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The generic impact scoring system (GISS): a standardized tool to quantify the impacts of alien species

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Abstract Alien species can exert negative environmental and socio-economic impacts. Therefore, administrations from different sectors are trying to prevent further introductions, stop the spread of established species, and apply or develop programs to mitigate their impact, to contain the most harmful species, or to eradicate them if possible. Often it is not clear which of the numerous alien species are most important in terms of damage, and therefore, impact scoring systems have been developed to allow a comparison and thus prioritization of species. Here, we present the generic impact scoring system (GISS), which relies on published evidence of environmental and socio-economic impact of alien species. We developed a system of 12 impact categories, for environmental and socio-economic impact, comprising all kinds of impacts that an alien species may exert. In each category, the intensity of impact is quantified by a six-level scale ranging from 0 (no impact detectable) to 5 (the highest impact possible). Such an approach, where impacts are grouped based on mechanisms for environmental impacts and receiving sectors for socio-economy, allows for cross-taxa comparisons and prioritization of the most damaging species. The GISS is simple and transparent, can be conducted with limited funds, and can be applied to a large number of alien species across taxa and environments. Meanwhile, the system was applied to 349 alien animal and plant species. In a comparison with 22 other impact assessment methods, the combination of environmental and socio-economic impact, as well as the possibility of weighting and

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ranking of the scoring results make GISS the most broadly applicable system.

Keywords Environmental impact · Socio-economic impact · Biological invasion · Management prioritization · Policy

Introduction

One of the main components of global change is the intentional and unintentional translocation of organisms across biogeographical boundaries. In their novel habitat, some of these alien species can cause considerable damage. The impact of alien species is considered to be the second most important threat to biological diversity, after habitat destruction (Millenium Ecosystem Assessment 2005). Many scientists, environmental managers, conservationists, and policy makers see such harmful alien species as unwanted additions to the environment (Simberloff 2005; Simberloff et al. 2013; Richardson and Ricciardi 2013). Therefore, administrations at different levels and sectors attempt to prevent further introductions, stop the spread of established species, and develop eradication programs. The concern regarding biological invasions is of such a global nature that the European Union has recently developed a new legislation on invasive species (EU Regulation 2014) to establish a common, homogenous response to their threats on biodiversity and ecosystem services to be applicable to all Member States. The EU Regulation considers the inclusion of an open list of "Invasive Alien Species of Union concern" (Roy et al. 2015). Among other criteria (such as likelihood of an invasion), it is compulsory to evaluate the impact of each species on the list through a standardized protocol (Genovesi et al. 2015).

Often, it is not clear which of the numerous alien species in a given area are the most damaging, and therefore where to start an action with limited funds at hand. Evidence has accumulated that the most invasive species (following Blackburn et al. 2011) are not necessarily the ones that have the greatest impacts (Ricciardi and Cohen 2007; Ricciardi et al. 2013; Horáčková et al. 2014), and often, action is needed for locally abundant species considered to be casual at the regional scale (Andreu et al. 2009). This is further complicated by the fact that impacts are context dependent (Pyšek et al. 2012; Hulme et al. 2013, Simberloff et al. 2013; Kumschick et al. 2015a; Vilà et al. 2015), which calls for standardized tools to quantify and compare impacts among species, taxonomic groups, sites, and regions. Such a tool can support the rational use of resources regarding management actions. However, the diversity of metrics for variables of impacts usually considered makes it impossible to directly compare impacts across taxa (Vilà et al. 2010; but see Blackburn et al. 2014; Kumschick et al. 2015b). Therefore, various impact scoring systems have been developed to integrate the variability of the empirical evidence on impacts in a comparable way (e.g., Leung et al. 2012 and references mentioned therein).

The generic impact scoring system presented here (hereafter called the GISS) was first developed and applied to alien mammals in Europe (Nentwig et al. 2010). When applying it to alien birds (Kumschick and Nentwig 2010), two impact categories were added (Table 1). Subsequent applications of the GISS to alien fish (van der Veer and Nentwig 2014), terrestrial (Vaes-Petignat and Nentwig 2014) and aquatic invertebrates (Laverty et al. 2015), and plants (Novoa et al. 2016; Marková et al. unpublished) showed, step by step, that each additional higher taxon required further modification of the GISS to include the specific features of that particular taxon while keeping it generic at the same time. The development of the GISS and its specific applications are outlined in Table 1. During this process, we have established an impact assessment method which addresses all kinds of impacts that an alien species may exert and can be applied to all taxa and environments. Despite its increasing usage, the rationale of the advanced GISS version has never been summarized and its methodology thoroughly discussed. Here, we describe in detail its structure, demonstrate its applicability, and compare main features to other impact assessment protocols.

