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Clarification and guidance on the use of the Socio-Economic Impact Classification for Alien Taxa (SEICAT) framework

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Abstract

Understanding the ways in which alien taxa threaten human well-being, beyond purely monetary costs, can be difficult as impacts differ vastly across social, cultural, and economic contexts. Failure to capture impacts outside of monetary costs means that impacts are unfairly weighted towards those that can be easily monetised, which is unlikely to be a realistic measure of how alien species truly affect human well-being. To address this issue, the Socio-Economic Impact Classification for Alien Taxa (SEICAT) was developed with the intention to facilitate standardised classifications and comparisons of the impacts of alien taxa on human well-being and livelihood. The framework measures impacts by assessing to what extent alien taxa have altered human activities, so has application across a broad range of reported impacts associated with different constituents of human well-being. Although in their original paper, Bacher et al. (2018) provided an overview of the SEICAT framework, comprehensive guidelines that enable assessors to overcome potential ambiguities were, until now, unavailable. This may be preventing the broad application of the framework due to reduced usability. Here, we provide clarification and guidance for the application of SEICAT to facilitate standardised, consistent assessments. In particular, we address uncertainties stemming from unclear definitions of impacted communities and activities, as well as the spatial and temporal scales of relevance. We clarify these key issues and give explicit recommendations, whilst encouraging the collection of additional contextual information to be recorded for each assessed impact report, to generate more practical information for end-users of SEICAT data. Further, we recommend

adopting an alternative terminology for the impact categories to reduce the potential misuse of the current descriptors. The intended outcome of this work is to aid the broad application of the SEICAT framework in a consistent and transparent manner.

Keywords
capability approach, ICAT frameworks, invasive species, non-native species, well-being

Introduction

Alien species have the capacity to negatively affect people by impacting various aspects of human well-being and livelihood. For instance, alien plants and insects trigger allergic reactions (Smith et al. 2013; Vidal 2022), alien ungulates cause road accidents (Edwards et al. 2010), alien grasses increase the occurrence and severity of wildfires (Fusco et al. 2019), and alien frogs can affect housing markets (Kaiser and Burnett 2006). Such disparate impacts are inherently linked to the extreme context-dependency in which human communities live, whereby the same alien species can have vastly different impacts depending on the local environmental characteristics and the individual circumstances of people (Global Invasive Species Programme 2006; Tessema 2012; Muller et al. 2017). The ability to characterise and ascribe standardised measures of impact is therefore essential to enable meaningful comparisons because the contexts under which impacts occur, and are observed and reported, greatly differ.

The Socio-Economic Impact Classification for Alien Taxa (SEICAT) framework was developed as a standardised method to classify and categorise the impacts of alien species to human well-being (Bacher et al. 2018). Given well-being is a multi-faceted concept, comprising how people both feel and function (Sen 1993; Cloninger 2004), the framework moves beyond describing impacts in purely monetary terms – which has been a prevailing method of evaluating the effects of biological invasions to socio-economic activities (van Wilgen et al. 2001; Diagne et al. 2021). Central to the SEICAT framework is understanding the way in which alien species affect human activities (Bacher et al. 2018). More specifically, SEICAT conceptualises activities as the "achieved functionings" of the capability approach (Sen 1999; Robeyns 2011; see Bacher et al. 2018), using changes to activities as a proxy to changes to human well-being. In order to capture the ways in which human well-being is affected by alien species, SEICAT links the impact of alien species to constituents of human well-being (i.e. health; security; social, spiritual and cultural relations; material and immaterial assets; adapted from the Millennium Ecosystem Assessment (2005)). These can then be connected to the way in which alien species impact socio-economic dimensions of human well-being. By identifying the relevant constituents of well-being affected, a broad understanding of how alien species affect peoples' capabilities is obtained. Using this approach enables greater recognition of how alien species can differentially affect people within similar and dissimilar socio-economic contexts. This is because some individuals, or wider communities, will have the means to compensate or tolerate

impacts more so than others due to various reasons including the inequalities and inequities associated with resource distribution, access to opportunities and personal circumstances. For instance, the potential loss of locally performed recreational activities may be compensated for by travelling farther at additional costs – in both money and time – that not all individuals in all communities will be able to afford.

SEICAT identifies how, and to what degree, activities performed by humans are affected by alien taxa. This allows impacts across all different social, cultural, and economic contexts to be assigned one of five semi-quantitative categories of severity based on the extent to which the alien taxon impacts the individual- and community-level way of life (Table 1). The framework emphasises that not all activities will be valued equally by different people and the intended outcome of SEICAT assessments is to identify consequences in a standardised manner rather than produce a prescribed weighted summary of impacts (Bacher et al. 2018). Impact data are obtained by conducting a review of the scientific and non-scientific literature targeted towards the focal alien species. These data may come from a range of different sources such as observational or experimental studies from the ecological, medical, and/or social sciences, government reports and media interviews. Consequently, the impact data can be collected and communicated in different ways meaning that information must be critically assessed for its relevance to the SEICAT criteria. Once a literature search is complete, an assessor reads each document to identify reported impacts to include in the assessment; within each document there may be several impacts (from one or more alien taxa) reported of relevance to the SEICAT criteria, or indeed, none. Each relevant impact is then linked to the relevant constituent(s) of well-being and assigned a confidence score of either low, medium or high, to indicate the level of certainty that the given impact classification represents the real situation – an important component of the assessment process given impacts can derive from quantitative or qualitative data of differing quality that also vary in terms of scope and scale (Probert et al. 2020). SEICAT thus aims to provide a method of assigning impacts across different contexts where alien species have been introduced based on the available evidence.

Although the original SEICAT publication by Bacher et al. (2018) provided a conceptual basis for the application of the framework, specific guidance that addresses a clear and nuanced understanding of the criteria is currently lacking. This is of particular importance given the recent advocacy for using the framework by the Convention on Biological Diversity (CBD 2023). Given that impact data are derived from different sources and not communicated with the SEICAT criteria in mind, an unambiguous understanding of how assessors should translate impacts into one of the five categories is necessary to ensure consistency in scoring among assessments. Consistent application among assessors is a major challenge for impact scoring systems (González-Moreno et al. 2019; Clarke et al. 2021; Bernardo-Madrid et al. 2022) and a clear conceptual basis that permits congruous scoring is crucial. In order to better fulfil the intention of SEICAT, conceptual and practical ambiguities that currently persist must be addressed. Indeed, new frameworks and tools within invasion science should be modified and adapted as additional knowledge is acquired, allowing future iterations

Table 1. Overview of the five semi-quantitative impact categories of the SEICAT framework. Impact categories for preferred activities follow those proposed by Bacher et al. (2018). New additions recommended in this manuscript, including a change to impact category terminology, are preceded by an asterisk. Note that when there is no or inadequate information to classify an alien taxon to one of the five SEICAT impact categories, the taxon should be classified as Data Deficient (DD).

