (Bekele et al., 2018). 	**Impact (5):** Alien flea beetle as a biocontrol agent, used to successfully control the invasive ragwort and reduce national control costs to dairy farms in New Zealand (Fowler et al., 2016). 	**Key features**			
						Consideration of both material and immaterial aspects.	Quantitative or semi/quantitative estimates of impact magnitude (when possible).	Clear distinction of varying degrees of impact magnitude.	Consideration of burdensome activities
SEICAT+	Although no specific activity is mentioned, a positive impact on a state of being (being well-nourished) has been recorded. **Impact magnitude: Minor positive (i.e. semi-quantitative).**	Positive impacts on human well-being by creating a commercial benthic fishing activity with dredges and hookah systems that did not exist before. High economic gain with catch per unit effort of 1050 kg/day and income rate of 78% for 207 vessels employing on average 3 individuals each. No other species caught with dredges and hookah systems are mentioned. **Impact magnitude: Major positive (i.e. semi-quantitative).**	Although no specific activities mentioned, a positive impact on a state of being (being happy) has been recorded with: "certain aboriginal interviewees commented on how the palms contributed to the area's 'beauty', with some remembering how they had played and swum in the presence of the shady trees as children" and "One middle-aged woman mentioned how she had not visited the place for some time due to her disappointment on the last occasion because of the clearing and burning of the palms by government environmental agencies".	Positive impacts on human well-being by facilitating pastoralism through microclimate regulation, as perceived by pastoralist communities. **Impact magnitude: Minor positive (i.e. semi-quantitative).**	Positive impacts on human well-being by reducing the cost of controlling the invasive ragwort, i.e. through a decrease in an existing burdensome activity, (Fig. 1). The invasive ragwort negatively affects farming activities and the dairy industry. "With a per farm cost of ragwort control of $2789, the total national saving in reduced ragwort control costs from the impact of ragwort flea beetle in 2005 was $24.5 million. " **Impact magnitude: Minor positive (i.e. semi-**	YES	YES	YES	YES

			Impact magnitude: Minor positive (i.e. semi-quantitative).		**quantitative).**				
Monetary approach	Although not reported, it would be possible to estimate how much of a household's income is spent on food now that the marble crayfish is available. **Impact magnitude: in USD (i.e. quantitative)**	"Average seasonal income of a vessel was 55,613 Turkish lira (TL) and the expense 12,483 TL, resulting in a 43,132 TL net average profit for 207 vessels." **Impact magnitude: in TL (i.e. quantitative)**	Intangible asset. No monetary value can be assigned. **Impact magnitude: NA (i.e. quantitative).**	"Considering microclimate regulation benefits of *Prosopis*, average respondent households from Afar and Baringo felt that if [*Prosopis*] is reduced below a certain threshold, they will lose USD 5.36 and USD 3.89 per annual, respectively". **Impact magnitude: in USD (i.e. quantitative).**	"With a per farm cost of ragwort control of $2789, the total national saving in reduced ragwort control costs from the impact of ragwort flea beetle in 2005 was $24.5 million. " **Impact magnitude: in NZD (i.e. quantitative).**	NO	YES	YES	Yes
INSEAT framework - Ecosystem services approach applied to introduced species	Noticeable reversible or substantial reversible increase in a provisioning ecosystem service **Impact magnitude: score 2 or 3 (i.e. semi-quantitative).**	Substantial reversible increase in a provisioning ecosystem service. **Impact magnitude: score 3 (i.e. semi-quantitative).**	Too small to be significant or noticeable reversible increase in a cultural ecosystem service. **Impact magnitude: score 1 or 2 (i.e. semi-quantitative).**	Noticeable reversible or substantial reversible increase in a regulating ecosystem service. **Impact magnitude: score 2 or 3 (i.e. semi-quantitative).**	Noticeable reversible or substantial reversible increase in a regulating ecosystem service. **Impact magnitude: score 2 or 3 (i.e. semi-quantitative).**	YES	YES	NO	NO
Nature's Contributions to People approach - IPBES report*	Impact classified as positive on food and feed (12.). **Impact magnitude: NA (i.e. qualitative).**	Impact classified as positive on food and feed (12.). **Impact magnitude: NA (i.e. qualitative)**	Impact classified as positive on physical and psychological experiences (16.). **Impact magnitude: NA (i.e. qualitative)**	Impact classified as positive on regulation of climate (4.). **Impact magnitude: NA (i.e. qualitative).**	Impact classified as positive on regulation of detrimental organisms and biological processes (10.). **Impact magnitude: NA (i.e. qualitative).**	YES	NO	NO	Yes
One Health Approach	Benefits on human health via good nutrition value and cheap cost**.** **Impact magnitude: NA (i.e. qualitative).**	Benefits on human health via increased livelihood. **Impact magnitude: NA (i.e. qualitative).**	Benefits on human health through increased psychological experiences. **Impact magnitude: NA (i.e. qualitative).**	Benefits on human health via increased livelihood. **Impact magnitude: NA (i.e. qualitative).**	Benefits on human health via increased livelihood. **Impact magnitude: NA (i.e. qualitative).**	YES	NO	NO	YES