The generic impact scoring system

Impact categories

The 12 impact categories of the GISS encompass six categories for environmental impact and six categories for socio-economic impact. Detailed descriptions of these categories are the core part of the GISS. Ten categories were first published by Nentwig et al. (2010). Kumschick and Nentwig (2010) added two more categories, and in subsequent publications, these

Table 1 Applications and development of the generic impact scoring system (GISS)

Year	Taxon	Region	Application/theory	Major development/criticism	Reference
2010	Mammals	Europe	Application	Original development of two main impact groups, environmental and economic, with 5 categories each; first application for mammals	Nentwig et al. (2010)
2010	Birds	Europe	Application	First application for birds; addition of one category per impact group; comparison between two taxa (mammals and birds)	Kumschick and Nentwig (2010)
2011	Birds	Europe	Application	Re-assessment of Kumschick and Nentwig (2010), criticism of consistency between assessors	Strubbe et al. (2011)
2011	Mammals and birds	Europe and native ranges	Application	Applied to native range; used to compare impact in native and invaded range	Kumschick et al. (2011)
2012	All	Global	Theory	Suggested management framework including impact scoring and stakeholder opinions	Kumschick et al. (2012)
2013	Mammals and birds	Europe	Application	Correlation of impact scores with species traits	Kumschick et al. (2013)
2014	Birds	Australia and Europe	Application	First application for Australia; comparison between continents; correlation of impact with traits to check for consistency	Evans et al. (2014)
2014	Fish	Europe	Application	First application for aquatic organisms; descriptions of categories modified accordingly	van der Veer and Nentwig (2014)
2014	Terrestrial arthropods	Europe	Application	First application for invertebrates; descriptions of categories modified accordingly	Vaes-Petignat and Nentwig (2014)
2014	All	Global	Theory	Adaptation suggested to be used as global classification system, similar to the Red List	Blackburn et al. (2014)
2015	Various	Europe	Application	Comparison of impact between five major taxonomic groups, including plants	Kumschick et al. (2015b)
2015	Spiders	Europe	Application	First application to spiders	Nentwig (2015)
2015	Aquatic invertebrates	Europe	Application	First application to aquatic invertebrates; descriptions of categories modified accordingly	Laverty et al. (2015)
2016	Birds	Global	Application	Scoring of the birds listed as “100 of the World’s Worst” and comparison to non-listed birds	Kumschick et al. (2016)
2016	Cactaceae	Global	Application	Comparing traits related to invasiveness and impact	Novoa et al. (2016)
2016	Plants	Europe	Application	Application to 128 plants invasive to Europe	Marková et al. (unpublished)

descriptions were further modified to account for potential impacts of organisms representing a wider taxonomic range, assessments of which were gradually being covered. These detailed impact descriptions were either presented as Supplementary Material (Vaes-Petignat and Nentwig 2014; Laverty et al. 2015) or as a table in the respective publication (van der Veer and Nentwig 2014). In the following section, we give the so far most detailed description for each impact category. These descriptions are taken from the previous papers and modified to reflect the gradual specification as the GISS was being developed, so as to cover all animal and plant taxa from all environments. For references to examples of particular impacts, see the primary GISS papers outlined above and listed in Table 1.

Environmental impacts

Category 1.1 Impacts on plants or vegetation (through mechanisms other than competition, see below) Impacts can cause changes in reproduction, survival, growth, and abundance of plants in the invaded community. In case of alien plants, their impacts may consist of allelopathy or the release of plant exudates such as oxygen or salt. In the case of alien animals, their impacts include herbivory, grazing, bark stripping, antler rubbing, feeding on algae, or uprooting of aquatic macrophytes. The impacts in this category result in restrictions in establishment, pollination, or seed dispersal of native species. The impacts range from population decline to population loss and also include minor changes in the food web. These impacts concern direct species interactions whereas impacts at the ecosystem level are covered by category 1.6. These impacts concern natural and semi-natural environments whereas agricultural and forestry ecosystems are dealt with in category 2.1.

