Supporting Information 1 to "Socio-economic impact classification of alien taxa (SEICAT)": Details of SEICAT application

Selection of activities

Not all activities are equally valued by people. This raises the questions how to select certain activities for analysis and how to weight activities. Following ideal theories of justice, one could argue that each and every activity is relevant and should count (Vallentyne 2005). However, considerations of justice call for discrimination between morally relevant and morally irrelevant activities (Pierik & Robeyns 2007). There is no universal solution how to do this, and different answers can be appropriate in different situations, depending on feasibility, data availability, practical relevance, and even parsimony. Thus, different activities are differently valued in different contexts. A first approach, often used in the socio-economic literature (Robeyns 2011), could be to discriminate activities that are essential to escape poverty. Poverty is understood as including not only deprivation of materially based well-being but rather a deprivation of opportunities (World Bank 2001). Alternatively, one might want to consider weighting activities that sustain human life higher than others. For example, Maslow's pyramid of needs (Maslow 1954) gives a hierarchy for levels of human needs ((i) physiological needs, (ii) safety needs, (iii) belongingness and love, (iv) esteem, (v) self-actualization) according to which each basal level needs to be met before individuals desire higher level needs. However, currently there is neither a generally accepted list of activities that contribute to avoid poverty nor a theoretically well-grounded method for weighting or aggregating (Robeyns 2011). A practical solution regarding the assessment of the importance of specific activities for a region could be to engage stakeholders. Activities could then be ranked according to their importance in a given region, e.g. based on the number of people participating in a specific activity (Pejchar & Mooney 2009).

For the assessment, activities need to be aggregated into categories that are meaningful in practice. Some activities might appear to be too specific and the number of people participating too small to

be of practical relevance for evaluating alien taxa impacts while others are too large to be impacted in their entirety by an alien taxon. There are no precise guidelines how to aggregate activities meaningfully. A relatively straightforward possibility that we applied for assessing amphibian impacts is to aggregate impacts according to the nature of the impact of an alien taxon such that all people in the focal region participating in the activity can be considered to be potentially affected. For example, for a pest that affects all cereals, specific activities (wheat, corn, rye farming) should be aggregated into the largest activity potentially affected as a whole. Thus, this pest should be assessed as affecting cereal farming but probably not all agricultural activities; farmers who do not cultivate cereals will probably not be affected by the alien taxon.

If this approach for aggregating activities leads to obvious imbalances in the importance of different activities for human well-being, then different weights could be assigned to these activities. These weights could be based on democratic assessments of the perceived importance of activities (Kumschick et al. 2012, Robeyns 2005b). In any case, weighting should be done with care, as minority activities could be disfavoured. In the absence of a well-justified weighting scheme and if there are no obvious imbalances without weighting activities, we use as a default for SEICAT that all activities affected by alien taxa are equal.

The impact of alien taxa that do not affect *specific* activities, but rather impede activities generally (e.g. by affecting human health) should be evaluated as impacting multiple activities. A pragmatic approach here is to not assess all possible activities (which can be a tedious task) but to limit the assessment to those activities that are particularly affected and are particularly important to human well-being. In the case when the impacts of an alien taxon result in the death of at least one person, the impacts are automatically classified as at least MO (fewer people participating in activities), but can be higher if they lead to activities being given up entirely in a region (not necessarily by more deaths, but e.g. by stopping activities to avoid the consequences of the impact of the alien). However, if the consequences of the impacts can be easily avoided and no further changes in human activities are observed, the impacts should be classified as MO even though they led to human

deaths. For example, there are cases where people died by eating certain toxic aliens (plants, fish, toads etc.). While such cases are tragic for the people involved, they can often easily be avoided by not eating the alien. This is comparable to not eating toxic native berries or mushrooms, which are also not causes of major concern for human well-being in most regions, although their consumption can have severe consequences. By contrast, impacts that cannot be directly controlled, e.g. exposure to allergenic pollen produced by an alien plant can have much more far-reaching impacts on human well-being and can change activities of larger parts of societies. Consequently, such less-controllable impacts will probably be classified as MR or MV more often.

Alien taxa can have indirect impacts on human well-being, which might even exceed the direct impacts in magnitude, and their impacts can occur in regions other than the ones invaded by the alien taxon. This is for instance the case with some alien pathogens that can lead to the local breakdown of production, education and health systems due to peoples' fear of infection and the resulting stop in participating in social activities, as happened for example during the resurgence of Dengue fever in South-America at the end of the 20th century (Gubler 2002).

Lastly, it should be mentioned that, in practice, it can sometimes be difficult to unambiguously attribute a change in activities to a particular alien taxon if the causal relations are not well known (passenger-driver problem; e.g. MacDougall & Turkington 2005). However, this phenomenon is not specific to socio-economic impact, or the system described here, but applies generally.