* Numbers refer to the classification by Díaz et al., 2018

A first advantage of SEICAT+ over approaches based on the monetary quantification is that both tangible and intangible aspects can be assessed. Cases in which alien species provide psychological satisfaction through their aesthetics, support the preservation of cultural or religious practices, or indirectly contribute to psychological stability by enabling access to specific resources, cannot be adequately addressed through monetary valuation. Instead, they require an approach that recognizes their symbolic, emotional, and ecological significance, which can be captured in SEICAT+ by assessing how alien species affect community-specific activities or individual states of being. Another key advantage of SEICAT+ is its ability to integrate information gathered through diverse methodologies and approaches into relevant, standardized semi-quantitative categories, thus producing data that enable more meaningful ranking and comparison across cases. While this feature is shared by most monetary approaches and by ecosystem service-based frameworks such as INSEAT (Martinez-Cillero et al., 2019), it is notably absent from several recently popular approaches in environmental assessment, including the Nature's Contributions to People (NCP) approach and the One Health framework. It follows that, although these approaches are well-suited for identifying theoretically complex links between ecosystem features and societal dimensions—and for providing a qualitative list of benefits alien species may offer to humans (e.g., Bacher et al., 2025)—they fall short in enabling meaningful and replicable comparisons across locations and species.—they fall short in enabling meaningful and replicable comparisons.

Additionally, compared to other bi-directional impact frameworks (Kumschick et al., 2012; Martinez-Cillero et al., 2019) SEICAT+ facilitates clear distinctions of different levels of impact magnitude. This level of clarity is absent in existing frameworks, which rely on vague and subjective terminology. For instance, INSEAT defines impact levels using phrases like 'too small to be significant,' 'noticeable,' 'substantial' or 'intense increase in the ecosystem service.' Similarly, the impact-based prioritisation framework proposed by Kumschick and colleagues (2012) used loosely defined expressions such as 'potential positive influence but not reported', 'occasionally leading to increased', 'regularly leading to increased', 'small quality increase,' 'larger quality increase,' or 'massive quality gain'. Notably, a similar terminological vagueness was observed in the widely used GISS framework (Nentwig et al., 2010, 2016), which ultimately led authors who originally contributed to its development to outline the well-defined SEICAT framework (Bacher et al., 2018). To minimize subjective judgments, SEICAT(+) frameworks build on the EICAT(+) frameworks (Blackburn et al., 2014; IUCN, 2020b; Vimercati et al., 2022) by adopting explicit demarcations between impact levels. Specifically, SEICAT+ differentiates: (1) Minor from Moderate impacts based on whether the number of people involved in the activity increased; (2) Moderate from Major impacts based on whether the entire activity's existence is reliant on the alien species; and (3) Major from Massive impacts depending on whether the activity's existence is contingent on the continued presence of the alien species (Figure 1, Table 2). Therefore, SEICAT+ does not rely on subjective thresholds for categorizing impacts, a feature acknowledged to improve consistency among assessors and inter-rater reliability of assessments across different species and contexts (Bernardo-Madrid et al., 2022).

Lastly, SEICAT+ profits from the recent clarification and expansion of the SEICAT framework (Probert et al., 2023) to account for cases in which alien species improve human well-being by reducing, minimizing or eliminating the need for burdensome activities. Several studies have documented cases where ecosystem disservices are mitigated following the introduction of species outside their native range (Castro-Díez et al., 2019; Milanović et al., 2020). Both the Nature's Contributions to People (NCP) framework and the One Health approach can qualitatively address these benefits: the former by recognizing positive impacts of alien species under the category "regulation of detrimental organisms and biological processes"; the latter by assessing improvements in human, animal, and environmental health resulting from reduced reliance on burdensome activities, such as the widespread use of insecticides or herbicides. However, neither approach provides an indicator that enables comparisons across taxa and regions. Semi-quantitative frameworks—such as INSEAT and the prioritization framework for management proposed by Kumschick et al. (2012)—have overlooked this aspect, as they do not offer a strategy to use studies reporting changes in burdensome activities only. Monetary approaches can capture such changes, especially when the economic impacts directly attributable to alien species are clearly separated from the costs of managing them or mitigating other ecosystem disservices. A notable example of this, albeit focused solely on negative impacts, is the InvaCost methodology and dataset (Bradshaw et al., 2024; Diagne et al., 2020) which systematically report both societal economic losses and management expenditures side by side. By integrating the aspects outlined above, SEICAT+ enables users to assign a magnitude of impact to all cases where an alien species reduces society's participation of burdensome activities (Figure 1), while—consistent with the InvaCost approach—clearly distinguishing direct effects on preferred activities from indirect effects related to compensatory measures (Fig. 2).