Category 1.2 Impacts on animals through predation, parasitism, or intoxication Impacts may concern single animal species or a guild, e.g., through predation, parasitism, or intoxication, measurable for example as reductions in reproduction, survival, growth, or abundance. When the alien species is a plant, the impact can be due to changes in food availability or palatability (e.g., fruits, forage or flowers affecting pollinators) and the uptake of secondary plant compounds or toxic compounds by animals. These impacts might act on different levels, ranging from population decline to population loss and they include also minor changes in the food web. These impacts concern direct species interactions whereas impacts on ecosystem level are covered by category 1.6. These impacts concern only free-living animals in the wild whereas animal production is covered by category 2.2.

Category 1.3 Impacts on species through competition Impacts concern at least one native species, e.g., by competition for nutrients, food, water, space, or other resources, including competition for pollinators which might affect plant fecundity (i.e., fruit or seed set). Often, the alien species outcompetes native species due to higher reproduction, resistance, longevity, or other mechanisms. In the beginning, these impacts might be inconspicuous and only recognizable as slow change in species abundance but might lead to the local/global disappearance of a native species. It includes behavioral changes in outcompeted species and ranges from population decline to population loss.

Category 1.4 Impacts through transmission of diseases or parasites to native species Host or alternate host for native or alien diseases (viruses, fungi, protozoans, or other pathogens) or parasites, impacts by transmission of diseases or parasites to native species.

Category 1.5 Impacts through hybridization Impacts are through hybridization with native species, usually closely related to the alien taxon, leading to a reduced or lost opportunity for reproduction, sterile or fertile hybrid offspring, gradual loss of the genetic identity of a species, and/or disappearance of a native species, i.e., extinction.

Category 1.6 Impacts on ecosystems Impacts are on the characteristics of an ecosystem, its nutritional status (e.g., changes in nutrient pools and fluxes, which may be caused by nitrogen-fixating symbionts, increased water turbidity, or fecal droppings), modification of soil or water body properties (e.g., soil moisture, pH, C/N ratio, salinity, eutrophication), and disturbance regimes (vegetation flammability, changes in hydrology, erosion, or soil compacting), changes in ecosystem functions (e.g., pollination or decomposition rates), or other physical or structural changes. Impacts on ecosystems also include modification of successional processes. Such modifications may lead to reduced suitability (e.g., shelter) for native species, thus causing their disappearance. The application of pesticides to control impacts might have side effects on non-target organisms which count as ecosystem impacts here.

Socio-economic impacts

Category 2.1 Impacts on agricultural production Impacts are through damage not only to crops, pastures, or plantations but also to horticultural and stored products. Impacts include competition with crops by weeds, direct feeding damage (from feeding traces which reduce marketability to complete production loss) and also reduced accessibility, usability, or marketability through contamination and cosmetic changes. Impacts include the need for applying pesticides which involve additional costs, also by reducing market quality. Impacts usually lead to an economic loss.

Category 2.2 Impacts on animal production Impacts are through competition with livestock, transmission of diseases or parasites to livestock and predation of livestock, or, more generally, affecting livestock health. Intoxication of livestock is through changes in food palatability, secondary plant compounds or toxins, and weakening or injuring livestock, e.g., by stinging or biting. Also, there are impacts on livestock environment such as pollution by droppings on farmland in which domestic stocks are then reluctant to graze. It also includes reduction of livestock accessibility to grazing land. Hybridization with livestock—impacts include the need for applying pesticides which involve additional costs, also by reducing market quality. Impacts usually lead to an economic loss. This category refers to livestock, poultry, game animals, fisheries, and aquaculture.

Category 2.3 Impacts on forestry production Impacts on forests or forest products are through plant competition, parasitism, diseases, herbivory, and effects on tree or forest growth and on seed dispersal. Impacts might affect forest regeneration through browsing on young trees, bark gnawing or stripping, and antler rubbing. Damage includes felling trees, defoliating them for nesting material or causing floods. Impacts include the need for applying pesticides which involve additional costs, also by reducing market quality. Impacts usually lead to an economic loss.

Category 2.4 Impacts on human infrastructure and administration Impacts include damage to human infrastructure, such as roads and other traffic infrastructures, buildings, dams, docks, fences, and electricity cables (e.g., by gnawing or nesting on them), or through pollution (e.g. by droppings). Impacts through root growth, plant cover in open water bodies or digging activities on watersides, and roadside embankments and buildings may affect flood defence systems, traffic infrastructure, or stability of buildings. Impacts include the need for applying pesticides and performing management and eradication programs, their development and further administration costs, as well as costs for research and control. Impacts usually lead to an economic loss.