Impact category	Impact criteria	
Terminology	**For preferred activities (after Bacher et al. 2018)**	***For non-preferred, burdensome activities**
Minimal Concern (MC) *Category 1 (C1)	No deleterious impacts reported despite availability of relevant studies with regard to its impact on human well-being.	*No change in any existent, non-preferred, burdensome activity compared to the scenario in which the alien species was absent.
Minor (MN) *Category 2 (C2)	Negative effect on peoples' well-being, such that the alien taxon makes it difficult for people to participate in their normal activities. Individual people in an activity suffer in at least one constituent of well-being (i.e. security; material and non-material assets; health; social, spiritual and cultural relations). Reductions of well-being can be detected through e.g. income loss, health problems, higher effort or expenses to participate in activities, increased difficulty in accessing goods, disruption of social activities, induction of fear, but no change in activity size is reported, i.e. the number of people participating in that activity remains the same. Also includes scenarios where novel activities commence as compensatory measures of an alien species impact (see right column).	*Existent, non-preferred, burdensome activities increase in frequency and/or intensity because of the alien species, but no change in activity size is reported, i.e. the number of people participating in the burdensome activity remains the same.
Moderate (MO) *Category 3 (C3)	Negative effects on well-being leading to changes in activity size, fewer people participating in an activity, but the activity is still carried out. Reductions in activity size can be due to various reasons, e.g. moving the activity to regions without the alien taxon or to other parts of the area less invaded by the alien taxon; partial abandonment of an activity without replacement by other activities; or switch to other activities while staying in the same area invaded by the alien taxon. Also, spatial displacement, abandonment or switch of activities does not increase human well-being compared to levels before the alien taxon invaded the region (no increase in opportunities due to the alien taxon).	*An increase in activity size for an existent, non-preferred, burdensome activity is reported because of the alien species, i.e. the number of people involved in the burdensome activity increases.
Major (MR) *Category 4a (C4a)	Local disappearance of an activity from all or part of the area invaded by the alien taxon. Collapse of the specific social activity, switch to other activities, or abandonment of activity without replacement, or emigration from the region. Change is likely to be reversible within a decade after removal or control of the alien taxon. "Local disappearance" does not necessarily imply the disappearance of activities from the entire region assessed, but refers to the typical spatial scale over which social communities in the region are characterised (e.g. a human settlement).	*People commence a novel non-preferred, burdensome activity – that was previously not performed before the alien species was present – because of the alien species. Such an activity would cease upon the hypothetical removal (or control) of the alien species.
Massive (MV) *Category 4b (C4b)	Local disappearance of an activity from all or part of the area invaded by the alien taxon. Collapse of the specific social activity, switch to other activities, or abandonment of activity without replacement, or emigration from the region. Change is likely to be reversible within a decade after removal or control of the alien taxon. "Local disappearance" does not necessarily imply the disappearance of activities from the entire region assessed, but refers to the typical spatial scale over which social communities in the region are characterised (e.g. a human settlement).	*People commence a novel non-preferred, burdensome activity – that was previously not performed before the alien species was present – because of the alien species. Such an activity would continue upon the hypothetical removal (or control) of the alien species.

to improve their application. In this paper, we aim to clarify potential sources of uncertainty related to 1) the definition and scoring of different preferred and burdensome activities, 2) the definition of activity size (that is the community of interest for which we are categorising impacts), and 3) the spatial and temporal scales of relevance for impact reports (see Box 1). We provide thorough explanations to reduce inconsistencies among assessments and improve comparisons of impact data collated using SEICAT. Further, we highlight that the current impact category terminology (Minimal Con-

Box 1. Summary of the main guidance and recommendations outlined in this paper.

1. SEICAT can ascribe impacts to both beings and doings yet impacts to the former will always be limited to scores of Minor*. This has important consequences when assigning confidence scores and interpreting SEICAT data. *except in cases where the alien species causes mortality, which is always scored at least as Moderate.

2. Non-preferred, burdensome activities are relevant to SEICAT and should be scored according to the new criteria proposed.

3. Constituents of well-being that are affected by alien species are not mutually exclusive and often must be inferred by assessors. Additional explanations should be provided by assessors to illustrate when constituents of well-being are provided within an impact report versus inferred by an assessor.

4. Impacted activities will be described at different specificities across impact reports. This has significant implications when interpreting SEICAT data. Assessors can generate increasingly transparent and practical assessment data by factoring in the hierarchical nature of activities.

5. Accurate evaluation of impacts requires knowledge of activity size (i.e. the number of individuals who performed the activity prior to the arrival, or impact, of the alien species). As we are in essence interested in people, rather than activities, assessors need to account for the fact that changes in activity size may not be reported in a way in which individual identity is clear.

6. Impacts should not be linked to specific areas as this does not account for our community of interest. Rather, the focus should be on a group of people as this accounts for when people decide to conduct their usual activities elsewhere in response to an alien species.

7. Impacts are subject to temporal change and depending on the timeframe in which they are reported, the impact score may be under- or overestimated. Assessors should be aware of the differences between ephemeral and longer-term impacts.

8. Adopting more neutral language for describing the category of impacts could help to reduce the potential misuse and misinterpretation of SEICAT data.

cern, Minor, Moderate, Major, Massive) may act on assessors' subjective judgement and, moreover, has the potential to be misinterpreted and misused to suit agendas of key stakeholders in species management. To avoid this, future assessments should adopt more neutral terminology to describe categories of impact magnitude. Lastly, we provide a template for data recording (see Suppl. material 1), recommending that assessors record additional information related to each impact report, to generate more useful socio-economic impact databases for end-users and facilitate future analyses to better understand how context relates to impact magnitude.

SEICAT and the capability approach: translating reported impacts into impact scores

The SEICAT framework was developed based on the capability approach to ascribe understanding of alien species impacts to human well-being (Sen 1979, 1999). Under the capability approach, well-being is conceptualised as functionings, where the focus is on what individuals are able to do and be, and capabilities, which reflect the actual opportunity individuals have to achieve these functionings. This allows well-being to be considered for individuals in terms of both what people are *able* to do and what they *choose* to do. Importantly, the capability approach focuses on the end outcomes for people, which means an individual's specific circumstances can be better incorporated into the concept of well-being.

In order to classify changes to activities, it is necessary to understand what activities are. Yet, understanding what constitutes an activity may be causing confusion, and thus inconsistencies, among assessors given that SEICAT also permits impacts that are not measured through changes in activities to be scored (Fig. 1).

Bacher et al. (2018) define an activity as "any human endeavour that is, or could be, affected in its entirety by an alien taxon". This aligns with the capability approach where an endeavour can be considered as both the doings and beings of people, wherein doings are actual activities (e.g. swimming, gardening, farming) and beings are states that a person has achieved (e.g. being healthy, being educated, being rested, being financially stable). Thus, SEICAT permits not only using changes to human activities as indicators of impact but also other changes to various dimensions of wellness, for example, reports of individuals feeling less happy or healthy because of an alien species. The argument proposed for the inclusion of such impacts by Bacher et al. (2018) can be based on the assumption that when changes to people's beings become significant enough to cause a person to suffer, in many cases, they may translate into changes to their activities (Fig. 1).

The inclusion of impact reports detailing changes to peoples' states of being represents a potential ambiguity that requires further clarification. Although Bacher et al. (2018) alluded to the inclusion of beings as relevant to SEICAT, there was no explicit guidance

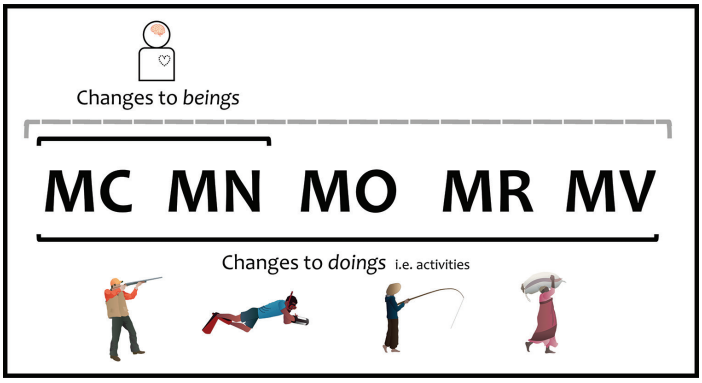

Figure 1. The five different impact scores that can be classified using SEICAT to assess the impacts of alien species to aspects of well-being in terms of what people do (doings) and how they feel (beings). Impact reports that mention changes to beings can only be assigned an impact score of Minor at the highest, even though the real impact might be higher (this uncertainty is captured in a lower confidence score). For instance, alien species may affect people's health where impacts are reported as people feeling less physically or mentally well as a result of an alien species. Other examples include impact reports stating individuals requiring medical advice or treatment as the result of an alien species would also be considered as impacts to beings. This does not necessarily mean that the alien species does not alter the activities of people, indicated by the grey dashed bracket, however, these impacts cannot be assigned a higher score as impact scores above Minor require information on peoples' activities (doings) in relation to the alien species. In most cases, changes to beings will result in changes to people's activities to some degree (e.g. by making them less-enjoyable or more difficult to perform) but often such information is not reported. Symbols obtained from the Integration and Application Network (ian.umces.edu/media-library).