Spatial and temporal scale of impact assessment

The spatial and temporal scale over which impacts are assessed can influence their perceived magnitude. This is particularly important for deciding whether activities disappear locally (criteria MR and MV). This problem applies also to environmental impacts and we propose addressing this in a similar way as suggested for EICAT (Hawkins et al. 2015). Often, the focal region (e.g. country, continent) is much larger than the spatial scale over which the alien taxon exerts its impacts and

assessing impacts at very large scales might underestimate their severity locally. By contrast, at very small spatial and temporal scales, a few individuals temporarily giving up an activity might lead to an overestimation of the impact when extrapolating to larger scales. It is therefore important that impacts of alien taxa are assessed at appropriate spatial and temporal scales, taking into account the habitats in which the alien taxon occurs and the typical spatial and temporal scales at which social communities in the region of interest can be characterised (e.g. a human settlement).

Small scale impacts should still be reported alongside the final classification to identify impacts that may be a cause for greater concern on larger scales in the future.

Dealing with limited data availability

SEICAT classification is possible in the absence of knowledge of a taxon's full impacts, as long as some impacts are reported. For taxa with well-established and widespread alien populations, there is likely to have been sufficient opportunity to gather data pertaining to the impacts of the alien taxa, so it is more likely that adequate data will be available to categorise such alien taxa. However for taxa with short alien population residence times, or invasions restricted to small areas, data evidencing socio-economic impacts may be limited, or restricted to impacts in one particular area. In some cases, there may be insufficient evidence to categorise a taxon with respect to its impacts, or the residence time may be too short for impacts to have become apparent. In these cases, information about impacts may be inferred from indirect observations, such as circumstantial evidence of impacts, or outcomes from mathematical models. However, inferred data are likely to provide a much lower level of confidence in the assessment (see next paragraph). Taxa assigned to one of the impact categories based on inferred data should be re-assessed when better observational or experimental data become available, to improve the confidence rating of the assessment. If there is inadequate information to classify a taxon with respect to its impact, the taxon should be listed as Data Deficient (DD).

Impacts of a taxon (both environmental and socio-economic) might not necessarily be related to its alien status and thus impacts can also arise in the native region. However, impacts are context dependent, thus it might not be easy to extrapolate them into new regions. This makes impacts from the native region not be the best predictors of impacts in the alien region. SEICAT can certainly be used to compare impact magnitudes between invaded and native ranges (for species where information is available on both), but we do not recommend using impacts from native ranges for classification of alien taxa because of the inherent contradiction. However, impacts from native ranges might still be reported, particularly if they deviate from those in the alien range or in case no other impacts are known.

Confidence

Confidence needs to be considered when classifying taxa in terms of the magnitude of their impacts (Leung et al. 2012; Kumschick et al. 2015a), and it is crucial to communicate this to policy makers and managers. We suggest considering confidence by following the procedure outlined for EICAT assessments (Blackburn et al. 2014; Hawkins et al. 2015) by categorising it into three levels—high, medium, and low confidence—based on approaches used by the Intergovernmental Panel on Climate Change (IPCC) (Table S2; Mastrandrea et al. 2010). The confidence score should capture the reliability of impact descriptions, i.e. how confident is the assessor that the description captures the "true" impact of the alien. The measure of relevance for impact descriptions (level of confidence) depends on the evidence observed rather than on the source (e.g. whether it was published in a peer-reviewed journal or data reported by a person during an interview). Even a fully-scientific, quantitative experimental study in a peer-reviewed journal does not necessarily describe impacts relevant for SEICAT classification. For example, studies on transmission of diseases by alien species often quantitatively describe the prevalence of human pathogens in aliens but rarely the transmission rates to humans or the resulting health impacts or changes in their activities. Thus, although they appear in peer-reviewed journals, the information given in them does not describe

sufficiently how people are affected in their well-being; impact classification would therefore be assigned a low confidence. By contrast, if people in an interview report that e.g. all the fisherman of their village had to give up their job due to an alien taxon and migrated to the cities, this would be directly relevant, transparent and pertinent information for SEICAT classification and would be assigned a high confidence.

For the classification, and in accordance with EICAT (Hawkins et al. 2015), we currently recommend to use the highest reported (current) impact regardless of its certainty. This follows the precautionary approach of the Rio Declaration and the Convention on Biological Diversity. A low confidence score on a high impact does not mean that a lower impact is more likely. Therefore, a reported high impact with low confidence should not be down-weighted in favour of a lower impact with higher confidence. However, an estimate of the degree of uncertainty is attached to all classifications, so that the degree of confidence in every classification is explicitly made clear.