Category 2.5 Impacts on human health Impacts comprise of injuries (e.g., bites, stings, scratches, rashes, accidents), transmission of diseases and parasites to humans, bioaccumulation of noxious substances, and health hazard due to contamination with pathogens or parasites (e.g., through contaminated water, soil, food, or by feces or droppings). It also includes human hazards to the ingestion or contact to plant secondary compounds, which are toxic or poisonous, or to allergenic substances such as pollen. Impacts might affect human safety and cause traffic accidents. Impacts include the need for applying pesticides which, due to their low selectivity and/or residues, might have side-effects on humans. Via health costs, impacts usually lead to economic costs due to medication and treatment costs, as well as the consequences in productive losses from these impacts on workforce.

Category 2.6 Impacts on human social life These include noise disturbance, pollution of recreational areas (water bodies, rural parks, golf courses or city parks), including fouling, eutrophication, damage by trampling and overgrazing, restrictions in accessibility (e.g., by thorns, other injuring structures, successional processes, or recent pesticide application) to habitats or landscapes of recreational value. Impact on human wellbeing also includes restrictions or loss of recreational activities, aesthetic attraction, touristic value, or employment possibilities. Restrictions concern also natural or cultural heritage.

Impact levels and scores

In each of the 12 impact categories, the magnitude of impact is quantified with 6 levels ranging from 0 (no data available, no impacts known, not detectable, or not applicable) to 5 (the highest possible impact at a site; Table 2). Several reasons may lead to zero impact and there is an important difference between "no data available" and "no impact detectable." Kumschick et al. (2015b) tested this for 300 alien species by a comparison of 2 data sets with first defining all 0 values as no data available (overestimating true impacts) and second defining all zeroes as no impact detectable (underestimating true impacts). The results did not differ between both, and therefore, for practical reasons, we list the different reasons for zero impact together.

A species can reach a maximum score of 60 (=12 impact categories × 5 maximum impact score per category). The assignment of impact levels is based on published evidence rather than on expert opinion (see "Procedure" section). If several studies report different impact levels in the same category, the maximum is

Table 2 Definition of the impact levels used for the generic impact scoring system (GISS)

Impact level	Impact description
0	No data available, no impacts known, not detectable or not applicable
1	Minor impacts, only locally, only on common species, negligible economic loss
2	Minor impacts, more widespread, also on rarer species, minor economic loss
3	Medium impacts, large-scale, several species concerned, relevant decline, relevant ecosystem modifications, medium economic loss
4	Major impact with high damage, major changes in ecosystem functions, decrease of species, major economic loss
5	Major large-scale impact with high damage and complete destruction, threat to species including local extinctions, high economic costs

A more specific description for each of the 12 impact categories is given as Supplementary Material

chosen as a representation of the highest potential impact a species can reach (precautionary principle). A detailed description of how these levels are scored within each of the 12 impact categories is given in the Supplementary Material.

There are several ways in which the final impact score for assessed species can be obtained depending on the focus of the assessment. Firstly, summing up the impact scores for all 12 impact categories indicates the relative total potential impact per species. It allows ranking the assessed species according to their overall impact magnitude, which makes it a convenient and robust measure to prioritize species (see also Nentwig et al. 2010). Among 349 alien species scored so far, no information was found for 15 % (and this did not allow to score them), 52 % had a total impact score of 1 to 9, and 33 % of species had impact scores ≥10. The highest scores of 36 and 37 were reached by a bird (Canada goose; *Branta canadensis*) and by a mammal (brown rat; *Rattus norvegicus*), respectively. These values are far lower than the maximum potential score of 60 (Fig. 1). Depending on priorities, one can also separate environmental and socio-economic impacts, which results in a maximum score of 30 per impact group.

For individual impact categories, 9–42 % of species analyzed had an impact >0 (Table 3). Among environmental impact categories, impacts through competition and ecosystems had the highest scores (41 and 42 % of species), whereas impact through hybridization was much rarer (11 % of species). Among socio-economic impact, agriculture and human health were most strongly affected (34 and 37 % of species with impacts) while forestry and human social life were the least affected (9 and 11 %) (Table 3). The average impact of species with impact per category was between 2 and 3 impact scores. Level 5 impact occurred in all 12 impact categories, most often on ecosystems and least often on human social life (Table 3).