of how such impact reports should be included in assessments. Conceptually, impacts of alien species reported in a way that link to either doings or beings can be scored but a critical difference between the two must be realised by assessors: any reported impact affecting a being (Table 2) – in the absence of any supporting information about how this translates to a change in activity – should be limited to a maximum score of Minor. This is because impacts above Minor, by definition, require information about whether individuals stop performing activities (Table 1, Fig. 1). In such cases where an impact to a being is scored, and it is unknown from the impact report whether – and to which extent – activities are affected, low confidence should accompany the impact score given the uncertainty whether or not the alien species is in actuality causing changes to peoples' activities (Fig. 1).

It should be noted that an impact of an alien species can, therefore, derive a score of Minor based on two differing scenarios: i) an observation where there was no evidence that any individuals abandon an activity due to an alien, although there was evidence that the alien species altered the duration or frequency at which the activity is performed, thus resulting in decreased well-being (Table 1) or, as discussed in the paragraph above, ii) an observation where there was evidence that an alien species negatively affected the mental or physical state of individuals' beings with unknown or unreported consequences for changes to activities. These two scenarios represent quite different impact situations that can be reflected in their confidence scores. For instance, the former can be assigned different levels of uncertainty depending on various aspects such as data quality, temporal and spatial scale, etc. (see Probert et al. 2020). In contrast, the latter scenario will likely always be assigned low confidence as the scope of the reported impact does not account for activities and, therefore, it cannot be determined based on the available information if activities are being affected. Differentiation between whether the impact report derives from scenario i) or ii) is, therefore, useful to ensure that SEICAT data is interpreted appropriately by end-users. A practical distinction can easily be made during the assessment procedure by including an additional column containing this information (see Suppl. material 1).

The common reporting of impacts that link the impacts of alien species to beings rather than doings is one of the reasons why there are many impacts assigned Minor with low confidence (e.g. Galanidi et al. 2018; Kenser and Kumschick 2018; Evans et al. 2020; Gruber et al. 2022; Jansen and Kumschick 2022; see Suppl. material 1: worksheet C).

Relevance of non-preferred, burdensome activities and novel, preferred activities to SEICAT

An important consideration of how alien species impact human well-being is that in some cases, people mount a compensatory response to mitigate their negative effects, specifically by expanding existent, or initiating new, non-preferred activities. Such activities can be considered as 'burdensome activities', and their assessment was not explicitly accounted for in Bacher et al. (2018). Since the foundational basis for SEICAT was that any change to an activity caused by an alien taxon would reflect some degree

Table 2. Examples taken from the literature where Minor impacts are scored for impact reports that detail an alien species affecting beings of individuals, rather than activities (doings). By definition, most impacts that are only reported at the level of beings cannot be assigned impacts higher than Minor as these are measured by changes to activities, that is the doings in the capability approach. The one exception to this is when mortality is recorded, in which cases, at least Moderate is always assigned. Scoring impact reports of beings using SEICAT provides important information on how alien species can affect different aspects of human livelihood and well-being and likely translate to changes in activities.

Alien species and country of introduction where impact was recorded	Quotation	Outcome	Constituent of well-being affected	Reference
Silver wattle (*Acacia dealbata*) introduced to South Africa	A few respondents at each site stated that they did not want *A. dealbata* anywhere near their villages because it might harbour criminals. They stated that the presence of *A. dealbata* allowed criminals to hide which would endanger the community. The majority of the respondents stated that the current abundance levels attracted a lot of criminals to their areas. In Caba village near Matatiele, several households had experienced theft of their livestock and they implicated *A. dealbata* because, they argued, it provides cover in which thieves hide and monitor the activities of the residents. Women also expressed fears of going to collect firewood as criminals would hide in *A. dealbata* patches.	Causing fear for safety (being afraid)	Safety	Ngorima and Shackleton (2019)
Wild dog (*Canis lupis familiaris*) introduced to Australia	There can be significant emotional upset and frustration associated with a wild dog or dingo attack on farm stock. Farmers spoke of 'the emotional upset of seeing animals hurt', 'gut wrenching' attacks and 'strong feelings of revenge and contest'.	Causing emotional upset (being emotionally upset)	Social, spiritual and cultural relations; material and immaterial assets	Fitzgerald and Wilkinson (2009)
Wild dog (*Canis lupis familiaris*) introduced to Australia	There is also a sense of psychological insecurity and uncertainty that farmers live with on a daily basis when wild dogs are present in the environment: 'One is always anticipating the possibility of wild dog attack. Whenever one goes into a sheep paddock one thinks "am I going to find a dead sheep here?".'...Farmers also experience a degree of anxiety and uncertainty over their rights with respect to reducing the risks from wild dogs and other pest animals.	Causing anxiety (being anxious)	Social, spiritual and cultural relations; material and immaterial assets	Fitzgerald and Wilkinson (2009)
Montserrat whistling frog *(Eleutherodactylus johnstonei*) introduced to Brazil	In São Paulo, Brazil, a citizen of the invaded neighbourhood in Brooklin has reported a disorder related to chronic stress due to the noise produced by *E. johnstonei*. This disorder eventually caused her to be hospitalised.	Causing chronic stress (being stressed)	Health	Melo et al. (2014)
Rose-ringed parakeet (*Psittacula krameri*) introduced to Hawai'i, USA	On Kaua'i, property owners of apartments, condominiums, and hotels complain about the noise from [Rose-ringed parakeet] ..[]. Similar complaints have been voiced on O'ahu, particularly from apartment residents adjacent to the largest RRP evening roost on O'ahu that is a large *Ficus* sp. tree on Beretania and Punahou Streets (A.B.S. and N.P.K., pers. obs.).	Causing noise disturbance (not being at peace)	Health	Shiels and Kalodimos (2019)
Brown marmorated stink bug (*Halyomorpha halys*) introduced to Maryland, USA	The unpleasant odour emitted when brown marmorated stink bugs are disturbed, and for which they are named, was far less unpleasant than the perceived nuisance caused by their sheer numbers and daily presence. For the period 1 January 2011 through 31 May 2011, on 56% of days 25 or more stink bugs were collected on the first and second floors, and 100 or more were collected on 21% of days.	Causing nuisance through odour and sheer abundance (not being at peace)	Health	Inkley (2012)

of suffering to individuals, scoring criteria focused only on changes to preferred activities that were already being performed. This was based on the implicit assumption that only changes to existing preferred activities are to be assessed, then conflating all impacts on non-preferred activities to Minor impacts. Indeed, Bacher et al. (2018) stated that, among others, Minor impacts are "…Reductions of well-being [that] can be detected through e.g. income loss, health problems, higher effort or expenses to participate in activities…". However, the existing literature often reports cases in which people do not alter their preferred activities (e.g. farming a crop) as a response to alien species (e.g. a crop pest), but rather they initiate or undertake compensatory activities, such as management activities, to secure and maintain well-being. A more explicit consideration of these activities in SEICAT might expand its functionality, as well as its applicability to a broader range of impact scenarios.