Impact and management

People have various options to avoid, mitigate or compensate for impacts of alien species on their well-being. For example, in affluent regions many agricultural pest species are well controlled but would probably be devastating to crop production, and human well-being, if the current control measures ceased, or were devastating before such measures were available. In such cases it is debatable whether classification of such alien taxa as having major or massive impacts is justified because the alien species concerned do not currently have a severe impact on human well-being. This might be different for the same pest species in regions where control methods are not readily available or come at relatively high costs compared to the resources available to local people. Impacts of the same species can therefore vary across regions, depending on the inherent vulnerability of the region and the possibilities for management. For example, the silverleaf whitefly (*Bemisia tabaci*) is a globally widespread alien species that both directly consumes crops and acts as

a vector of crop diseases. An outbreak of whitefly in Uganda in the late 1980s was responsible for the rapid spread of the virus that causes Cassava Mosaic Disease (University of Greenwich 2004). This drastically reduced production of the staple cassava crop, leading to widespread food shortages and an estimated 3,000 human deaths. Economic hardships arising from crop losses forced villages and families to break apart as individuals looked for food and work. In a contrasting example, whitefly also became a serious agricultural pest in the United States during the late 1980s. A rapid response from government agencies and the private sector, however, saw the development and distribution of control technologies, including commercial pesticides. Although the impacts of this invader in the US were and continue to be large, there have been no recorded human deaths, and the impacts have not been broadly felt (Oliveira et al. 2001). We therefore generally recommend that impacts are best represented considering the locally applied compensation measures. In this case, *B. tabaci* in Uganda would be classified as MR or MV (depending on whether or not the impact to crops by the virus would be reversible after removal of the whitefly as vector) while in the US the species would be classified as MN (in the absence of reports of farmers giving up their activities due to the whitefly). At the global scale, *B. tabaci* would be classified as MR or MV (its highest impact anywhere) to indicate its potential risk.

Assessment at different spatial scales and across taxa

Assessment at different spatial scales and across taxa in SEICAT follows the principles outlined in Hawkins et al. (2015) for EICAT. Consequently, SEICAT classification can be applied across taxa, so that different taxa can be compared using a common currency in terms of their socio-economic impact. SEICAT can also be applied to impacts assessed at a range of spatial scales, from global to national or regional. As most taxa that are alien and have impacts somewhere have not been introduced to many of the locations where they could potentially thrive and have impacts, the vast majority of assessments will use ‘focal region’ data to generate a global level species assessment. This reflects the precautionary principle for alien impacts, which is important as there is evidence

that many alien taxa can have strong impacts in at least part of their invaded range, if distributed sufficiently widely. However, impact listings are likely to be context dependent: an alien impact that is observed in one area of the introduced range may not occur elsewhere, or may not be as important elsewhere. Therefore national or regional level assessments, which only take into account impacts which have occurred within a particular country or region, may differ markedly from global level assessments which are based on the highest level of impact recorded anywhere in the alien range of the taxon being assessed. Non-global assessments should therefore be clearly identified as such. They may still be based on data from focal regions outside the particular country or region of interest, however, in these cases the area(s) from which data on impacts are considered for these assessments should be clearly stated.

Additional References

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Table S1. Detailed SEICAT scores for alien amphibians

(please see separate file “SI2 Table S1 SEICAT Application to Amphibians.xlsx”)

Table S2. Guidance regarding the use of the confidence rating (modified from Blackburn et al. 2014; Hawkins et al. 2015).

Confidence level	Examples
High (approx. 90% chance of assessment being correct)	There is direct relevant observational evidence to support the assessment (including causality); *and* Impacts are recorded at the typical spatial scale over which social communities in the region of interest can be characterised; *and* There are reliable/good quality data sources on impacts of the taxa; *and* The interpretation of data/information is straightforward; *and* Data/information are not controversial or contradictory.
Medium (approx. 65-75% chance of assessment being correct)	There is some direct observational evidence to support the assessment, but some information is inferred; *and/or* Impacts are recorded at a spatial scale which may not be relevant to the scale over which social communities in the region of interest can be characterised, but rescaling of the data to relevant scales is considered reliable, or to embrace little uncertainty; *and/or* The interpretation of the data is to some extent ambiguous or contradictory.
Low (approx. 35% chance of assessment being correct)	There is no direct observational evidence to support the assessment, e.g. only inferred data have been used as supporting evidence; *and/or* Impacts are recorded at a spatial scale which is unlikely to be relevant to the scale over which social communities in the region of interest can be characterised, and rescaling of the data to relevant scales is considered unreliable or to embrace significant uncertainties. *and/or* Evidence is poor and difficult to interpret, e.g. because it is strongly ambiguous. *and/or* The information sources are considered to be of low quality or contain information that is unreliable.