SEICAT+ in practice

Given the innovative features and conceptual flexibility of the SEICAT+ framework, we anticipate that it will serve a wide range of purposes across various domains and environmental contexts. While SEICAT has been used to compare negative impacts of alien species across disparate stakeholder groups and well-being dimensions (Bacher et al., 2023; Evans et al., 2020; Galanidi et al., 2018; Gruber et al., 2022), to demonstrate the exacerbation of their widespread damages on target activities over time (Gourari et al., 2025; Oussellam et al., 2021), and to design questionnaires capturing data on stakeholders' perceptions and alien-mediated socio-economic losses (Nardelli et al., 2024), similar applications can be envisioned for SEICAT+. The novel framework can also be used to systematically identify alien species that, despite their well-documented negative impacts on people and nature, provide significant positive contributions to human activities across both global and national contexts (Kumar et al. in preparation). This seems particularly relevant where human populations significantly rely on nature, as in most tropic regions (Mungi et al., 2025). Such insights may inform management but also ensure that active alien species control is accompanied by the restoration of native species capable of providing comparable ecosystem services (Bekele et al. 2018). Additionally, SEICAT+ can deliver insights on which alien species can be pro-actively employed, for example as biocontrol agents (Van Driesche

et al., 2010), or temporarily tolerated given their benefits on human well-being. SEICAT+ data can therefore inform risk analysis processes informing regulatory frameworks (Kumschick et al., 2020), support conflict resolution strategies (Estévez et al., 2015) and facilitate deliberative, participatory approaches involving affected stakeholders (Crowley et al., 2017).

From a heuristic perspective, when integrated with data derived from other semi-quantitative frameworks of the ICAT family, SEICAT+ can contribute to a more comprehensive understanding of human–nature interdependencies, while also investigating which social and ecological agents, institutions, and processes mediate these interactions, for instance via the promising social-ecological network methodology (Rickowski et al., 2025). With the development of SEICAT+, the ICAT frameworks can now capture all types of impacts, both environmental and socio-economic, and in all directions, positive and negative, enabling a more comprehensive assessment of their effects on systems and stakeholders. Bi-directional impact assessment studies that employ both SEICAT and SEICAT+ may also explore factors that influence the distribution, magnitude and direction of socio-economic impacts associated with alien species, in parallel with efforts to disentangle drivers of alien-mediated environmental change (Bescond--Michel et al., 2025).

Concluding remarks

The development of the SEICAT+ framework responds to calls for more inclusive assessments of alien species by accounting for their positive impacts on relational, instrumental, and intrinsic values (Sax et al., 2022), while not overlooking their negative effects on biodiversity or human societies. SEICAT+ also contributes to broadening the scope of invasion science by integrating the perspectives of diverse stakeholders and acknowledging the wider social and political dimensions involved in impact evaluation (Reed et al., 2023), while remaining grounded in established frameworks and approaches validated by multiple scholars in the field to ensure transparency and advance the discipline (Lockwood et al., 2023). The framework complements existing approaches in welfare economics by providing a structured means of capturing and assessing the positive impacts of alien species to humans, thereby enriching scientific inquiry and supporting more informed, context-sensitive management decisions.

Acknowledgements

We gratefully acknowledge the many individuals who contributed over the years to the envisioning and development of this framework through their valuable advice, constructive feedback, and stimulating conversations, especially the members of the InvasiBES project.

This research was supported by the 2017–2018 Belmont Forum and BiodivERsA joint call under the BiodivScen ERA-Net COFUND programme through the InvasiBES project, and by the Swiss National Science Foundation (SNSF) through grants 31003A_179491, 31BD30_184114 and IC00I0_231475.