Examples of compensatory non-preferred activities include when farmers have to reinforce pest control activities (Dent and Binks 2020), or when boat owners have to initiate maintenance activities – previously unnecessary – to remove and prevent biofouling (Peters et al. 2019), both in response to an alien species. Whilst often related to alien species management, not all burdensome activities will be related to control or prevention. For instance, the unwanted presence of alien species at localities where people usually, and preferentially, perform certain activities may mean they now have to travel (travel being the new activity that is a burden) to new localities where the alien species is absent. In order to account for such impacts found during SEICAT assessments, the current guidance for scoring needs to be expanded. A rational suggestion would be to consider such non-preferred activities among the activities relevant for assessment, so that their initiation or reinforcement can be used as a proxy for negative impacts on well-being.

Analogous to the classification of preferred activities, but with opposite direction, we suggest classification of burdensome activities in five steps as: (Minimal Concern) no change in burdensome activities compared to without the alien species; (Minor) burdensome activities increase in frequency or intensity, but no increase in number of people participating in burdensome activities; (Moderate) increase in number of people involved in burdensome activities; (Major/Massive) initiation of burdensome activities that were formerly not performed, that can be abandoned after hypothetical removal of the alien species or will need to continue, respectively (Table 1).

Consider a hypothetical scenario in which biofouling of an alien mussel species causes damage to boats used for recreational fishing. This situation necessitates the adoption of vessel cleaning – which is a non-preferred activity – in order to counteract the adverse effects of mussels on human well-being (see Fig. 2). If the non-preferred activity was already conducted prior to the focal alien taxon arrival (for instance to control other already present biofouling agents) and no change has been reported, this impact would be classified as of Minimal Concern. If the cleaning was already implemented but changes to this activity occur because of the alien species, for instance cleaning now takes longer and/or must be conducted more frequently, or the number of people performing cleaning increases, such impacts would be considered as Minor or Moderate, respectively. If the non-preferred activity had to be initiated in response to alien mussels,

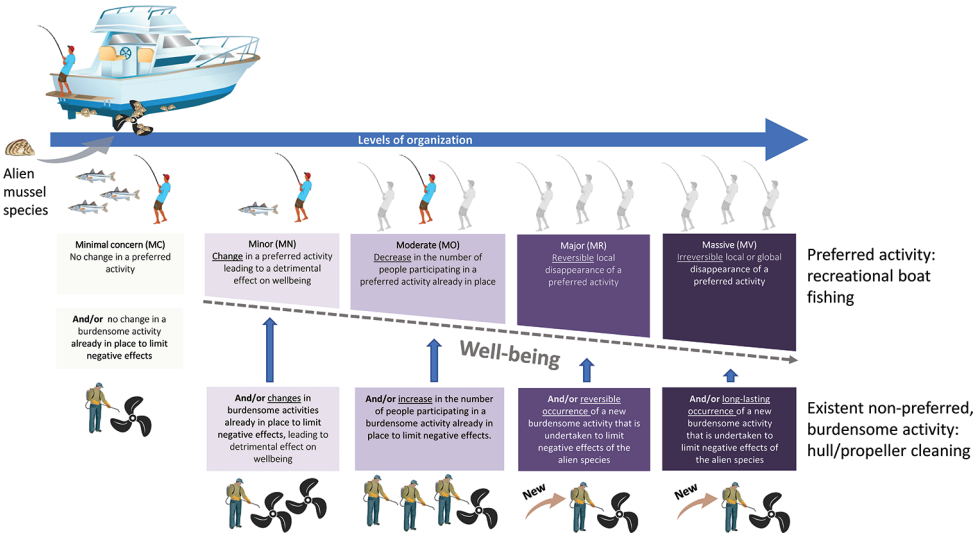

Figure 2. Scoring of SEICAT categories, demonstrating that an alien species can reduce well-being by affecting both preferred and non-preferred, burdensome activities. Here, descriptions for each scoring category are shown with illustrations for different scenarios where an alien mussel species could hypothetically affect the preferred activity of recreational boat fishing and also the non-preferred, burdensome activity, which is the cleaning of the hull and propellers of the boat. Symbols obtained from the Integration and Application Network (ian.umces.edu/media-library).

and is an entirely novel activity for all people in the community of interest, an impact of Major or Massive would be assigned in accordance with their reversibility (see Table 1).

It is important to note that non-preferred activities do not belong to the capability set, i.e. the opportunity set of potential activities (Bacher et al. 2018). In fact, non-preferred activities are generally undertaken in an effort to prevent alien species from negatively affecting preferred activities. Considering one of the examples provided above and illustrated in Fig. 2, boat hull cleaning (the non-preferred activity) is undertaken to mitigate the negative effects that alien mussels have on recreational boat fishing (the preferred activity). While preferred activities can be undertaken regardless of burdensome activities, the latter are pursued only to prevent or mitigate negative consequences of alien species on preferred activities or on the environment. Distinction between changes in preferred and non-preferred activities is therefore critical to meaningfully interpret SEICAT assessments and we emphasise that these two types of activities are kept separate while assessing impacts (see Suppl. material 1: worksheet B). For instance, if an alien species that causes a decline in the number of people involved in recreational boat fishing also provokes the initiation of a new burdensome activity such as hull cleaning (see Fig. 2), this impact should be classified as Moderate for the preferred activity and Major for the burdensome activity, with whether the impact relates to preferred or burdensome activities identified in an additional column. Keeping preferred and burdensome activities separate avoids double counting of impacts when summarising SEICAT data for end-users, as it is expected that the time allocated to bur-

densome activities (performed to mitigate the impact of alien species) will encroach on the time allocated to preferred activities. A critical interpretation of the different meanings of burdens and preferred activities will help to reduce introducing potential biases.

A further point worth clarifying is that there are some cases where impact reports are not relevant to SEICAT assessments, for instance, when alien species create new opportunities (i.e. preferred activities) thereby increasing the capability set of people. In these situations, alien species are considered as beneficial to people which is not relevant under SEICAT. Although measuring and quantifying the positive/beneficial impacts of alien species certainly warrants more attention to improve our understanding of impacts and aid prioritisation (Vimercati et al. 2020), positive impacts are not captured by the SEICAT framework and should not be considered in SEICAT assessments.

Constituents of well-being

The SEICAT framework assigns one or more of the four core constituents of well-being (health; security; social, spiritual and cultural relations; material and immaterial assets) to each reported impact. Each of these constituents is fundamental to the overarching constituent of freedom of choice and action, which is intrinsically linked to the opportunity to be able to pursue and obtain what people value being and doing.

The impacts of alien species to socio-economic dimensions of human well-being and livelihood are highly context dependent since people live in different environmental, socio-political and economic settings but also because individuals can have different motivations for performing the same activity. Linking constituents of well-being to each impact can help highlight these differences, providing different contexts in which impacts are occurring. For example, the effects of an alien pest species that causes significant damage to crops (leading to a reduction in agricultural activities) may result in different consequences for people that farm for subsistence versus those that commercially farm. It may be that for the commercial farmer, loss of income due to crop failure best links to material and immaterial assets whereas for the subsistence farmer, this impact may also link to health in that crop failure leads to a deficiency in obtaining adequate nourishment. This example also demonstrates how constituents of well-being for peoples' impacts are not mutually exclusive. The crops of the subsistence farmer are still a material asset and the activity of farming is often related to social and cultural relations via traditional practices that can be negatively impacted when disrupted by alien pest species.