By default, all impact categories are considered to be of equal value, but it is possible to put individual weights to some categories, for example, to take into account different value systems of stakeholders (Kumschick et al. 2012; see also Supplementary Material). A potential downside of summing up scores is that impacts leading to the same outcome but through different mechanisms may be double-counted, e.g., competition and predation can both lead to a decline in the same native species' population. Furthermore, more frequently studied species are more likely to show evidence for impacts in different categories than would species with fewer studies. Complementarily, those species with assumed high impact or those that were the subject of a high number of publications continue to receive most attention from scientists (Hulme et al. 2013). Although these trends can bias the total impact score, they can also give us an indication of the sampling effort.

On the other hand, a species which is capable of influencing its recipient environment through different mechanisms may warrant being listed as having a high impact. Furthermore, especially regarding socio-economic matters, impacts on different sectors can affect different stakeholders. Therefore, listing all impacts and summing them up can give us a transparent and more representative picture on how high the impact really is. This value can be used to compare species across taxa and habitats.

Another way to present the overall impact of a species is to use the maximum impact score in any of the 12 categories (or separately for environmental and socio-economic impact) similar to the method proposed by Blackburn et al. (2014). The authors of this study suggested classifying species into categories ranging from minor (similar to GISS impact level of 0–1) to massive (similar to impact level 5 of GISS), rather than summing up all scores over the categories. A level 5 impact indeed deserves special attention because it refers to large-scale impact, complete destruction, loss of ecosystem functions, and high economic costs. Some effects such as species extinction are even irreversible. Therefore, it is meaningful to identify level 5 impacts for generating lists of invasive species to be targeted by priority programs. All species which had a total score of at least 25 reached level 5 in at least one impact category (Fig. 1). However, even species with a relatively low total score could reach level 5 in a single category and thus should be considered as potentially highly damaging. For example, this might refer to species threatening native species by hybridization (e.g., the ruddy duck *Oxyura jamaicensis* Smith, Henderson and Robertson 2005) or by transfer of pathogens (e.g., the eastern crayfish *Orconectes limosus*; Kozubíková et al. 2011). Both species have a total impact score of 8 (Kumschick & Nentwig 2010; Laverty et al. 2015), demonstrating that even relatively low total impact scores can include serious impacts.

In conclusion, the GISS allows impacts to be integrated and standardized across different categories and the categories with the highest impacts to be identified. However, we refrain from declaring a given threshold of summed impact scores as "medium" or "high." If managers using the GISS as part of a prioritization process want to apply such a threshold, our experience with the system has shown that summed impact scores of 10–19 could be a reasonable proposition for medium impact (26 % of the 349 species included in Fig. 1 are in this impact range) and scores of 20 and more for high impact (7 % of species).

Procedure (modus operandi)

Since the GISS relies on published evidence of the impacts caused rather than on expert knowledge, it is crucial to systematically search the literature for relevant publications. This can be achieved, for example, by searching Google Scholar (http://scholar.google.com) or ISI Web of Knowledge (http://portal.isiknowledge.com) for the Latin species name, relevant synonyms, and common names and considering journal articles, taxon-specific books, online databases on alien species, and references therein. Additional search terms such as impact, vegetation, plants, herbivory, predation, parasitism, competition, transmission, disease, hybridization, biodiversity, ecosystem, agriculture, yield loss, pest, livestock, aquaculture, fisheries, economic impact, forestry, pesticide, infrastructure, human health, allergen, and/or recreation have proven to be useful in cases