References

Andriantsoa, R., Jones, J. P. G., Achimescu, V., Randrianarison, H., Raselimanana, M., Andriatsitohaina, M., Rasamy, J., & Lyko, F. (2020). Perceived socio-economic impacts of the marbled crayfish invasion in Madagascar. *PLOS ONE*, *15*(4), e0231773. https://doi.org/10.1371/journal.pone.0231773

Aydın, M. (2016). Rapa whelk (Rapana venosa Valenciennes, 1846) fishery along the Turkish coast of the Black Sea. *Journal of Aquaculture Engineering and Fisheries Research*, 85-96. https://doi.org/10.3153/JAEFR16011

Bacher, S., Blackburn, T. M., Essl, F., Genovesi, P., Heikkilä, J., Jeschke, J. M., Jones, G., Keller, R., Kenis, M., Kueffer, C., Martinou, A. F., Nentwig, W., Pergl, J., Pyšek, P., Rabitsch, W., Richardson, D. M., Roy, H. E., Saul, W.-C., Scalera, R., … Kumschick, S. (2018). Socio-economic impact classification of alien taxa (SEICAT). *Methods in Ecology and Evolution*, *9*(1), 159-168. https://doi.org/10.1111/2041-210X.12844

Bacher, S., Galil, B., Nuñez, M., Ansong, M., Cassey, P., Dehnen-Schmutz, K., Fayvush, G., Hiremath, A., Ikegami, M., Martinou, A., McDermott, S., Preda, C., Weyl, O., Fernandez, R., & Ryan-Colton, E. (2023). *Chapter 4. Impacts of invasive alien species on nature, nature's contributions to people, and good quality of life. In : Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Roy, H. E., Pauchard, A., Stoett, P., and Renard Truong, T. (eds.)*. y. https://doi.org/10.5281/zenodo.743073

Bacher, S., Galil, B. S., Nuñez, M. A., Ansong, M., Cassey, P., Dehnen-Schmutz, K., Fayvush, G., Hiremath, A. J., Ikegami, M., Martinou, A. F., McDermott, S. M., Preda, C., Vilà, M., Weyl, O. L. F., Fernandez, R. D., & Ryan-Colton, E. (2024). *IPBES Invasive Alien Species Assessment : Chapter 4. Impacts of invasive alien species on nature, nature's contributions to people, and good quality of life*. Zenodo. https://doi.org/10.5281/zenodo.10677193

Bacher, S., Ryan-Colton, E., Coiro, M., Cassey, P., Galil, B. S., Nuñez, M. A., Ansong, M., Dehnen-Schmutz, K., Fayvush, G., Fernandez, R. D., Hiremath, A. J., Ikegami, M., Martinou, A. F., McDermott, S. M., Preda, C., Vilà, M., Weyl, O. L. F., Aravind, N. A., Angelidou, I., … Zengeya, T. A. (2025). Global Impacts Dataset of Invasive Alien Species (GIDIAS). *Scientific Data*, *12*(1), 832. https://doi.org/10.1038/s41597-025-05184-5

Bekele, K., Haji, J., Legesse, B., & Schaffner, U. (2018). Economic impacts of Prosopis spp. invasions on dryland ecosystem services in Ethiopia and Kenya : Evidence from choice experimental data. *Journal of Arid Environments*, *158*, 9-18. https://doi.org/10.1016/j.jaridenv.2018.07.001

Bernardo-Madrid, R., González-Moreno, P., Gallardo, B., Bacher, S., & Vilà, M. (2022). Consistency in impact assessments of invasive species is generally high and depends on protocols and impact types. *NeoBiota*, *76*, 163-190. https://doi.org/10.3897/neobiota.76.83028

Bescond--Michel, Z., Bacher, S., & Vimercati, G. (2025). Harms of introduced large herbivores outweigh benefits to native biodiversity. *Nature Communications*, *16*(1), 8260. https://doi.org/10.1038/s41467-025-63807-2

Blackburn, T. M., Essl, F., Evans, T., Hulme, P. E., Jeschke, J. M., Kühn, I., Kumschick, S., Marková, Z., Mrugała, A., Nentwig, W., Pergl, J., Pyšek, P., Rabitsch, W., Ricciardi, A., Richardson, D. M., Sendek,

A., Vilà, M., Wilson, J. R. U., Winter, M., … Bacher, S. (2014). A Unified Classification of Alien Species Based on the Magnitude of their Environmental Impacts. *PLoS Biology*, *12*(5), e1001850. https://doi.org/10.1371/journal.pbio.1001850

Bradshaw, C. J. A., Hulme, P. E., Hudgins, E. J., Leung, B., Kourantidou, M., Courtois, P., Turbelin, A. J., McDermott, S. M., Lee, K., Ahmed, D. A., Latombe, G., Bang, A., Bodey, T. W., Haubrock, P. J., Saltré, F., & Courchamp, F. (2024). Damage costs from invasive species exceed management expenditure in nations experiencing lower economic activity. *Ecological Economics*, *220*, 108166. https://doi.org/10.1016/j.ecolecon.2024.108166