How impacts relate to constituents of well-being is sometimes clearly stated in an impact report. For example, the invasion of the alien tree *Acacia dealbata* in rural villages of Eastern Cape, South Africa, has induced fear of attack among women who collect firewood due to the trees providing patches for criminals to conceal themselves (Ngorima and Shackleton 2019). Here, the constituent of well-being being affected can directly be discerned as safety. However, oftentimes assessors will have to infer which constituent(s) of well-being are most appropriate for an impact. To provide better context, thus facilitating more meaningful interpretations of SEICAT data, assessors may want to identify where constituents are inferred versus when they are more clearly indicated in the text.

The hierarchical nature of activities – at what level should an activity be assessed?

The human activities that are affected by alien species can be defined and reported at different levels of specificity. This is of great importance for assessors to recognise and understand given the implication for scoring impacts. Activity specificity represents a notable challenge in ensuring that the SEICAT framework standardises impacts in a manner that allows meaningful comparisons because depending on the specificity at which an activity is assessed, the appropriate impact score can be markedly different. Much of an assessor's ability to assign an impact score will depend on the specificity and context under which an impact is reported. Here, issues arise because if activities are too specific and no broader context is available, impacts will not be consistently scored.

To illustrate this point, take a hypothetical example of an impact report that details a complete cessation of swimming in a lake because of an alien species (see Fig. 3A, B). For the purpose of the example, we will assume there are no other lakes in reasonable proximity, meaning people cannot swim elsewhere. If the focal activity for an assessment is considered as "swimming", the most appropriate impact score would be Major or Massive depending on reversibility (see Table 1). However, it is unlikely that swimming is the only activity performed in or on the lake and it could be that whilst all activities where people are fully, or partially, submerged in water have to be abandoned because of the alien species, other activities, such as kayaking and sailing, are carried out as usual (and thus for these specific activities the impact score would be Minimal Concern). It could be that an impact report rather notes a reduction in "water sports" as opposed to more specific water-based activities. The activity water sports would in actuality consist of several activities that are differentially affected by the alien species, such as swimming and sailing (swimming has to be abandoned but sailing can continue per usual), with no further specificity about individual activities. In this case, if the focal activity for an assessment is considered as "water sports", as fewer people participate (all swimmers abandoned swimming) the most appropriate impact score would be Moderate (see Table 1).

To potentially overcome this issue, Bacher et al. (2018) suggest to aggregate activities at the largest activity that could possibly be affected as a whole – thus, for the example above, the activity "water sports" would be scored. This does require knowledge about the alien species and the nature of its impacts that may not necessarily be contained within impact reports. Arguably, determining what constitutes the largest activity that could be affected is not straightforward and relies on assessors using subjective judgement which introduces a potential form of bias (see Probert et al. 2020) that can reduce the standardisation of impacts across taxa. Further, assessors aggregating impacts this way may unnecessarily lose important details and context that are of use to SEICAT data end-users. For these reasons, we suggest assessors acknowledge the hierarchical nature of activities and include different levels of activity specificity when possible (Fig. 3). Taking this approach means that assessors should score at the level the impact is reported but also consider how this can fit into a hierarchy of activities, particularly in context of the entire assessment. This is because in many cases, similar impacts will be reported for (functionally) similar alien taxa as they often affect people

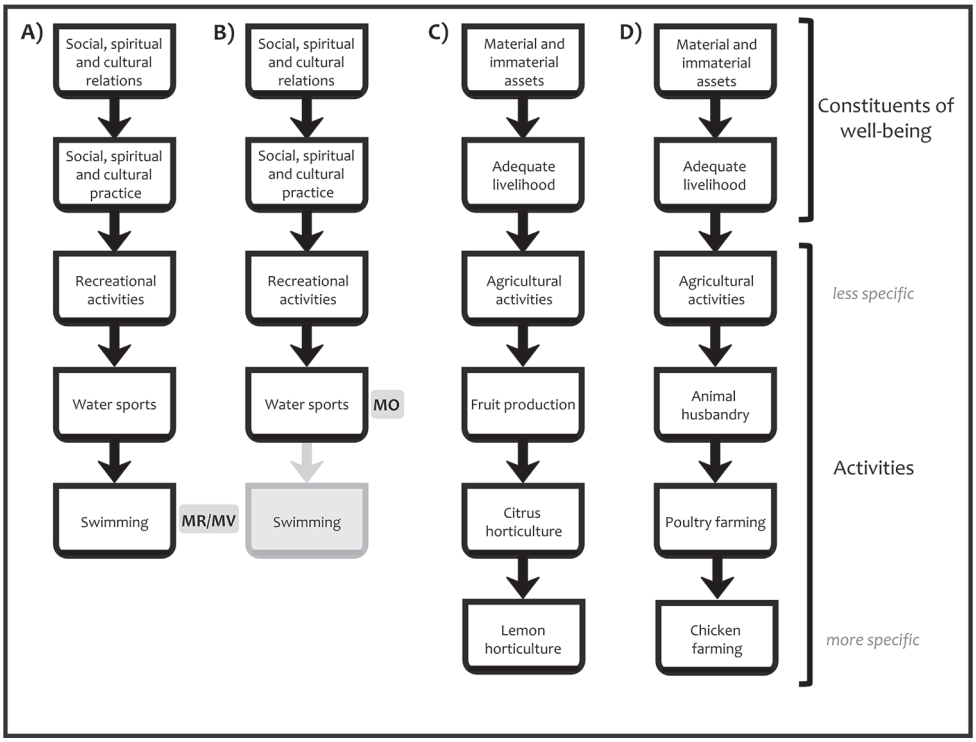

Figure 3. Schematic demonstrating how the different constituents of well-being (under SEICAT, material and immaterial assets; subcategory adequate livelihood) can link to activities that can be defined hierarchically. In the examples **A** and **B** an alien species renders a lake unsuitable for any activity where people are submerged in water (e.g. because the alien species has toxic or skin irritating properties). For **A** the lowest activity being scored is "swimming" and a score or Major/Massive (MR/MV) is assigned as all people abandon this activity because of the alien. In **B** the same scenario is being assessed but the lowest activity being scored is "water sports". Although all swimmers abandon the activity of swimming, some people continue with other activities on the lake such as kayaking and sailing, thus for the activity "water sports" a score of Moderate (MO) is assigned. This demonstrates how the level, or specificity, at which impacts are reported can result in different impact scores. The ability to be able to assign scores will be based on the level of information that is available to an assessor. In **C** and **D** examples of different levels of activities that may be under the umbrella term "agricultural activities" are shown. It is possible that other higher- or lower-level of specificity of activities could be defined but assessors should consider levels that are most of use for comparisons in their assessments. Future assessments should consider activity specificity when applying impact scores and may benefit from ascribing scores in hierarchical natures as illustrated in this diagram. SEICAT data will be more useful and informative if the relevant levels are considered and included within a single assessment.

through similar ways. For example, invasive aquatic plants tend to smother freshwater ecosystems, meaning activities performed in and on lakes are usually directly affected.

By scoring activities at different specificities, end-users of SEICAT data should be better equipped with the necessary information to standardise impacts based on their needs if these data are incorporated into the assessment spreadsheet (provided as Suppl. material 1). Doing so will allow information at different activity levels to be accounted

for in downstream analyses. Whilst for global comparisons and summaries of impacts, it is likely that the highest impact recorded would be most relevant depending on activity specificity, for local decision-makers and stakeholders, the different levels of activities and their impact scores will likely be more important and provide crucial context.

Defining activity size – who is the community of interest?