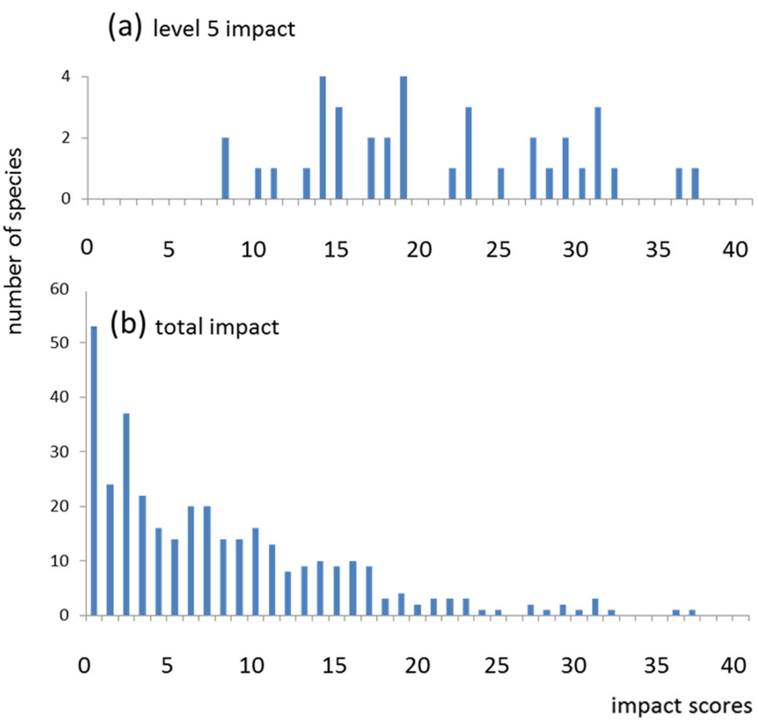

Fig. 1 Impact score distribution according to the GISS for 349 alien species scored so far. **a** Distribution of level 5 impact (i.e., number of species with at least one level 5 score impact), occurring in 34 out of the 349 species. **b** Distribution of impact scores per species for 349 species. Data for mammals (Nentwig et al. 2010), birds (Kumschick and Nentwig 2010), terrestrial invertebrates (Vaes-Petignat and Nentwig 2014), fish (Van der Veer and Nentwig 2014), plants (Marková et al. unpublished), and aquatic invertebrates (Laverty et al. 2015). The maximum impact score would be 60

Table 3 Distribution of impact scores per impact categories of the GISS for 349 alien species scored so far

Impact category	Environmental impact						Socio-economic impact					
	1.1 On plants	1.2 On animals	1.3 Competition	1.4 Disease transmission	1.5 Hybridization	1.6 Ecosystems	2.1 Agricultural production	2.2 Animal production	2.3 Forestry production	2.4 Human infrastructure	2.5 Human health	2.6 Human social life
Percentage of species with impact 1–5	35.2	31.5	41.8	24.4	10.9	41.0	34.4	16.0	8.9	24.4	37.2	11.2
Total impact per category over all species	280	234	384	185	98	431	295	152	88	205	245	88
Average impact per species with impact	2.3	2.1	2.6	2.2	2.6	3.0	2.5	2.7	2.8	2.4	1.9	2.3
Number of species with level 5 impact	4	6	7	7	3	12	4	3	2	3	2	1

For full description of impact categories see text. Data for mammals (Nentwig et al. 2010), birds (Kumschick et al. 2015a, 2015b), terrestrial invertebrates (Vaes-Petignat and Nentwig 2014), fish (Van der Veer and Nentwig 2014), plants (Marková et al. unpublished) and aquatic invertebrates (Laverty et al. 2015)

where the species name leads to a huge number of search results. In the case of species with a limited number of publications, a narrow search might miss relevant articles. Fact sheets for many alien species can be found in specialized databases, such as the Global Invasive Species Database (GISD 2015), the Invasive Species Compendium (CABI 2015), the European Network on Invasive Alien Species (NOBANIS 2015), the European and Mediterranean Plant Protection Organization (EPPO 2015), and DAISIE (2015). If no publications on impact can be found, this species cannot be scored by the GISS. Finding no published impacts can be an important finding because it points out research gaps and highlights demand for future studies.

The impact scored by the GISS should ideally be observed in the focal invaded range. However, if the species shows no impact, for example because its density is still too low or it has just started spreading, no published information can be expected. In such cases, impact reports from other invaded areas ("impact elsewhere") can be taken into consideration and in some cases, even including impacts from the native range is justified, especially for species that are vectors of parasites or are toxic or allergenic (i.e., possess features that are unlikely to change between ranges). Birds alien to Europe have shown similar impacts in the native and invaded range in general (Kumschick et al. 2011). In fact, the GISS can be a complementary tool for horizon scanning to evaluate alien species that are potentially harmful to a certain region. However, whether or not we can assume an impact to occur in any habitat and occupied range strongly depends on the impact mechanism of the alien species, because impacts are highly context dependent (Pyšek et al. 2012; Hulme et al. 2013; Kumschick et al. 2015a). This is obvious for non-specialized species where they are unlikely to be restricted due to the composition of their food or the structure of their habitat. Their impact is difficult to predict. With specialized species or species potentially hybridizing with other species, the presence of the host plant or of closely related species is most important, thus their impact should be more predictable and less context dependent. Therefore, conclusions regarding other areas have to be drawn very carefully.