Capinha, C., Essl, F., Seebens, H., Moser, D., & Pereira, H. M. (2015). The dispersal of alien species redefines biogeography in the Anthropocene. *Science*, *348*(6240), 1248-1251. https://doi.org/10.1126/science.aaa8913

Castro-Díez, P., Vaz, A. S., Silva, J. S., Van Loo, M., Alonso, Á., Aponte, C., Bayón, Á., Bellingham, P. J., Chiuffo, M. C., DiManno, N., Julian, K., Kandert, S., La Porta, N., Marchante, H., Maule, H. G., Mayfield, M. M., Metcalfe, D., Monteverdi, M. C., Núñez, M. A., … Godoy, O. (2019). Global effects of non-native tree species on multiple ecosystem services. *Biological Reviews*, *94*(4), 1477-1501. https://doi.org/10.1111/brv.12511

Crowley, S. L., Hinchliffe, S., & McDonald, R. A. (2017). Conflict in invasive species management. *Frontiers in Ecology and the Environment*, *15*(3), 133-141. https://doi.org/10.1002/fee.1471

Crowley, S. L., Hinchliffe, S., & McDonald, R. A. (2019). The parakeet protectors : Understanding opposition to introduced species management. *Journal of Environmental Management*, *229*, 120-132. https://doi.org/10.1016/j.jenvman.2017.11.036

De Carvalho-Souza, G. F., Kourantidou, M., Laiz, I., Nuñez, M. A., & González-Ortegón, E. (2024). How to deal with invasive species that have high economic value? *Biological Conservation*, *292*, 110548. https://doi.org/10.1016/j.biocon.2024.110548

Diagne, C., Leroy, B., Gozlan, R. E., Vaissière, A.-C., Assailly, C., Nuninger, L., Roiz, D., Jourdain, F., Jarić, I., & Courchamp, F. (2020). InvaCost, a public database of the economic costs of biological invasions worldwide. *Scientific Data*, *7*(1), 277. https://doi.org/10.1038/s41597-020-00586-z

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., Hill, R., Chan, K. M. A., Baste, I. A., Brauman, K. A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P. W., van Oudenhoven, A. P. E., van der Plaat, F., Schröter, M., Lavorel, S., … Shirayama, Y. (2018). Assessing nature's contributions to people. *Science*, *359*(6373), 270-272. https://doi.org/10.1126/science.aap8826

Estévez, R. A., Anderson, C. B., Pizarro, J. C., & Burgman, M. A. (2015). Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. *Conservation Biology*, *29*(1), 19-30. https://doi.org/10.1111/cobi.12359

Evans, T., Blackburn, T. M., Jeschke, J. M., Probert, A. F., & Bacher, S. (2020). Application of the Socio-Economic Impact Classification for Alien Taxa (SEICAT) to a global assessment of alien bird impacts. *NeoBiota*, *62*, 123-142. https://doi.org/10.3897/neobiota.62.51150

Ferraro, P. J. (2009). Counterfactual thinking and impact evaluation in environmental policy. *New Directions for Evaluation*, *2009*(122), 75-84. https://doi.org/10.1002/ev.297

Fowler, S., Gourlay, A., & Hill, R. (2016). Biological control of ragwort in the New Zealand dairy sector : An ex-post economic analysis. *New Zealand Journal of Agricultural Research*, *59*(3), 205-215. https://doi.org/10.1080/00288233.2016.1170050

Galanidi, M., Zenetos, A., & Bacher, S. (2018). Assessing the socio-economic impacts of priority marine invasive fishes in the Mediterranean with the newly proposed SEICAT methodology. *Mediterranean Marine Science*, *19*(1), 107. https://doi.org/10.12681/mms.15940

Gallardo, B., Bacher, S., Barbosa, A. M., Gallien, L., González-Moreno, P., Martínez-Bolea, V., Sorte, C., Vimercati, G., & Vilà, M. (2024). Risks posed by invasive species to the provision of ecosystem services in Europe. *Nature Communications*, *15*(1), 2631. https://doi.org/10.1038/s41467-024-46818-3

Gourari, K., Mabrouki, Y., Parenteau-Mauffette, É., Legssyer, B., Mancinelli, G., & Taybi, A. F. (2025). Assessing the Ecological and Socio-Economic Impacts of the Invasive Bleu Crab Callinectes sapidus Using Local Knowledge and Field Surveys in Eastern Morocco. *Thalassas: An International Journal of Marine Sciences*, *41*(2), 118. https://doi.org/10.1007/s41208-025-00876-6

Gozlan, R. E., Bommarito, C., Caballero-Huertas, M., Givens, J., Mortillaro, J.-M., Pepey, E., Ralaiarison, R. P., Senff, P., & Combe, M. (2024). A One-Health approach to non-native species, aquaculture, and food security. *Water Biology and Security*, *3*(2), 100250. https://doi.org/10.1016/j.watbs.2024.100250