One of the core tenets of SEICAT is that the magnitude of an impact is measured by the effect on changes in human activity. In particular, to be able to assign an impact score of Moderate or above, information must be available indicating that the number of people participating in an activity (the definition of "activity size" in Bacher et al. 2018) is reduced because of the alien species. However, understanding the concept of activity size can be ambiguous, particularly in light of the differences in impact reporting and the nature of different activities.

A clearer distinction is required to clarify the concept of activity size to reduce the potential ambiguity that may lead assessors to interpret the same information differently. From a conceptual standpoint, activity size should be considered as all the people in the community of interest participating in an activity *before* the alien species caused impacts. Therefore, to accurately determine changes in activity size we would require information regarding the individual identity of people within the community of interest and their personal response (i.e. change in activity) to the arrival (or perceived impact) of the alien species (Fig. 4).

Using only the total number of people participating in an activity – and how it changes in response to an alien species – without any reference to their individual identity, centres the impacts to the activity rather than to the people affected. This then means that the true impacts of alien species to facets of human well-being are not being captured. For instance, there may be cases whereby some people stop performing an activity completely because of an alien species, but others take up the activity (despite or due to the alien species), resulting in no measurable net reduction in the total number of people that perform the activity (Fig. 4). Scoring this as no change in activity size would ignore the evident impact on those people that stopped their activity in response to the alien. People themselves are thus not replaceable and assessors must bear this in mind when assigning impact scores. Although it is plausible that for some people the presence of an alien species could lead to the uptake of new preferred activities, such beneficial impacts are not of relevance to a SEICAT assessment (see section above on novel preferred activities and Fig. 4).

In practice, this information is often not available within impact reports; people's identity is usually unknown except perhaps in situations where data are derived from questionnaires. However, to account for this uncertainty lower confidence may be assigned where appropriate to indicate that the true impact score could be different from the one reported.

Defining the community of interest – that is the specific group of people whose activities are affected by an alien species – can be of central importance to capture flow-on

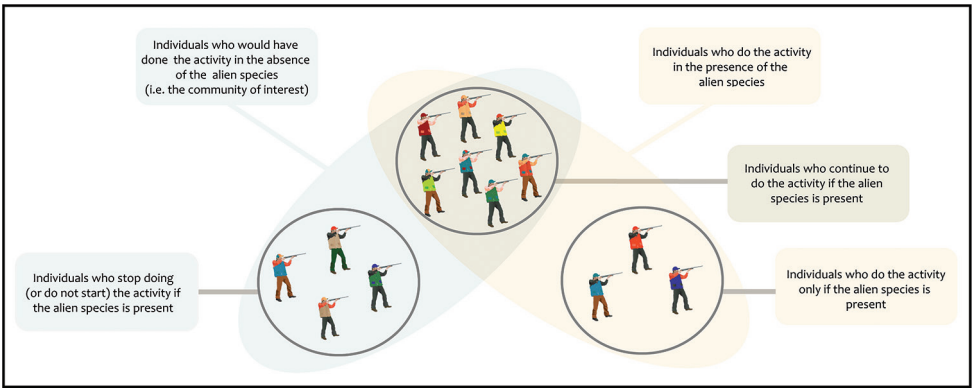

Figure 4. Identity of people performing the activity is important to define activity size. Each hunter here represents a different individual within a group of people that either perform the activity in the presence (yellow oval) or absence (blue oval) of an alien species (e.g. a deer). In this example, the activity is generalised as hunting i.e. it is not defined as hunting a specific species. Note the overlap between the two ovals indicating that the two situations are not mutually exclusive; an individual may perform the activity irrespective of whether the alien species is present or not such that when the alien deer is not present, the individuals continue to hunt albeit a different species. Here, some individual hunters stop hunting once the alien has been introduced (perhaps because it has largely replaced their favourite game species), while other individuals take up hunting because of the alien species. Although in this case more people are hunting in presence of the alien than in its absence, this example would still be considered as a Moderate impact in SEICAT (decrease in the activity size), because people stop the activity because of the alien. The fact that other people pick up the activity due to the alien presence is not considered in SEICAT as only individuals that were participating in the activity prior to the alien species arrival are of interest. Concretely, the community of interest for this example are the 11 individuals in the large grey oval; since four abandon the activity due to the alien, we have evidence that fewer individuals are participating in the activity and therefore can justify the appropriate impact category of Moderate. Symbol obtained from the Integration and Application Network (ian.umces.edu/media-library).

impacts where an alien species' impacts on one group of people subsequently affects other individuals. For example, a reduction in a specific crop caused by an alien pest species can impact both commercial growers, by reducing their income, and consumers that rely on that crop for sustenance. Recognising that growers and consumers represent two distinct communities of interest affected by the same alien species may enable us to better disentangle chain-effects and unravel the complexity of socio-economic impacts.

Understanding the relevant spatial and temporal scales

Assessors should be aware that activities should not be defined in relation to space or time, however, it is important to understand that these two aspects are relevant to how we measure impacts. Understanding the spatial and temporal scales is particularly informative when evaluating the degree of confidence assigned to an impact score.

The spatial scale of an impact measurement

Impact measurements for alien taxa are subject to considerable context-dependency when viewed at different spatial scales (Essl et al. 2017). SEICAT assessors must be able to determine the relevant spatial scale at which an impact score should be assigned. However, this can be challenging given that impact reports will invariably contain different spatial scales and encompass communities of different sizes.

The relevant spatial scale at which impacts should be assessed must consider the 'community of interest'; that is, the group of individuals participating in an activity that *can* be affected by an alien taxon, and are relevant to measuring changes in activity size (see section above). The distinction of *can* is necessary to ensure that assessors are aware that the community of interest may be a subset of people within a surveyed community, i.e. the surveyed community is not necessarily representative of the community of interest. Making this distinction can be difficult, however, given the complexities of human behaviour. For example, if households within a hypothetical town were surveyed to determine if an invasive alien fire ant was affecting their gardening activities it may be reasonable to conclude that the community of interest would comprise only of those households who have the fire ant occurring on their property, and therefore the community of interest directly overlaps with the range of the alien species. However, it is also possible that some individuals beyond the range of the alien species alter their activities out of fear that the fire ant is present (when it is not) or might be in the future.

To illustrate simply why understanding the community of interest is important for impact scoring, take the above scenario, where fire ants affect some households in a suburb, and assume that only people who have the fire ant on their property change their activities. If the town's population was 2000 people but only 30 people lived in properties affected by the fire ant, and all those people had to completely stop gardening due to the infestation, then the level at which we focus the community of interest is important to scoring. If our community of interest is the entire town, the score would be Moderate, whereas if we only include those that have the fire ant present on their property, the score would be Major or Massive depending on whether the fire ant could be controlled and the impact reversed. Being able to discern this, will likely be dependent on the information available in the impact report. Any uncertainty an assessor has regarding whether the impact report accurately reflects what is truly happening can be reflected by lowering confidence.

Assessors should be aware that in some circumstances communities of interest can be situated at great distances from where the focal alien species is established. For example, an alien species affecting water quality of a river or other water body could hypothetically have significant impacts on communities who rely on that water many kilometres downstream.

Assessors should also be aware that within a single impact source (e.g. a scientific publication) impacts of alien species can be reported at different community scales and should be scored as such within an assessment. For example, in Mujingni (2012) the effects of the alien water hyacinth (*Eichhornia crassipes*) were assessed for 16 villages within five regional areas in Cameroon. As the author conducted the surveys at each village and

communicated the results for each village individually, SEICAT results can and should ideally be reported for each village individually. These can be entered as separate observations (rows) in an assessment sheet, facilitating data usability for end-users. However, impact data will not always be reported at the level of individual communities and information is often summarised across surveyed communities (i.e. regions). In these cases, increasing uncertainty as to whether the impacts to the community of interest are appropriately captured in the impact score can be reflected by assigning lower confidence.