For each of the impact categories, the confidence of the assessors' answer must be stated. Three confidence levels are distinguished: low, medium, and high. There are multiple possibilities to define confidence and its quantification (Leung et al. 2012). For the GISS, we

Table 4 Comparison of 23 protocols to compare impact assessment with respect to selected criteria

Assessment name	Regions applied	Groups applied	Generic	Environmental impact considered	Socio-economic impact considered	Weighting possible	Confidence considered	Reference
Expert system for screening potentially invasive alien plants in South African fynbos (SAF)	South Africa	Plants	No	Partly	No	No	Yes	Tucker and Richardson (1995)
Australian weed risk assessment (A-WRA)	Australia	Plants	No	Yes	Yes	Yes	Yes	Pheloung et al. (1999)
Classification key for Neophytes (WG)	Central Europe	Plants	No	Yes	No	Yes	No	Weber and Gut (2004)
Fish invasiveness screening KIT (FISK)	UK	Fish	No	Yes	No	Yes	No	Copp et al. (2005, 2009)
Invasive species environmental impact assessment protocol (ISEIA)	Belgium	Plants and vertebrates	Yes	Yes	No	No	Yes	Branquart (2007)
Biopollution level index	Baltic Sea	Marine species	No	Yes	No	No	No	Olenin et al. (2007)
U.S. weed ranking model	USA	Plants	No	Yes	Partly	Yes	Yes	Parker et al. (2007)
Full risk assessment scheme for non-native species in Great Britain (GB NRRA)	Great Britain	Invasive species	Yes	Yes	Yes	No	Yes	Baker et al. (2008)
Risk assessment models for establishment of exotic vertebrates	Australia, New Zealand	Vertebrates	No	Yes	Yes	Yes	No	Bomford (2008)
European non-native species in aquaculture risk assessment scheme (ENSARS)	Europe	Aquaculture species	No	Yes	Yes	No	Yes	Copp et al. (2008)
Chinese weed risk assessment	China	Plants	No	Yes	Partly	Yes	No	Ou et al. (2008)
Invasive ant risk assessment	New Zealand	Ants	No	Yes	Yes	No	No	Ward et al. (2008)
Trinational risk assessment for aquatic alien invasive species (CEC)	North America	Aquatic species	No	Yes	Yes	No	Yes	CEC (2009)
EPPO prioritization process for invasive alien plants	Europe, North Africa	Plants	No	Yes	Yes	No	Yes	Brunel et al. (2010)
Freshwater invertebrates scoring kit (FI-ISK), based on FISK	Italy	Invertebrates (crayfish)	No	Partly	No	No	Yes	Tricarico et al. (2010)
EPPO computer-assisted pest risk assessment scheme (CAPRA)	Europe, North Africa	Plant pests and weeds	No	Yes	Yes	No	Yes	EPPO (2011)
EFSA PLH scheme for PRA	Europe	Plants	No	Yes	Yes	No	No	EFSA (2011)
German-Austrian black list information system (GABLIS)	Germany, Austria	Plants, fish	Yes	Yes	No	No	Yes	Essl et al. (2011)
Norwegian alien species impact assessment	Norway	All groups	Yes	Yes	No	No	Yes	Sandvik et al. (2013)

Table 4 (continued)

Assessment name	Regions applied	Groups applied	Generic	Environmental impact considered	Socio-economic impact considered	Weighting possible	Confidence considered	Reference
Risk analysis and prioritization	Ireland and Northern Ireland	All groups	Yes	Yes	Yes	No	No	Kelly et al.(2013)
Unified classification of alien species based on the magnitude of their environmental impacts	World	None	Yes	Yes	No	No	Yes	Blackburn et al. (2014)
Risk screening tools for potentially invasive organisms (Harmonia)	Belgium	Several	Yes	Yes	Yes	No	Yes	D'hondt et al. (2014)
Classification of non-indigenous species based on their impacts	Marine ecosystems	None	No	Yes	Yes	No	No	Ojaveer et al. (2015)
Generic impact scoring system (GISS)	World	Animals, plants	Yes	Yes	Yes	Yes	Yes	This study

List derived from assessments reviewed by Essl et al. (2011) and/or listed in Appendix S1 in Leung et al. (2012) with recent additions

suggest the approach given by Blackburn et al. (2014) who restrict uncertainty to data quality. Comparably, the GISS does not charge the outcome of the confidence statement against the impact scores. It is suggested that this is mentioned separately in the final conclusion. The assessor must declare their contact details, and we recommend that the assessments undergo a review process in order to check for completeness and accuracy (i.e., consistency of the assessment). It is also recommended that a small group of assessors discuss their scores to achieve consensus. Alternatively, the scores of each assessor are documented individually and a mean score is calculated. In this case, statistics on the inter-reviewer agreement such as Cohen's Kappa coefficient are recommended.