Gruber, M. A. M., Santoro, D., Cooling, M., Lester, P. J., Hoffmann, B. D., Boser, C., & Lach, L. (2022). A global review of socioeconomic and environmental impacts of ants reveals new insights for risk assessment. *Ecological Applications*, *32*(4), e2577. https://doi.org/10.1002/eap.2577

Hicks, C. C., Levine, A., Agrawal, A., Basurto, X., Breslow, S. J., Carothers, C., Charnley, S., Coulthard, S., Dolsak, N., Donatuto, J., Garcia-Quijano, C., Mascia, M. B., Norman, K., Poe, M. R., Satterfield, T., St. Martin, K., & Levin, P. S. (2016). Engage key social concepts for sustainability. *Science*, *352*(6281), 38-40. https://doi.org/10.1126/science.aad4977

Hill, R., Díaz, S., Pascual, U., Stenseke, M., Molnár, Z., & Van Velden, J. (2021). Nature's contributions to people : Weaving plural perspectives. *One Earth*, *4*(7), 910-915. https://doi.org/10.1016/j.oneear.2021.06.009

Hoffmann, M., Elliff, C. I., & Nunes, G. T. (2025). Effects of invasive species on the ecosystem services of a tropical insular protected area in Brazil. *Ecosystem Services*, *72*, 101703. https://doi.org/10.1016/j.ecoser.2025.101703

IUCN. (2020a). *Guidelines for using the IUCN Environmental Impact Classification for Alien Taxa (EICAT). Categories and Criteria : First edition.*

IUCN. (2020b). *IUCN EICAT Categories and Criteria. The Environmental Impact Classification for Alien Taxa. IUCN EICAT Categories and Criteria: first edition.* https://doi.org/10.2305/IUCN.CH.2020.05.en

Jarić, I., Fernández-Llamazares, Á., Molnár, Z., Arbieu, U., Canavan, S., Correia, R. A., Essl, F., Kamelamela, K. L., Ladle, R. J., Maurice, A.-C., Meinard, Y., Novoa, A., Nuñez, M. A., Pyšek, P., Roll, U., Sbragaglia, V., Shackleton, R. T., Shani, L., Sherren, K., … Jeschke, J. M. (2025). Cultural integration of invasive species. *Npj Biodiversity*, *4*(1), 25. https://doi.org/10.1038/s44185-025-00097-3

Kourantidou, M., Haubrock, P. J., Cuthbert, R. N., Bodey, T. W., Lenzner, B., Gozlan, R. E., Nuñez, M. A., Salles, J.-M., Diagne, C., & Courchamp, F. (2022). Invasive alien species as simultaneous benefits

and burdens : Trends, stakeholder perceptions and management. *Biological Invasions*, *24*(7), 1905-1926. https://doi.org/10.1007/s10530-021-02727-w

Kumschick, S., Bacher, S., Dawson, W., Heikkilä, J., Sendek, A., Pluess, T., Robinson, T., & Kühn, I. (2012). A conceptual framework for prioritization of invasive alien species for management according to their impact. *NeoBiota*, *15*, 69-100. https://doi.org/10.3897/neobiota.15.3323

Kumschick, S., Wilson, J. R. U., & Foxcroft, L. C. (2020). A framework to support alien species regulation : The Risk Analysis for Alien Taxa (RAAT). *NeoBiota*, *62*, 213-239. https://doi.org/10.3897/neobiota.62.51031

Liss, K. N., Mitchell, M. G., MacDonald, G. K., Mahajan, S. L., Méthot, J., Jacob, A. L., Maguire, D. Y., Metson, G. S., Ziter, C., Dancose, K., Martins, K., Terrado, M., & Bennett, E. M. (2013). Variability in ecosystem service measurement : A pollination service case study. *Frontiers in Ecology and the Environment*, *11*(8), 414-422. https://doi.org/10.1890/120189

Liu, Y., Fu, B., Wang, S., Rhodes, J. R., Li, Y., Zhao, W., Li, C., Zhou, S., & Wang, C. (2023). Global assessment of nature's contributions to people. *Science Bulletin*, *68*(4), 424-435. https://doi.org/10.1016/j.scib.2023.01.027

Lockwood, J. L., Lieurance, D., Flory, S. L., Meyerson, L. A., Ricciardi, A., & Simberloff, D. (2023). Moving scholarship on invasion science forward. *Trends in Ecology & Evolution*, *38*(6), 495-496. https://doi.org/10.1016/j.tree.2023.01.006