It is important to mention that impacts should not be linked to specific localities. Rather, impacts should be linked to the people that comprise the community of interest since it is them performing the activities that are the focus. For instance, if an alien species renders a specific area unsuitable for an activity to be performed, people may be able to compensate for this by performing the activity elsewhere. Take a hypothetical example where an alien algal species invades a local lake (Lake Sykat) – which is a popular location for freshwater scuba diving – causing a significant reduction in water clarity. At this lake, the activity of freshwater scuba diving is completely abandoned as a result of the alien species. Incorrectly linking the activity to a location could then lead an assessor to the incorrect impact score of Major. However, within the local area, there are several other lakes where the alien species is absent, meaning not all people actually abandon the activity. Thus, there may be two potential scenarios here. In scenario one, all people who previously used to dive at Lake Sykat (i.e. our community of interest) now continue to dive at the other lakes. In this case then, the appropriate impact score would be Minor because the activity is still carried out but not in the preferred location so there is an additional degree of difficulty in performing the activity (e.g. it may take longer to get to the alternative lakes and is therefore associated with an additional cost in fuel and time, or other lakes are not as diverse or beautiful for diving). In scenario two, some people who previously used to dive at Lake Sykat continue to do so but some decide to stop diving altogether, in which case the impact score would be a Moderate.

The temporal scale of an impact measurement

Temporal variability represents a major challenge in obtaining representative measurements that accurately describe the impacts of alien species (Sapsford et al. 2020). If a measurement is taken over a time period that does not capture the true impact magnitude of an alien species, impacts can be either over- or under-estimated. Temporal effects impacting humans in terms of both beings and doings most often persist because of the life-history and phenological traits of alien species that are associated with time. As such, impacts are not necessarily constant. For example, this is seen when human health is impacted at a specific time of year because of pollen allergies caused by alien weeds (Bernard-Verdier et al. 2022) or due to increased abundances of species that can be of medical concern, such as insects with venomous or urticant properties like vespid wasp species or oak processionary moth (McGain et al. 2000; Battisti el al. 2017). Thus, maximum impacts will not be well captured if measuring the effects of alien species to human well-being does not coincide with the relevant time during which the impact occurs, and this should be captured in the confidence score.

To quantify impacts related to doings (see earlier section), information on activities performed by the affected communities needs to be available in order for assessors to evaluate how these activities have changed. Ideally, this would include baseline knowledge on how frequently the activity was conducted by individuals prior to the arrival of the alien species (Fig. 5). Very few activities are carried out continuously and activity patterns differ among individuals and activities. Some may be conducted regularly, for instance, on a daily basis, such as walking to work, whereas other activities may occur more ephemerally or erratically over larger time periods (e.g. monthly or annually) and not necessarily at regular intervals. Likewise, certain activities will only take place during specific seasons (e.g. recreational activities like skiing, agricultural activities). In order to determine if some individuals have abandoned a particular activity (i.e. a Moderate impact) or whether an entire community of interest has abandoned the activity (i.e. a Major or Massive impact) some knowledge about activity patterns is required.

Activity patterns can differ in terms of the frequency, duration and periodicity (Fig. 6). The frequency and duration relate to how often an activity is carried out, and for how long, respectively, whereas the periodicity refers to the trends or reoccurring

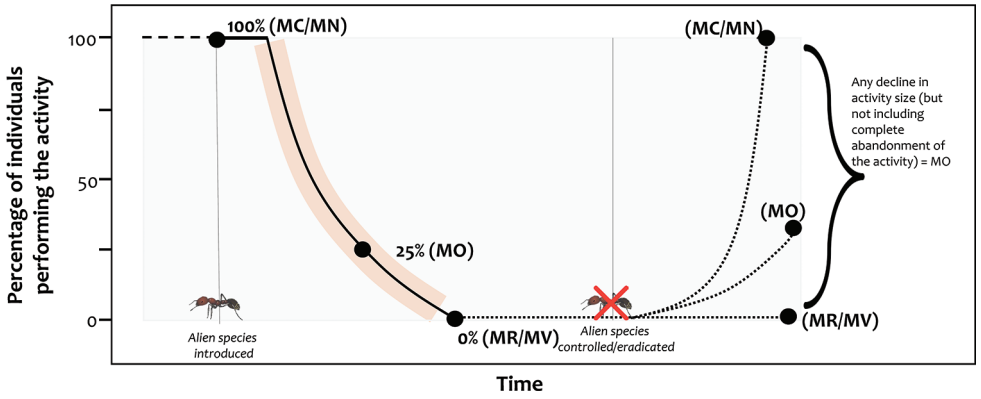

Figure 5. Impact magnitude can change over time. Conceptual drawing illustrates how the impact category depends on the percentage of people in the community of interest that continue to perform an activity in relation to the arrival, and subsequent management, of an alien across time. To accurately measure impact in terms of the effects on human activities, we must know the number (and ideally, the individual identity, see also Fig. 4) of people in our community of interest that are performing the activity prior to the alien being introduced. When all people are still performing the activity (i.e. 100% of people that would perform the activity in the absence of the alien still perform the activity in the presence of the alien), the impact score is restricted to either Minimal Concern (MC) or Minor (MN). However, any decline observed in the activity size – that is the number of people performing an activity – is assigned a Moderate (MO) (demonstrated by brackets and shaded orange area of line) until the point at which no people continue with the activity (Major/Massive; MR/MV). Impacts are subject to temporal variation due to life-history and phenological traits of alien species and dynamics of human activities. Taking snapshots at certain points (represented by large black dots) will lead to certain impact scores based on SEICAT criteria. In this figure, how the impact score could theoretically change over time if management of the alien species population commences is demonstrated with the dotted lines. Symbol obtained from the Integration and Application Network (ian.umces.edu/media-library).

variation in when an activity is performed and is often thought of as seasons or cycles. Understanding periodicity is therefore important to understand if an activity has been abandoned. However, measuring impacts of alien species is often restricted to sampling within short, discrete temporal periods, often referred to as 'snapshots' (Crystal-Ornelas and Lockwood 2020), due to logistic restrictions limiting the feasibility of longer-term data collection. Understanding whether such snapshots accurately characterise the true impact of an alien species will depend on the time interval and the timing of the onset of measurements. If the timescales used to measure potential changes in activity are too short, it may give the assessor the impression that activities have been abandoned by some people when in actuality people are just performing them less frequently (which would be a Minor impact category) (Fig. 5). Take, for example, a situation where an alien jellyfish that blooms over a period of a few weeks leads to the majority of people giving up activities in the water during that time, but the activities resume after the jellyfish disappear again. This impact should be scored as Minor as the activity resumes across the recorded time scale despite the fact that there was a period of time in which all members of the community of interest completely abandoned their water activities.