To make the application of the GISS standardized and unambiguous, we developed a self-explanatory spreadsheet table (in Microsoft Excel) for performing the impact assessment (see Supplementary Material). The completed spreadsheet represents a comprehensive documentation of the scoring procedure, including information on the geographical range for which the assessment is done (e.g., a region, country, or continent). It also includes the taxonomy of the considered species, ecosystems and areas affected, native and introduced ranges, reasons for introduction, and pathways. For each of the 12 impact categories, a short concrete description of the given impact is required, including references. This is an important step for transparency of the scoring procedure and also allows for efficient quality control of the data and conclusions. It also makes it possible to reassess the species when more information is available, hence monitoring of the trends in impacts of a given species in an area.

Discussion

The GISS has a very broad coverage of potential fields of impact and equally involves environmental (including ecosystem patterns and processes) and socio-economic impacts. By doing so, it broadly assesses impacts on biodiversity and ecosystem services. In a comparison of the GISS with other impact assessments, the GISS is global, generic, and applies to all taxa (Table 4). Only 7 of the other 23 protocols available are truly generic and thus can be applied to all taxa, usually animals and plants. While all measure environmental impact, only 14 measure socio-economic impact.

Weighting of the scoring results can only be performed with 6 other protocols and 14 ask for the assessors' confidence of the given answers. Only six other assessments allow a ranking of the results while the outputs of the other assessments typically consist of an attribution to three or five categories or lists. Combining such criteria, the GISS is the only generic assessment that measures environmental and socio-economic impact and allows weighting of scores. Furthermore, when considering the possibility to rank the scoring outcome, the GISS is the most broadly applicable system, with Harmonia+ being the closest to it (D'hondt et al. 2014). In the face of the EU Regulation of IAS (EU Regulation 2014), the GISS is compliant with all minimum standards with regard to impact classification (Roy et al. 2014).

One of the outcomes of the GISS is the sum of the impact scores for a given species, including special consideration of the level 5 impact. The broad nature of the GISS and its applicability across taxa and environments allows for the establishment of comparative lists and country-wide rankings that can be used for prioritization (Kumschick et al. 2012). Comparative lists have the advantage that a result obtained for a newly scored species can be put into a meaningful context in relation to other species. During the prioritization process, this can be very important to justify the investment of limited human and financial resources. Such a procedure also allows for the compilation and ranking of lists of species of invasion concern. Such lists can have a remarkable effect for education and public opinion, as existing lists such as the 100 world's worst invasive alien species (GISD 2015) or 100 of the most invasive alien species in Europe (DAISIE 2009) have shown. In addition to such "100 worst" lists, which reflect expert opinion, a list based on impact scores has a semi-quantitative basis and can assist expert or stakeholder discussion on species selection (Kumschick et al. 2015a).

Another potential application of the GISS can also be seen regarding prediction of potential impacts. If impact scores available in the literature can be predicted by using a suite of species traits (Kumschick et al. 2013), in interaction with environmental settings related to geography and climate (as done for the significance of local impact as a response variable by Pyšek et al. 2012), then scientifically sound information can be provided to local managers and authorities as to which species are potentially most damaging to their regions. At the moment, the application of such an approach is constrained by limited availability of rigorous data on impact (note that for the species scored so far using the GISS, assessments were based on average on 3–4 publications per species) which prevents the fine-scale variation in species impacts from being addressed. However, given the increasing interest in studying and assessing the impacts of biological invasions in the last decade (Pyšek and Richardson 2010), accompanied by a rapid increase in the number of case studies and conceptual papers (Blackburn et al. 2014; Jeschke et al. 2014; Kumschick et al. 2015a), the situation is likely to improve. The GISS is a suitable tool at hand that can contribute to the data being used for powerful predictions of the impact of invasive species.

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