Martinez-Cillero, R., Willcock, S., Perez-Diaz, A., Joslin, E., Vergeer, P., & Peh, K. S.-H. (2019). A practical tool for assessing ecosystem services enhancement and degradation associated with invasive alien species. *Ecology and Evolution*, *9*(7), 3918-3936. https://doi.org/10.1002/ece3.5020

McElwee, P. (2017). The Metrics of Making Ecosystem Services. *Environment and Society*, *8*(1). https://doi.org/10.3167/ares.2017.080105

Milanović, M., Knapp, S., Pyšek, P., & Kühn, I. (2020). Linking traits of invasive plants with ecosystem services and disservices. *Ecosystem Services*, *42*, 101072. https://doi.org/10.1016/j.ecoser.2020.101072

Millennium Ecosystem Assessment (Éd.). (2005). *Ecosystems and human well-being : Synthesis*. Island Press.

Mungi, N. A., Galetti, M., Ratnam, J., Chala, D., Sanín, M. J., & Svenning, J.-C. (2025). Alien plants and novel ecosystems in the Greater Tropics. *Nature Reviews Biodiversity*, *1*(8), 515-531. https://doi.org/10.1038/s44358-025-00068-3

Nardelli, L., Fucilli, V., Pinto, H., Elston, J. N., Carignani, A., Petrontino, A., Bozzo, F., & Frem, M. (2024). Socio-economic impacts of the recent bio-invasion of Callinectus sapidus on small-scale artisanal fishing in southern Italy and Portugal. *Frontiers in Marine Science*, *11*, 1466132. https://doi.org/10.3389/fmars.2024.1466132

Nentwig, W., Bacher, S., Pyšek, P., Vilà, M., & Kumschick, S. (2016). The generic impact scoring system (GISS) : A standardized tool to quantify the impacts of alien species. *Environmental Monitoring and Assessment*, *188*(5), 315. https://doi.org/10.1007/s10661-016-5321-4

Nentwig, W., Kühnel, E., & Bacher, S. (2010). A Generic Impact-Scoring System Applied to Alien Mammals in Europe. *Conservation Biology*, *24*(1), 302-311. https://doi.org/10.1111/j.1523-1739.2009.01289.x

Oussellam, M., Selfati, M., Ouamari, N. E., & Bazairi, H. (2021). *Using the new SEICAT methodology to study the socio-economic impacts of the American blue crab Callinectes sapidus from Marchica lagoon, Morocco*. *14*(6).

Pandeya, B., Buytaert, W., Zulkafli, Z., Karpouzoglou, T., Mao, F., & Hannah, D. M. (2016). A comparative analysis of ecosystem services valuation approaches for application at the local scale and in data scarce regions. *Ecosystem Services*, *22*, 250-259. https://doi.org/10.1016/j.ecoser.2016.10.015

Panel (OHHLEP), O. H. H.-L. E., Adisasmito, W. B., Almuhairi, S., Behravesh, C. B., Bilivogui, P., Bukachi, S. A., Casas, N., Becerra, N. C., Charron, D. F., Chaudhary, A., Zanella, J. R. C., Cunningham, A. A., Dar, O., Debnath, N., Dungu, B., Farag, E., Gao, G. F., Hayman, D. T. S., Khaitsa, M., … Zhou, L. (2022). One Health : A new definition for a sustainable and healthy future. *PLOS Pathogens*, *18*(6), e1010537. https://doi.org/10.1371/journal.ppat.1010537

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R. T., Başak Dessane, E., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S. M., Wittmer, H., Adlan, A., Ahn, S., Al-Hafedh, Y. S., Amankwah, E., Asah, S. T., … Yagi, N. (2017). Valuing nature's contributions to people : The IPBES approach. *Current Opinion in Environmental Sustainability*, *26-27*, 7-16. https://doi.org/10.1016/j.cosust.2016.12.006

Pienkowski, T., Williams, S., McLaren, K., Wilson, B., & Hockley, N. (2015). Alien invasions and livelihoods : Economic benefits of invasive Australian Red Claw crayfish in Jamaica. *Ecological Economics*, *112*, 68-77. https://doi.org/10.1016/j.ecolecon.2015.02.012

Pires, A. P. F., Padgurschi, M. C. G., Castro, P. D. de, Scarano, F. R., Strassburg, B., Joly, C. A., Watson, R. T., & Groot, R. de. (2020). Ecosystem services or nature's contributions? Reasons behind different interpretations in Latin America. *Ecosystem Services*, *42*, 101070. https://doi.org/10.1016/j.ecoser.2020.101070