Also relevant to activity patterns are where changes to the frequency and/or duration of activities occur as a result of an alien species. Whereas some individuals may perform an activity for a shorter duration each time because of the alien, others may have to spend a longer time performing the activity because of the alien as it makes an activity more arduous to obtain the same previous result. For instance, people may spend

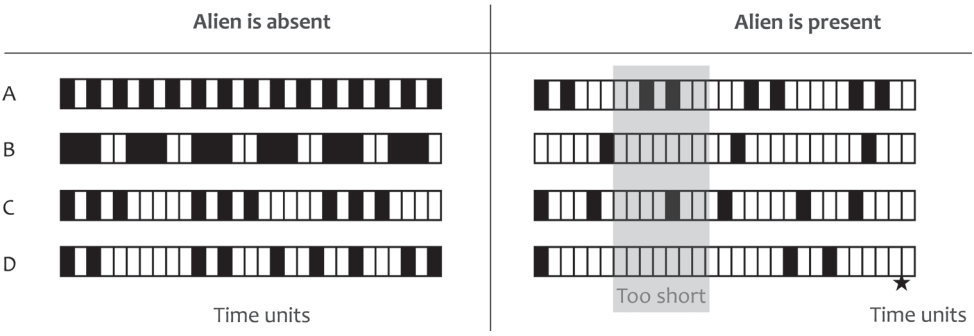

Figure 6. Examples of the frequency in which four people (**A–D**) participate in an activity across time, where black cells indicate the activity being performed at that point in time. The individual activity patterns are seen on the left panel when the alien species is absent, and on the right panel when the alien species is present. If the timescale over which the change in activity is evaluated is too short, the true impact may not be accurately identified. In this example, all people abandon the activity at the point indicated by the star (although prior to this their duration and frequency of performing the activity may have changed as a result of the alien), yet the measurement is made in the shaded area. Note that it is unlikely that people will change the activity patterns immediately in response to the arrival of an alien species as the abundance will be low and therefore impacts will not be pronounced. Here, because the timescale in which the change to activity was measured is too short, the relevancy to activity patterns of people is not realised. Based on the timescale the measurement was made, it may be assumed that individuals **A** and **C** continue the activity whilst individuals **B** and **D** have stopped it entirely.

less time participating in activities outdoors because of alien mosquito or wasp species, or anglers may have to spend more time fishing in order to catch the same number of fish they had previously, as an alien species is causing negative effects to the fish population. Impact reports detailing such changes but with no indication that individuals stop performing the activity altogether should always be reported as Minor (Table 1, Fig. 2).

Terms used to describe impact categories

The current terms used to describe impact categories are intended to reflect the increasing severity of impact that alien species have on human well-being. Yet the usage of these terms could be problematic as they may be interpreted differently by different people, therefore introducing an additional source of subjective judgement in the scoring process (see Probert et al. 2020). For example, even impacts classified as "Minimal Concern" or "Minor" may be sufficiently large to apply management, although both terms may suggest they are not significant enough to warrant action. Moreover, there is concern that the terms could become misused and misrepresented to suit political agendas in biodiversity management and decision-making. Arguments in support or opposition of species management should not be based on SEICAT scoring in isolation of the critical contexts in which impacts occur.

As such, the usage of more neutral terms for each impact category could help address the issue of terms being used improperly. One option would be to rename categories numerically, where the current descriptors of Minimal Concern (MC), Minor (MN), Moderate (MO), Major (MR) and Massive (MV) are replaced with Category 1 (C1), Category 2 (C2), Category 3 (C3), Category 4a (C4a) and Category 4b (C4b), respectively. The decision to assign the two highest impact scores of Major and Massive with Category 4a and Category 4b reflect the situation where both categories represent when an entire activity has been abandoned, with the only difference being that Massive is (hypothetically) irreversible, wherein even if the alien species were removed, people would not commence participating in the activity again. Whilst such categories still imply an ordinal scale of impact, the use of more neutral terminology reduces the potential of more value-laden categories being politicised in management decisions and may be less-prone to eliciting subjective judgement during the assessment process. Compared to other frameworks that adopt these categories for scoring biodiversity impacts (IUCN 2020; Vimercati et al. 2022) this is of particular importance given that activities differ vastly in their importance for human well-being and the ethical implications of misusing the qualitative terminology.

Generating detailed and transparent SEICAT assessments

A primary recommendation for future assessments is to adopt an open-data policy. This is required to promote transparency and to generate broadly accessible and useful information. At a minimum, research using the SEICAT framework should ensure

data records are available upon publication (i.e. not only the maximum score for each species) and that each scored impact is accompanied with the source reference, impact and confidence scores, and quotation(s) supporting the assessment. However, there is additional information that may be available for each impact report that if included, would generate even more comprehensive and useful impact assessments.

The new additional information recommended as columns in the SEICAT spreadsheet include: type of impact report (e.g. survey, observation), spatial scale (e.g. national, regional), and clearly separates the impacts to preferred activities and those impacts that lead to compensatory or burdensome activities (see Suppl. material 1). Assessors are also encouraged to detail in a notes section any additional information that is valuable when available, such as whether impact information is inferred, or whether the impact is subject to seasonal variation. For observations that are not relevant to SEICAT (e.g. a report of a positive impact), an additional column, non-scorable justification, is included. These additional variables are intended to make SEICAT assessment data more useful and user-friendly.

To demonstrate the proposed refinements and recommendations, we use SEICAT assessments (see Suppl. material 1: worksheet C) for a range of different alien taxa, selecting examples that affect different constituents of human well-being at different global localities. Using these data, we provide an exemplary data collection template for future SEICAT assessors to use. The increased level of detail that we suggest assessors record when evaluating the impact of an alien species is intended to provide more context for end-users of SEICAT assessments and remove the necessity to re-examine impact records to make more meaningful intra- and inter-specific comparisons. It is important to understand that our suggestions for specific improvements should not be perceived as the endpoint for assessments. Future improvements to the SEICAT framework and its application are likely necessary to further advance our ability to capture and compare socio-economic impacts under different invasion scenarios.

Future directions: structuring surveys to capture SEICAT data

Data availability is one of the limiting factors to applying SEICAT across different taxonomic groups. For instance, in a global analysis of alien bird species, only 14% of birds assessed yielded impact reports (Evans et al. 2020). Similarly, for one of the best studied groups of alien trees, Australian acacias, only 19 impact records were found for SEICAT (Kumschick and Jansen 2023). Impacts of most alien species are generally not well understood, although there is a growing body of literature for some environmental and economic contexts (Gallardo et al. 2015; David et al. 2017; Diagne et al. 2021; Dueñas et al. 2021). One general exception may be alien taxa of medical concern, such as species with toxic or venomous properties or vectors of disease, whose impacts tend to be documented in the medical literature (e.g. see Galanidi et al. 2018). Other recorded impacts to various facets of human well-being can be found (Shackleton et al. 2019), although environmental impacts in general tend to be more frequently reported (Measey et al. 2020; Allmert et al. 2022). Furthermore, language barriers reduce the accessibility of impact data for alien species (Angulo et al. 2021) and thus

future SEICAT assessments can benefit greatly from targeted literature searches in the local language where alien species are likely to be affecting communities. For instance, in their assessment of invasive fishes in the Mediterranean, Galanidi et al. (2018) obtained 17% of their impact scores from non-English sources. To overcome some of the challenges associated with data availability, we posit that a key area for future research lies in generating new socio-economic impact data.

Unlike ecological impact studies, which generally require field observation and experiments to effectively quantify the effects of alien species, understanding the socio-economic impacts of alien species can be facilitated through questionnaires and interviews with people. These tools allow researchers to directly ask (potentially) affected people about their experiences and perceptions. Questionnaires can be developed with SEICAT criteria in mind meaning that true impacts based on SEICAT's semi-quantitative scale can be effectively captured with relatively low uncertainty if robust survey methods are adopted. Surveys may allow the rapid-generation of data for alien species that may help expedite decision-making processes, which is especially crucial given another major source of uncertainty stems from temporal biases in alien species impact reporting, where there are distinct lags between the alien species establishment, impacts, and impact reporting (Pyšek et al. 2008; Hulme et al. 2013). Future research should be invested into what are the most suitable methods and study designs to capture different social contexts and impact types.

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Supplementary material 1

SEICAT assessment supplementary material

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Data type: xlsx

Explanation note: Template reporting for SEICAT assessments.

Link: https://doi.org/10.3897/neobiota.89.109911.suppl1