Probert, A. F., Vimercati, G., Kumschick, S., Volery, L., & Bacher, S. (2023). Clarification and guidance on the use of the Socio-Economic Impact Classification for Alien Taxa (SEICAT) framework. *NeoBiota*, *89*, 45-70. https://doi.org/10.3897/neobiota.89.109911

Reed, E. M. X., Schenk, T., Brown, B. L., Rogers, H., Haak, D. C., Drake, J. C., & Barney, J. N. (2023). Holistic valuation of non-native species requires broadening the tent. *Trends in Ecology & Evolution*, *38*(6), 497-498. https://doi.org/10.1016/j.tree.2023.01.004

Reeves, R. D., Baker, A. J. M., Jaffré, T., Erskine, P. D., Echevarria, G., & Ent, A. van der. (2018). A global database for plants that hyperaccumulate metal and metalloid trace elements. *The New Phytologist*, *218*(2), 407-411.

Rickowski, F. S., Ruland, F., Bodin, Ö., Evans, T., Fowler, M., Kluger, L., Latombe, G., Lenzner, B., Macedo, R., Adriaens, T., Arlinghaus, R., Castellanos-Galindo, G., Dick, J. T. A., Dickey, J., Essl, F., Gallardo, B., Hilt, S., Itescu, Y., Jaric, I., … Jeschke, J. (2025). *A systems perspective : How social-ecological networks can improve our understanding and management of biological invasions*. https://ecoevorxiv.org/repository/view/8895/

Robeyns, I. (2005). The Capability Approach : A theoretical survey. *Journal of Human Development*, *6*(1), 93-117. https://doi.org/10.1080/146498805200034266

Roy, H. E., Pauchard, A., Stoett, P., & Renard Truong, T. (2024). *IPBES Invasive Alien Species Assessment : Full report* (Version 4). Zenodo. https://doi.org/10.5281/ZENODO.7430682

Sax, D. F., Schlaepfer, M. A., & Olden, J. D. (2022). Valuing the contributions of non-native species to people and nature. *Trends in Ecology & Evolution*, *37*(12), 1058-1066. https://doi.org/10.1016/j.tree.2022.08.005

Sen, A. (1999). Commodities and capabilities. *OUP Catalogue*. https://ideas.repec.org/b/oxp/obooks/9780195650389.html

Trigger, D. S. (2008). Indigeneity, ferality, and what 'belongs' in the Australian bush : Aboriginal responses to 'introduced' animals and plants in a settler-descendant society. *Journal of the Royal Anthropological Institute*, *14*(3), 628-646. https://doi.org/10.1111/j.1467-9655.2008.00521.x

Van Driesche, R. G., Carruthers, R. I., Center, T., Hoddle, M. S., Hough-Goldstein, J., Morin, L., Smith, L., Wagner, D. L., Blossey, B., Brancatini, V., Casagrande, R., Causton, C. E., Coetzee, J. A., Cuda, J., Ding, J., Fowler, S. V., Frank, J. H., Fuester, R., Goolsby, J., … Van Klinken, R. D. (2010). Classical biological control for the protection of natural ecosystems. *Biological Control*, *54*, S2-S33. https://doi.org/10.1016/j.biocontrol.2010.03.003

Vimercati, G., Kumschick, S., Probert, A. F., Volery, L., & Bacher, S. (2020). The importance of assessing positive and beneficial impacts of alien species. *NeoBiota*, *62*, 525-545. https://doi.org/10.3897/neobiota.62.52793

Vimercati, G., Probert, A. F., Volery, L., Bernardo-Madrid, R., Bertolino, S., Céspedes, V., Essl, F., Evans, T., Gallardo, B., Gallien, L., González-Moreno, P., Grange, M. C., Hui, C., Jeschke, J. M., Katsanevakis, S., Kühn, I., Kumschick, S., Pergl, J., Pyšek, P., … Bacher, S. (2022). The EICAT+ framework enables classification of positive impacts of alien taxa on native biodiversity. *PLOS Biology*, *20*(8), e3001729. https://doi.org/10.1371/journal.pbio.3001729

Zengeya, T., Ivey, P., Woodford, D. J., Weyl, O., Novoa, A., Shackleton, R., Richardson, D., & Van, W. B. (2017). Managing conflict-generating invasive species in South Africa : Challenges and trade-offs. *Bothalia - African Biodiversity & Conservation*, *47*(2), 1-11. https://doi.org/10.4102/abc.v47i2.2160

Zhang, L., Rohr, J., Cui, R., Xin, Y., Han, L., Yang, X., Gu, S., Du, Y., Liang, J., Wang, X., Wu, Z., Hao, Q., & Liu, X. (2022). Biological invasions facilitate zoonotic disease emergences. *Nature Communications*, *13*(1), 1762. https://doi.org/10.1038/s41467-022-29378-2